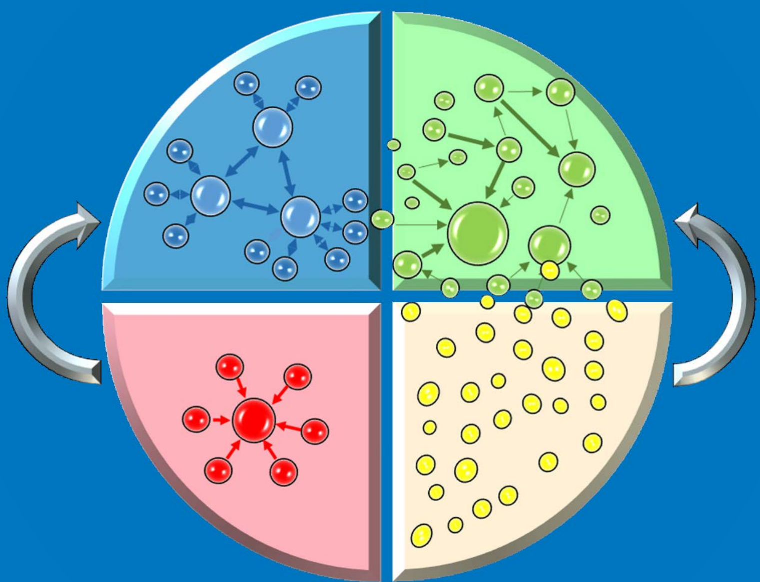
Department of Communications and Networking

On Complex Value Systems in the Connected World

Examining Structures and Dynamics of the ICT Driven Value Systems in Mobile Communication, Internet, and Transportation.

Timo A Ali-Vehmas



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DOCTORAL DISSERTATIONS

Aalto University publication series
DOCTORAL DISSERTATIONS 43/2019

On Complex Value Systems in the Connected World

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Timo A Ali-Vehmas

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Electrical Engineering, at a public examination held at the lecture hall T2 of the school on 5th of April 2019 at 12 noon.

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Opponent
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Aalto University publication series
DOCTORAL DISSERTATIONS 43/2019

ISBN 978-952-60-8449-7 (printed)
ISBN 978-952-60-8450-3 (pdf)
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)
http://urn.fi/URN:ISBN:978-952-60-8450-3

Unigrafia Oy
Helsinki 2019

Finland

Publication orders (printed book):
timo.ali-vehmas@iki.fi

Printed matter
4041-0619

Aalto University

Abstract

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Name of the doctoral dissertation
On Complex Value Systems in the Connected World

Publisher School of Electrical Engineering

Unit Department of Communications and Networking

Series Aalto University publication series DOCTORAL DISSERTATIONS 43/2019

Field of research Network Economics

Manuscript submitted 25 October 2018 **Date of the defence** 5 April 2019

Permission to publish granted (date) 17 January 2019 **Language** English

☐ **Monograph** ☒ **Article dissertation** ☐ **Essay dissertation**

Abstract

Information and Communication Technologies (ICT) enable companies to provide critical services and products to their customers globally. Consequently, understanding the complex interrelations between the technologies and value systems of the companies has become crucially important. As the existing literature on value systems recognizes systemic complexity often implicitly only, a question arises: is it possible to develop a holistic system model to examine the ICT-driven value systems embracing complexity?

In this thesis, a qualitative complex value system model is developed and evaluated. Existing literature provides the framework for the modelling. Complex system attractors used in studying complex adaptive systems set the reference to the examination of the value systems and their system states. The thesis models the ICT-driven complex value systems through the technical and operative structures, boundary conditions, and dynamic behaviours observed in those value systems. The research examines global mobile communications and internet value systems complemented by studies on emerging ICT driven value systems of transportation in Finland. Agent-based simulations and social network analyses applied to the boundaries of the value systems set by regulation and standardization, respectively, provide a quantitative environment for the limited evaluation of the developed model.

This thesis identifies the four complex value system states that characterize the examined value systems. The research provides insights into the structures and dynamics in the value systems. For instance, the research presents a categorization of the key standardization organizations in alignment with the value systems they serve by analysing the documents used in those organizations. The observed complex characteristic of the value systems, including the scenarios for system state transitions, provide points of consideration to business leaders, standardization practitioners, as well as for policy makers in their pursuit to consider developments in the ICT-driven value systems, such as 5G mobile communication in the context of the future data-based society.

Keywords Value system, regulation, standardization, ICT, mobile communication, internet, complexity

ISBN (printed) 978-952-60-8449-7 **ISBN (pdf)** 978-952-60-8450-3

ISSN (printed) 1799-4934 **ISSN (pdf)** 1799-4942

Location of publisher Helsinki **Location of printing** Helsinki **Year** 2019

Pages 321 **urn** http://urn.fi/URN:ISBN:978-952-60-8450-3

Aalto-yliopisto

Tiivistelmä

Aalto-yliopisto, PL 11000, 00076 Aalto www.aalto.fi

Tekijä
Timo A Ali-Vehmas

Väitöskirjan nimi
Kytketyn maailman kompleksit arvoverkot

Julkaisija Sähkötekniikan korkeakoulu

Yksikkö Tietoliikenne- ja tietoverkkotekniikan laitos

Sarja Aalto University publication series DOCTORAL DISSERTATIONS 43/2019

Tutkimusala Tietoverkkotalous

Käsikirjoituksen pvm 25.10.2018 **Väitöspäivä** 05.04.2019

Julkaisuluvan myöntämispäivä 17.01.2019 **Kieli** Englanti

☐ **Monografia** ☒ **Artikkeliväitöskirja** ☐ **Esseeväitöskirja**

Tiivistelmä

Tieto- ja tietoliikennetekniikka (ICT) ovat avainasemassa, kun yritykset tarjoavat yhteiskunnallisesti merkittäviä palveluita ja tuotteita maailmanlaajuisille markkinoille. Tämän vuoksi on tärkeää ymmärtää, miten monimutkaiset sidokset teknologioiden ja yritysten muodostamien arvoverkkojen välillä toimivat. Koska arvoverkkoja käsittelevä laaja kirjallisuus tarkastelee tällaisten järjestelmien kompleksisuutta usein vain viitteellisesti, herää kysymys, olisiko mahdollista kehittää kokonaisvaltainen systeeminen malli, jonka avulla tällaisia ICT -pohjaisia arvoverkkoja voitaisiin tutkia myös kompleksisuuden näkökulmasta.

Tämä tutkimus kehittää ja evaluoi erään tällaisen laadullisen mallin. Tutkimus nojaa kompleksisuusteoriasta tunnettuihin mallinnusmenetelmiin ja ajatuspolkuihin, kuten systeemeitä luonnehtiviin tiloihin, niihin liittyviin atraktoreihin sekä mahdollisiin siirtymiin tilojen välillä. Malli perustuu arvoverkoissa havaittuihin teknisiin ja toiminnallisiin rakenteisiin huomioiden verkkojen reunaehtojen vaikutukset sekä tarkastellen ilmiöitä toimijoiden käyttäytymisessä. Tutkimuksen kohteena ovat maailmanlaajuiset mobiilin tietoliikenteen ja internetin arvoverkot, mitä täydennetään tutkimalla syntymässä olevia ICT pohjaisia arvoverkkoja tieliikenteeseen Suomessa. Mallin evaluoimiseksi työssä tarkastellaan arvoverkon reunaehtojen vaikutuksia verkon käyttäytymiseen ja rakenteisiin. Agenttipohjaisella simulaatiolla tutkitaan radiospektrin saatavuuden vaikutuksia radioverkon arvonluontijärjestelmän dynamiikkaan sekä sosiaalisen verkostoanalyysin avulla tarkastellaan yhteistyötapojen rakenteita käytännön standardointityössä. Tutkimuksessa havaitaan neljä erilaista systeemistä arvoverkkojen tilaa, joiden mukaan malli rakentuu. Malli ja sen evaluointi tuovat esille tietoa kompleksisten arvoverkkojen rakenteista ja toiminnasta. Esimerkiksi analysoimalla tutkittavien arvoverkkojen standardointityössä syntyvää laajaa dokumentaatiota voidaan löytää systeemisiä linjauksia standardointityön ja niiden pohjalle syntyvien arvoverkkojen rakenteiden välillä. Havaittujen kompleksisten arvoverkkojen ja niiden tilasiirtyminen luokituksia voivat käyttää niin lainsäätäjät, liiketoimintojen kehittäjät kuin standardoinnin ammattilaiset pohtiessaan, kuinka ICT pohjaisia arvoverkkoja, kuten juuri käynnistymässä olevaa 5G mobiiliverkkoa, voitaisiin parhaiten käyttää suunniteltaessa tulevaisuuden tietoon nojaavaa yhteiskuntaa.

Avainsanat Arvoverkko, sääntely, standardointi, tele- ja tietotekniikka, liikkuva tietoliikenne, internet, kompleksisuus

ISBN (painettu) 978-952-60-8449-7 **ISBN (pdf)** 978-952-60-8450-3

ISSN (painettu) 1799-4934 **ISSN (pdf)** 1799-4942

Julkaisupaikka Helsinki **Painopaikka** Helsinki **Vuosi** 2019

Sivumäärä 321 **urn** http://urn.fi/URN:ISBN:978-952-60-8450-3

Preface

Feeling frustration and impatience is a gift. I would have never ever been dreaming about writing a thesis like this without frustration to multiple conflicting business requirements that I often felt to be unfair and unreasonable. Difficulties in adopting new ideas and product concepts drove my impatient mind to make irrational decisions, such as quitting my job at Nokia, the leading company in mobile communications in 2003, and knock on the door of my Alma Mater.

First, I would like to thank Professor Heikki Hämmäinen for opening the door and letting me in to his office. Especially I thank Heikki for his open attitude, for not asking me to commit to complete the project ever. Heikki has given me an exceptional opportunity to explore technologies of mobile communications and internet as well as to look at communications business from multiple theoretical perspectives. Heikki's continuous support, sharp criticism and professional guidance have gently push me forward during all the 16 years of this journey. Many thanks go also to the pre-examiners of my dissertation, Prof. Harry Bouwman and Prof. Vladislav Fomin for their detailed comments and suggestions.

My co-authors have been invaluable, each in their own way. When I met Dr. Thomas Casey for the first time, a very fast systemic alignment and synchronization took place immediately. Thomas has been the crucial co-researcher, colleague and later a friend with whom I have been able to share and discuss any ideas and issues. Thomas has brought energy to these discussions, has motivated, even demanded me to continue. His deep devotion to the scientific approach and his persistence in driving the publication process gave me the necessary push over the mental barrier to accept the target to complete my studies. The joint publications with Thomas address the corner stones of the value system dynamics.

In the early phase of my research, Dr. Sakari Luukkainen took a personal task to encourage me to start the publication process. Our joint interest in platforms and the disruptions they were about to create in mobile business made us to search solutions for this innovators' classical dilemma. Sakari has the hearth and soul of a teacher and mentor. He showed me the way into practical academic research. Collaboration with Ville Valovirta and Dr. Jarkko Pellikka has been highly inspiring and productive in exploring the emerging ecosystems further. I thank Thomas, Sakari, Ville and Jarkko for excellent

collaboration, contributions and commitment in joint research and for co-dissemination.

This journey, however, started almost three decades ago when I had the privilege to meet Professor Yrjö Neuvo for the first time. Ever since, I have been working in numerous positions in Nokia where Yrjö's vision and leadership has been the strong lighthouse guiding the work. Over the years Yrjö has been the single most important mental sponsor for this thesis. There is no way I possibly could thank Yrjö enough for what he has done to make this thesis to finally complete. Additionally, I want to thank also all my direct managers, especially Professor Henry Tirri and Dr. Ilkka Rahnasto for the continuous encouragement and support during this long process.

Furthermore, I want to thank very warmly all my colleagues and friends in Nokia and broader in the Mobile Communication and Internet communities for fruitful discussions and their deep and insightful views, which all have contributed to the models, findings and conclusions of this thesis. Nokia Corporation with the global network of exceptional people has been a wonderful, awesome, environment to work and to research.

Aalto University has been the asylum to learn and to study. I have especially enjoyed systems intelligence seminars and courses of Professor Esa Saarinen and Professor Raimo Hämäläinen complemented by Professor Heikki Hyötyniemi's lectures on systems theory and cybernetics. I was lucky to have the opportunity to study with Professor Ahti Salo and Professor Raimo Kantola in multiple technology scenarios, decision making and portfolio planning issues and theories. I want to give special thanks to Professor Jari Saramäki and Dr. Kalevi Kilkki for their deep insights related to complex social networks.

Last, I want to thank my friends and my family. This research would have not happened without the loving support and understanding that my wife and dearest friend Ritva and our sons Janne, Aki and Ilari have shown to my aspiration. The practical guidance by my sister Dr. Terhi Ali-Vehmas and my brother-in-law Dr. Ilmari Absetz have helped me to focus on academic writing. And finally, I want to thank my parents, my late mother Raili and my father Anselm for setting up the light of curiosity and confidence in the better future into my mind.

Kauniainen, 9 February 2019
Timo Ali-Vehmas

Contents

List of Publications

Publication I Ali-Vehmas, Timo; Luukkainen Sakari; 2008. Service adoption strategies of push over cellular, Personal and Ubiquitous Computing, vol. 12, no. 1, pp. 35-44.

Publication II Ali-Vehmas, Timo; Casey Thomas R.; 2012. Evolution of wireless access provisioning: A systems thinking approach, Competition and Regulation in Network Industries, vol. 13, no. 4, pp. 333-361.

Publication III Ali-Vehmas, Timo; 2016. Complex network perspective to collaboration in the ICT standardization, International Journal of Standardization Research, vol. 14, no. 2, pp. 32-63.

Publication IV Casey, Thomas R.; Ali-Vehmas, Timo; 2012. Value system evolution toward a cognitive radio era: Implications of underlying market dynamics, in Proceedings of the 2012 IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN), pp. 77-88, Bellevue, WA, USA, October 2012.

Publication V Ali-Vehmas, Timo; Casey, Thomas R.; 2015. Examining value system transitions: The case of smart mobility services, in Proceedings of the 48th Hawaii International Conference on System Sciences (HICSS), pp. 4366-4375, Kauai, HI, USA, January 2015.

Publication VI Casey, Thomas R.; Ali-Vehmas, Timo; Valovirta, Ville; 2017. Evolution toward an open value system for smart mobility services: The case of Finland, Competition and Regulation in Network Industries, vol. 18, no. 1, pp. 1-27.

Author's Contribution

Publication I Service adoption strategies of push over cellular
The original ideas for the framework came from both Ali-Vehmas and Luukkainen. Ali-Vehmas provided the initial case data while Luukkainen provided primarily theoretical contributions. Both Luukkainen and Ali-Vehmas further developed the journal article based on the initial joint conference paper in the International Conference of Mobile Business (ICMB'05) "Service diffusion strategies for push to talk over cellular", pp 427-433, 2005 presented by Ali-Vehmas.

Publication II Evolution of wireless access provisioning: A systems thinking approach
The original idea for the developed framework came from Ali-Vehmas. Casey conducted the interviews. Ali-Vehmas and Casey together further developed the framework and did the analysis. Ali-Vehmas and Casey together also wrote and edited the article.

Publication III Complex network perspective to collaboration in the ICT standardization
The original idea for the research came from Ali-Vehmas. Ali-Vehmas is the sole contributor of this article. Nokia Corporation provided the raw data sets.

Publication IV Value system evolution toward a cognitive radio era: Implications of underlying market dynamics
The article continued the work of Publication II. Casey developed the simulation model to which Ali-Vehmas provided comments. Casey and Ali-Vehmas together did the analysis. Casey wrote the first version of the article. Ali-Vehmas added text, further developed some of the conceptual ideas, and edited the article. Casey presented the paper in the IEEE 2012 DySPAN conference.

Publication V Examining value system transitions: The case of smart mobility services
The article is an application of the methodologies of Publications II and III in a qualitative analysis. Ali-Vehmas and Casey contributed to the case study. Ali-Vehmas further developed the detailed analysis. Ali-Vehmas and Casey wrote and edited the article. Ali-Vehmas presented the paper in the HICSS 48 conference.

Publication VI Evolution toward an open value system for smart mobility services: The case of Finland

The article continues the work of Publication V. Casey and Valovirta carried out the field research and the body of the article is based on the research project in Teknologian Tutkimuskeskus VTT Oy. Ali-Vehmas contributed to the system concept and analysis. All authors wrote and edited the article.

List of Abbreviations

1G	First Generation of technologies and standards for public mobile communications networks, e.g. NMT for Nordic countries and AMPS for North America
2G	Second Generation, e.g., GSM system in Europe
3G	Third Generation, e.g., UMTS in Europe
3GPP	Third-Generation Partnership Project. A global collaborative project, which was set to standardize the 3G technologies for mobile communication
3GPP2	Third-Generation Partnership Project 2. Another separate third-generation standardization project to develop a competing technology and standards parallel to the 3GPP
4G	Fourth Generation, e.g., LTE/SAE technologies used globally
5G	Fifth Generation of mobile communication, under development
AMPS	Advanced Mobile Phone System. One of the first-generation mobile communication systems used mainly in the Americas
CDMA	Code Division Multiple Access. A technique to share one communication channel for many users by separating the users using dedicated codes
CDMA 2000	Code Division Multiple Access for the new millennium. A brand name for radio access technologies developed by the 3GPP2 community
CEPT	European Conference of Postal and Telecommunications (Administrations)
D-AMPS	Digital Advanced Mobile Phone System. A digitized second-generation mobile communications system mainly used in the Americas
ECMA	European Computer Manufacturers Association. Currently ECMA International, a voluntary standardization organization focusing on Information and Communications technologies and Consumer Electronics, Headquartered in Geneva, Switzerland
Ethernet	A family of computer networking protocols developed by the IEEE 802 community
ETSI	European Telecommunications Standards Institute
EU	European Union

GPRS	General Packet Radio System. A specific packet-oriented data transmission subsystem of the second-generation GSM technology
GSM	Groupe Special Mobile. A CEPT group initially responsible for specifying the digital mobile communications system for the CEPT countries. Later became a generic name for Global System for Mobile communications using the original concepts of CEPT further developed by ETSI and 3GPP.
HTML, HTML5	Hypertext Markup Language. A standard developed by W3C. Most recent fifth generation of the markup language
ICT	Information and Communications Technology
iDEN	Integrated Digital Enhanced Network. A trunked mobile communications technology developed by Motorola, a communications technology company headquartered in Illinois, USA.
IEEE	Institute of Electrical and Electronics Engineers
IEEE 802.11	A subgroup of the IEEE 802 set to define a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5, and 60 GHz frequency bands
IETF	Internet Engineering Task Force
IMS	Internet Multimedia Subsystem. A specific functionality for the 3G and later communications systems developed by 3GPP
IP	Internet Protocol. The fundamental protocol used in the Internet to route the data packets between host computers
ISM	Industrial, Scientific and Medical. Specific radio frequency bands used also for mobile applications at, e.g., 2.4 GHz.
ISOC	Internet Society. An American non-profit organization set to take the role of a legal entity to support the IETF and to provide leadership in Internet-related standards etc.
LTE	Long Term Evolution. Initially a working area for future radio technologies in 3GPP, later the acronym is specifically used for a set of radio technologies of the 3GPP system of release 8 and later, parallel to the more generic term 4G
MaaS	Mobility as a Service. A concept to provide physical transportation as a service
MS	Mobile station. A combination of a User equipment (UE) and a Subscriber Identity Module (SIM), a specific GSM/3GPP term
MNO	Mobile Network Operator. A company having the license to operate a mobile network on a dedicated radio spectrum in a dedicated geographical area
NMT	Nordisk Mobiltelefon, Nordic Mobile Telephone. The first-generation analog mobile communications technology and standard mainly used in the Nordic countries

OFDMA	Orthogonal Frequency Division Multiple Access A technique to share one communication channel for many users by separating the users using narrow strongly coordinated sub-channels
OMA	Open Mobile Alliance. A voluntary standardization group developing application enablers, i.e. protocols to enable applications on top of the mobile communications platform
OTT	Over the Top. Referring to services operated independently on top of the mobile communications network and devices
PDC	Personal Digital Communications system. A specific second-generation technology for mobile communication used in Japan
PoC	Push to talk over Cellular. A concept to control voice communication over a cellular network by pushing the transmission key
POTS	Plain Old Telephone Service. Referring to the initial person-to-person voice service provided by early telephone networks
RFC	Request for Comments. A specific type of document used in the IETF community to collect comments for a new standard under development
SAE	System Architecture Evolution. A set of core network technologies developed parallel to LTE radio technologies in 3GPP
SIM	Subscriber Identity Module. A functionality used in the GSM system to contain user-specific information; typically, a detachable smart card
SIP	Session Initiation Protocol. A specific protocol to set up voice call and other sessions on top of the transport and network communication layers such as the TCP/IP
SNA	Social Network Analysis
SSO	Standards Setting Organization. A generic term to cover any organization creating and publishing standards
TACS	Total Access Communications System. A first-generation mobile communications system, a variant of AMPS, mainly used in the U.K.
TCP/IP	Transport Control Protocol. A specific protocol to control the packet transmission in communications networks using Internet Protocols (IP)
TDMA	Time Division Multiple Access. A technique to share one communication channel for many users by allocating a different time slot for each user
UMTS	Universal Mobile Telecommunications System The original name for the third-generation mobile communication system in Europe
USIM	Enhanced version of SIM specifically developed for the UMTS

WCDMA	Wideband Code Division Multiple Access. A version of the CDMA technologies with rather broad carrier bandwidth. Technology used in the 3G networks specified by 3GPP.
Wi-Fi	Wireless Networking Technology originally specified in the IEEE 802.11 group for wireless high-speed internet access and network connections. Trademark owned by the Wi-Fi Alliance.
WFA	Wi-Fi Alliance. A non-profit organization that promotes Wi-Fi technology and certifies Wi-Fi products
WLAN	Wireless Local Area Network. Refers to networks and technologies used in relatively short-range wireless communications
WWW	World Wide Web. Refers both to the technologies and the functionality of the HTML-based cross-referenced network of documents, developed by the W3C

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1 Introduction

During the last 30 years, products and services utilizing Information and Communication Technologies (ICT) have experienced significant growth, and today they form a major business sector of their own. Nicholas Negroponte predicted that *All the information that can be digitized will be digitized* (Negroponte 1995). Today, all the predictions of Being Digital have materialized. However, the structural and dynamic influence of ICT on society has so far been only modest. Development will continue beyond digital movies, books, and music until a digital shadow will gradually trails everything we have.

Sophisticated technologies enable complicated and complex[1] technical, organizational, and economic structures to emerge, some of them well defined, while others set challenges to the traditional business logic. When pursuing new value, companies, institutions, and individuals become dependent on each other as competing and collaborating actors in these visible and invisible structures. Often such value-creating networks are called value systems (Porter 1985). When value systems grow and become complex their structures include loops and nonlinearities, which make dynamic behaviors difficult to understand and predict (Sterman 2001). A paradigm of business ecosystems emerges (Moore 1993). Traditionally, value systems focus primarily on creating financial value within rather explicit structures, while ecosystems allow more stakeholders and contributors to join, self-organize, and create value in different ways in loosely connected networks.

This thesis examines developments in value systems driven by ICT technologies, specifically related to mobile communication and the Internet. The ICT-driven value systems are powered by innovations and shaped by the actions of people and organizations. Regulation and standardization provide specific lenses to study ICT-driven value systems, to observe behaviors and interplay of the participants, in other words, to observe the value systems through these boundaries and examine their structures and dynamics (Fransman 2010). Regulations, complemented by standardization, constrain and facilitate the use of the radio spectrum and communications technologies, the critical resources and enablers of wireless mobility (Clark & Claffy 2015). This research assumes the

[1] The word "complex" is used in this research to reflect the paradigm of complexity, observed for instance in many complex adaptive systems. Furthermore, “complex system” in this research refers in general to systems where complexity is considered. “Complicated” refers to systems which may include many parts and connections but do not show the unpredictable behaviors associated with the high complexity.

solid value system literature as the starting point complemented by elements of complexity to explore scenarios of *complex value systems* of the connected world.

1.1 Motivation of research

During the past decades, growth in the ICT sector has been exceptional, and its direct contribution to national economies is significant[2]. The indirect effects of ICT, such as increased productivity, enhanced social services, and better environmental protection, provide many benefits to society, and currently systemic influence of ICT deeply penetrates all sectors of life. The growth, however, is not always only positive, but it can reverse to negative, as was experienced in Finland[3] when the growth of the electronics industry was dropped sharply as shown in Figure 1.

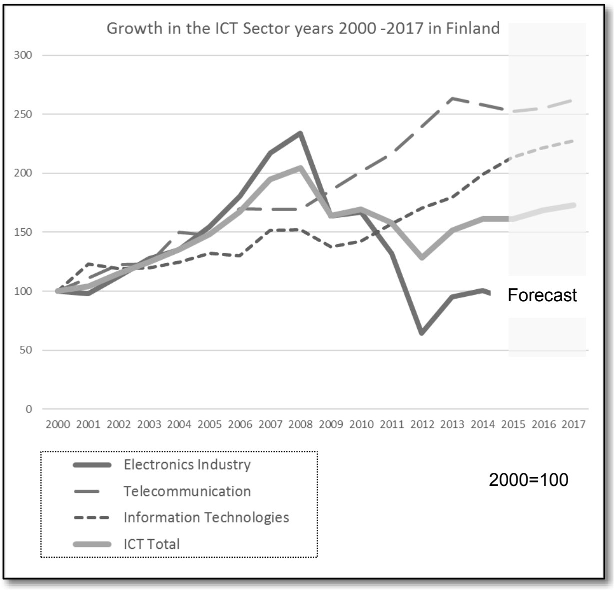

Figure 1. ICT Sector growth in Finland between 2000 and 2017
Source: Tilastokeskus (Statistics Finland)

Root causes of such major changes are multiple, as are the difficulties in recovery. Old ways of doing business become obsolete almost overnight when a product logic is converted to a service logic enabled by computing technologies and platforms in a competitive global digital market (Zysman et al. 2010).

[2] Direct ICT sector contribution to the American economy in 2014 was 5.9% http://internetinnovation.org/images/misc_content/Report_on_the_Economic_Impact_of_Broadband_-_Hassett-Shapiro_-_Rev_-_March_23_2016.pdf and to the Finnish economy 4% in 2012. http://teknologiateollisuus.fi/sites/default/files/file_attachments/pohjolan_raportti_suomi_uuteen_nousuun.pdf. Accessed May 19, 2016.

[3] ICT direct contribution was above 8% in Finland during the period of 2000–2007. After 2007, the growth has been negative.

History shows that the power of creative destruction is beneficial to those who can anticipate the future and who can develop strategies to exploit the opportunities. Popular macroeconomic models, since the introduction of K-waves (Kondratieff 1926, 1979), are typically based on statistical data and are looking backwards. When business systems are complex, predicting systemic transitions accurately becomes impossible and therefore *policy makers and business leaders should stop pretending that economy can be controlled. Instead, building resilience and adaptability is needed*[4]. Furthermore, it is utterly difficult to see opportunities and threats when being inside an existing business system. Therefore, a high-level, objective, and balanced systems thinking approach is necessary in addressing problems of business complexity (Senge 1990; Sterman 2000). Discoveries in the field of complex networks and complex systems have enabled new ways to study dynamic developments, to examine structures, network topologies, and feedback loops of our Linked (Barabási 2002) society.

Initially, motivation for this research was accidental. After a long successful growth period, leaders in Nokia Mobile Phones recognized the need to renew business processes, including standardization, to address a paradigm shift in market dynamics from traditional voice-oriented phones toward smarter and more versatile mobile devices. Mobile communication networks were evolving from the second-generation systems toward third-generation technologies and converging with emerging internet and web technologies. Consequently, the number and scope of standardization initiatives spawned beyond the planned budgets and plans. The initial outcome of the new standardization strategy in 2005 had a prescriptive name “Cookbook” to reflect the need to have a set of recipes instead of one fixed approach. Over time, understanding complexity and its implications became the key theme of this research, with an ambitious goal to characterize value systems, to see the different shades of grey, in evolutional and disruptive developments in leading ICT-driven value systems of Mobile Communications and Internet. Today, information and communication technologies drive emerging digital value systems in healthcare, transportation, logistics, energy, education, and in practice in all sectors of our life, opening demand and possibilities to extend the research even further.

Currently, expectations related to innovations and growth are leaning toward edges of networks, mobile applications, cloud services, and the Internet of Things. One of the leading spearhead application areas is transportation. In Finland, the current vivid debate in policymaking and broad renewal of business models span from start-ups to large companies and to public-sector actors. ICT have a visible role in all scenarios and considerations, including the holistic transportation concept of Mobility as a Service (MaaS).

Motivation of this research has evolved from a simple business-driven need to a challenging endeavor to build a framework and a model that can be used to examine and explore complex value systems and their behaviors in our complex ICT-driven society.

[4] OECD Report: http://www.oecd-ilibrary.org/economics/debate-the-issues-complexity-and-policy-making_9789264271531-en. Accessed November 30, 2017.

1.2 Research objective and main questions

The influence of ICT on modern society is overwhelming, but the tools to analyze the interplay of traditional business sectors and ICT are limited. Especially systemic transitions, paradigm shifts in business, have been difficult to manage, like the transition from 2G to 3G mobile communication (Steinbock 2003; Ansari & Garud 2009). Earlier research on Mobile Communication and Internet is broad. Literature reviews show interest in many areas such as mobile system development (Hosbond & Nielsen 2005), mobile applications (Donner 2008; Ngai & Gunasekaran 2007), and in general, issues with service adoption, for instance in case of smartphone technologies (Aldhaban 2012), while holistic structural analyses are still scarce.

The objective of this research is to examine the fabrics of ICT-driven value systems, find the embedded strings and tensions, and to study the developments, build a model, and examine these complex value systems and their evolution. Therefore, the main research question consists of two main parts:

RQ1: How to develop a model to examine ICT-driven value systems and their evolution?
RQ2: Which criteria are suitable to evaluate the model?

These high-level research questions induce multiple sub-questions. For instance, how to define characteristics of the building blocks, structures, and causal logic that drive the value systems? The inherent complexity of ICT-driven value systems raises a concern whether such modelling is even possible. Complex systems show behaviors that emerge as results of system boundaries including endogenic factors such as networking of the system actors and exogenous factors such as policies and technology change, and including availability of critical resources (Sterman 2000). Therefore, categorizing the value systems with complexity is important but challenging, since the presence of complex behavioral patterns alone cannot be taken as an indicator of complexity (Manson 2007).

The second research question RQ2 is also challenging. Models gain credibility if their qualitative aspects can be evaluated quantitatively, as seen, for instance, in the case of mobile communication (Di Minin & Bianchi 2011). However, the fundamental chaotic nature of complexity limits the usability of techniques used for simple, linear models. The evaluation criteria must transform to practical questions related to usability of the model, for instance, whether the model builds a bridge between the theories and reality (Manson 2007).

1.3 Research approach

Concepts and methods developed for studying complex adaptive systems provide a compelling framework for the research on value systems with complexity. This thesis applies earlier conceptual models of complex systems to empirical ICT-driven value systems to develop a model for complex value systems, which can be used to examine behaviors of such systems. Empirical value systems of Mobile Communications, Internet and emerging transportation value systems such as Mobility as a Service provide the knowledge and data for the qualitative modelling. Technical and operational structures of the value systems with the related boundaries provide the input for a systemic approach, where each value system is examined to identify local dynamics and finally to model the high-level phenomena. Figure 2 illustrates the framework for the overall research approach.

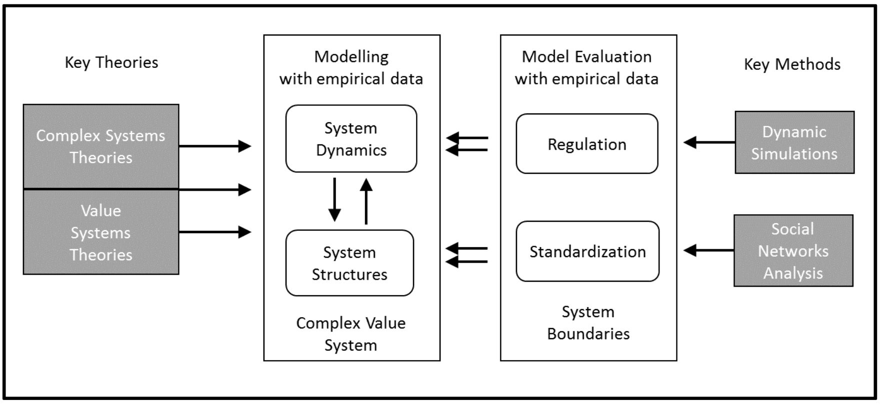

Figure 2. Research approach as a framework

Qualitative complex value system modelling examines the interdependences between the value system structures and their dynamics within the value system boundaries of regulation and standardization, shown by the vertical arrows. Boundaries are used to evaluate the system model against multiple criteria, shown by double arrows, using dynamic system simulation and social network analysis, respectively. Evaluations utilize both qualitative and quantitative analyses. The research approach is top down, where the unit of analysis is a group of actors with similar interests and behaviors, such as mobile network operators. Individual value system actors, individual companies, occasionally provide illustrative examples of group members. Earlier theories and methods are shown in grey and their contribution as directional horizontal single arrows.

This thesis utilizes a multi-disciplinary approach to examine ICT-driven value systems, to identify the value system types, and to characterize their behaviors with variable levels of complexity. Value system theories related to competition, such as (Porter 2001; Prahalad & Ramaswamy 2004), and collaboration, for instance (Iansiti & Levien 2004; Schilling & Phelps 2007; Adner 2017) provide the starting point. Related theories and literature on regulation, such as (Fransman 2010; Cherry 2007) and standardization, for instance (Swann 2010) with specific focus on collaboration (Leiponen 2008; Hillebrand 2013; Fomin 2012) and competition (Shapiro & Varian 1999) frame the value system thinking. Complex systems theories encourage focusing on network models, such as (Barabási 2002), and theoretical aspects, like the set of conceptual system attractors (Strogatz 2001), which provide a reference to the characterization of complex value systems. Complexity complements the traditional logic in research methods and models in analyzing and conceptualizing real life businesses.

Research on dynamical systems is challenging for multiple reasons (Sterman 2002). The borders of the system may be difficult to define, dependences within the system may be poorly visible, and the local logic of system components is often unknown. Dynamic system simulations provide mechanisms to model the structures and examine the system level behaviors based on the lower level interdependences (Forrester 2007). Dynamic system simulations are applied to examine the influence of different radio spectrum allocation methods to the dynamics of the wireless value systems utilizing advanced technologies, such as cognitive radio. Radio spectrum regulations set the well-defined boundary for all wireless value networks. Furthermore, Social Network Analyses (SNA) reveal information on the operational structures (Wasserman & Faust 1994) and their long-term evolution (Basole et al. 2012). SNA is used to study collaboration network structures in five key standardization organizations of mobile communications and internet value systems.

Qualitative system modelling utilizing system theories to analyze the technical and operation structures of the value systems is evaluated by quantitative and quantitative studies using the dynamic system simulations and structural social network analyses. A multidisciplinary approach is a natural choice because it includes also rigorous quantitative elements like the social network analyses (De Reuver 2009). Different angles of views complement each other and gradually build a holistic picture (Di Minin & Bianchi 2011).

1.4 Outline of thesis

This thesis implements the research approach as a process. Figure 3 depicts the research process and outline of the thesis including the role of publications, which are shown in bold.

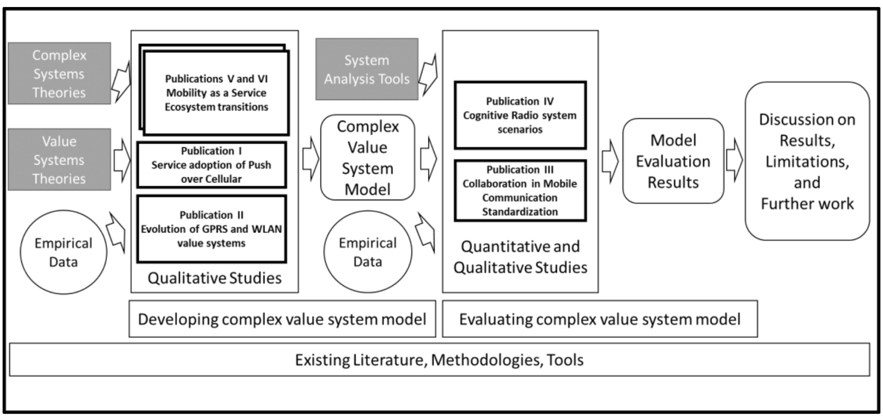

Figure 3. Research process and outline of the thesis

The research process reflects the two research questions by focusing on the development of the complex system model and model evaluation in two different phases. The two phases of the research utilize two independent data sets: one for model development and another for model evaluation. Theories related to complex systems and value systems set the starting point for modelling, while system dynamic simulations and social network analysis provide the tools for model evaluation.

The research consists of six separate studies and related publications, which cumulate data, knowledge, and insights. Four of the publications focus on the development of the qualitative model and two of them on evaluating the model. Each publication focuses on a specific business-relevant issue. Publications I and II examine empirical mobile communication and internet value systems to build an initial system model. Publications V and VI extend the research to examine value systems in transportation under strong influence of digital information and communication technologies. Consolidation of these four qualitative studies yields a qualitative complex value system model and a simple set of considerations (exogenous impact through boundaries, and internal structures and dynamics) to examine the system states and state transitions in value systems.

The second segment, consisting of Publications III and IV, focuses on mobile communication and internet value systems and provides a limited evaluation of the system model. Qualitative and quantitative studies examine specific boundaries of regulation, and standardization and address a set of evaluation criteria. Discussion on the results of modelling and model evaluation, limitations of the research, and possible future research areas finalizes the research process.

As it relates to the thesis outline, section 1 introduces the research and sets the framework. Section 2 provides an overview of the main underlying theoretical pillars and concepts and defines three modelling propositions. Section 3 describes developments in mobile communications and internet value systems to position the research in the relevant context. Furthermore, section 3 introduces the context of the transportation value system with a specific focus on Mobility as a Services in Finland.

Section 4 presents the qualitative case studies with their consolidated contributions to the development of the complex value system model. It also presents a conceptual and qualitative complex value system model. Section 5 provides two detailed quantitative analyses to test the conjectures related to the system model. The first quantitative study explores competition and collaboration in mobile communications and internet standardization by utilizing social network analysis. The second quantitative study builds a simulation model to study scenarios of future wireless market dynamics based on the different regulative models to allocate radio spectrum, for instance for 5G.

Section 6 discusses and summarizes the discoveries and conclusions. It provides some implications to policy makers and practitioners to consider when building efficient and effective complex value systems that utilize ICT. Finally, the specific limitations of this thesis as well as further research opportunities related to value systems with complexity are discussed.

As it relates to earlier literature and theories, each publication is an independent study with partially overlapping literature and theoretical framework.

This thesis consolidates and complements the frameworks of the publications. The original publications are included in the appendix.

2 Theoretical framework

Systems thinking aims to explain causal phenomena. When value systems grow and become complex, their behaviors become unpredictable, like behaviors of complex adaptive systems. Sometimes such systems influence their environment, and it becomes difficult to draw a clear line between the system and its boundaries. Furthermore, such systems can change their behavior, sometimes incrementally and sometimes radically.

Section 2.1 provides a high-level view of complex systems and networks. Section 2.2 looks at the value systems of earlier literature. Regulation and standardization provide special lenses, discussed in sections 2.4 and 2.5, whereas section 2.6 addresses briefly the background of system modelling and social network analysis. Section 2.7 consolidates the earlier literature and presents the propositions for complex value system modelling.

2.1 General systems theory and complex networks

For complex problems, general systems theory has been a source of inspiration (Bertalanffy von 1972) and concern (Sterman 2002). Systems thinking observes and influences system behaviors through interactions between the system parts and their environment (Granovetter 1973). Systems thinking examines human systems using physical and theoretical systems as metaphors. Interconnections form structures of influence and system archetypes can be used to model personal mastery and to build mental models for shared vision and team learning (Senge 1990). The Fifth Discipline Fieldbook defines the word "system" as follows: *A System is a perceived whole, whose elements 'hang together' because they continually affect each other over time and operate toward a common purpose* (Senge et al. 1994).

Complexity theory studies for instance Complex Adaptive Systems (CAS), which consist of structures, networks of feedback loops, that form an underlying mechanism and drive the observed phenomena on the system level. Often, a system is expected to provide different (more) value than the arithmetic sum of its parts. Predicting the behavior of a system is problematic due to the difficulties in observing all the subtle interactions and understanding their complex pan-causal effects. Finite, non-zero delays in the interactions add complexity, and therefore a snapshot provides only limited information on the long-term behavior of the system. Relationships between simple individual feedback loops and the overall system level behavior are often far from being simple (Sterman 2001). Furthermore, when the speed of change is significantly different in different parts of the system, the system falls apart. Slowly changing parts become boundaries while the fast-moving sections are considered as noise. In neo-cybernetic models, there is no separation between the system and its environment, but in practical studies this ambition is generally too high (Hyötyniemi 2006).

Algorithmic complexity focuses on the complexity of system structure, while aggregate complexity studies how individuals working together create complex systems such as economies. The third way to examine complexity is to explore the convergence of complex systems toward some deterministic state of balance (Manson 2007). Defining the level of complexity in a system is often addressed qualitatively (Grösser 2017). Complexity in this context can also be seen as an ambitious opportunity to design the systems and products to address the "whole" rather than to bring in small incremental improvements only (Stolterman 2008). A system can be understood as a process and an organization, as a holistic time-variant network of people with their visible and invisible interrelations.

Figure 4 provides a visualization of the landscape for this research, where the components (nodes) of a system are connected by a set of ties (links). Nodes and links may have many parameters, and multiple connected systems form a system of systems. Feedback loops – shown as dark curved arrows – through the network of links create regular and irregular dynamical behaviors. The system includes positive feedback when the system state and its output signals enforce specific behaviors in the system and negative feedback in the opposite case. Positive feedback is connected to the growth and instability while the negative feedback balances the system behavior. The overall system state is typically a function of combined positive and negative feedback signals.

Visualized by grey arrows, patterns of behaviors emerge as results of actions of network nodes and network effects yielding linear or nonlinear dynamics depending on the characteristics of the feedback loops (e.g., structure, shape, strengths (sign and multiplier), and path lengths (delays)). The system communicates with its environment by exchanging information through input and output mechanisms, shown as dark straight arrows.

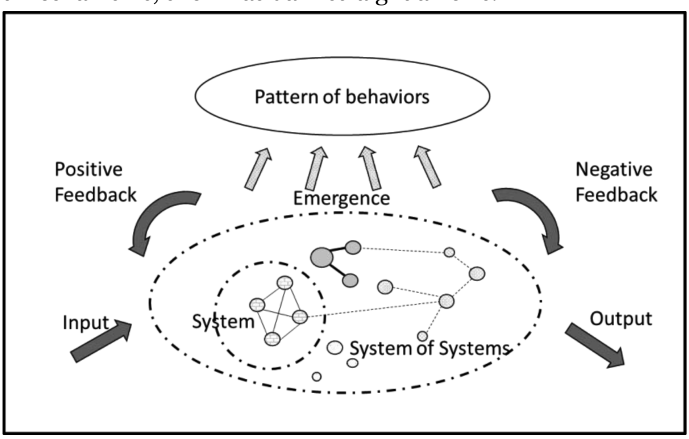

Figure 4. A system of systems
Adapted from D. Calvin Andrus (Andrus 2005)

Motions of systems are often studied using dynamic systems theory (Sterman 2000), including studies on interactions of multiple systems having similar or different structures (Strogatz 2001). In dynamic systems, a conceptual attractor is often used to describe a state of balance, toward which the system evolves from arbitrary initial conditions. The system maintains its attraction unless some external impact is strong enough to make the system change its state toward a different attractor. The attractor concept is useful to address system behaviors otherwise impossible to describe, especially in case of chaotic systems, such as climate. Climate is also an example of an energy dissipating system that require an external driving force to keep the system active, in this case the energy source is the radiation from the sun. Dynamic balance, equilibrium within the network structure between the dissipation and driving force characterize the system type, i.e. its state of balance, which is visualized by a related conceptual attractor. The significant advantage of the attractor model is that there is only a limited set of different attractor archetypes observed.

The following complex attractor archetypes, identified for instance in (Strogatz 2001), are used as a reference in this thesis.

Fixed attractor defines the system that returns to the same detailed setup where all the parameters are evidently known. If the system is slightly disturbed, after some transient time, the system returns to the same state. A power-dissipating pendulum without a driving force is a simple example. In a fixed attractor system, all the feedback loops have a negative, balancing effect. Such simple systems do not show complex behaviors.

Limit cycle attractor defines the system with more degrees of freedom. The system state is limited to a rather simple chain of events, which gives the other name for a limit cycle attractor: periodic attractor. A power dissipating pendulum with a driving force is a simple example of a system with a limit cycle attractor. In limit cycle attractor systems, negative feedback dominates, while some positive feedback makes the system to cycle. Limit cycle systems may show “complicated” behaviors but typically their behavior is predictable.

Strange attractor defines the system with even fewer constraints. Strange attractor characterizes a system state which seems to have no rationale, but still the system stays together showing some chaotic behaviors. There is a broad body of literature and mathematics on different strange attractors. Locally unstable and globally stable system behavior as well as a fractal nature of the system structure are typical characteristics of strange attractors. In strange attractor systems, the positive feedback is strong, while the negative feedback keeps the system globally stable. Strange attractor-oriented systems are considered systems with high complexity.

No attractor defines a “system state” without any recognized stable structure. Conceptually, a system without any connections or interdependences is strictly speaking not even a system, and therefore systems studies sometimes ignore such situations. Dominating positive feedback prevents any stable system structure from emerging. It is necessary, however, to recognize such a situation. Fully disconnected systems with no attractor include no elements of complexity.

In connected systems, the impact of weak ties is often significant (Granovetter 1973). New interactions may result in synchronization of the two originally separate, disconnected systems. Distributions of the connections in the network characterize the system (Barabási & Bonabeau 2003) and influence the co-existence behaviors of interacting complex networks (Strogatz 2001). For instance, Strogatz has found that if a dynamic system at each node has a stable exclusive fixed-point attractor, the network tends to lock into a static pattern. Similarly, an equally coupled network of limit-cycle attractors with different amplitudes and natural frequencies can self-organize itself and become a completely synchronized system with harmonized amplitudes and with the phase variable indicating the earlier difference in frequency. Furthermore, two systems with strange attractor characteristics can also synchronize their erratic fluctuations, although it requires that the coupling be neither too weak nor too strong (Pecora et al. 1997). Under certain conditions, systems with different attractors can also coexist permanently (Sprott, Wang & Chen 2013). For this research, it is important to note the "not-a-system" state without any attractor. A state without any attractor or with many "attractor candidates" with positive feedback is only random, and the system behavior resembles Brownian motion until it is arrested by some external limit (Fowler 2003). Therefore, it is convenient to call such a system type as random.

The framework of four different system types is a common approach in managing complexity using systems thinking (Grösser 2017). The four levels of complexity (simple, complicated, complex, and hyper-complex) align with the four types of attractors. Similarly, the Cynefin framework, focusing on strategic issues like knowledge management, is used to address different system behaviors and transitions. The Cynefin framework builds on the thinking with "order" and "un-order" (Kurtz & Snowden 2003). Systems thinking applied to system dynamics provide ways to solve the possible negative impacts of each system archetype[5] (Wolstenholme 2003). Related systems theories have been used, for example, to examine signaling networks in biology (Maayan et al. 2005), oligopolies in economics (Chiarella & Khomin 1996), to formulate business strategies (Fowler 2003), in organizational psychology (Losada & Heaphy 2004), in regulations (Cherry 2007; Longstaff 2003), as well as in fighting policy resistance (Sterman 2001). A research process itself can be an example of a systems thinking process, where context, function, structure, and dynamics form a cycle of iterative learnings (Gharajedaghi 2007).

Complexity is a general word with several different meanings. Complex systems can be, for instance, biological, economical, or technical, and often those systems are studied using mathematical and computational models (Kauffman 1995). In this thesis, complexity is a characteristic to partially connected systems, which under certain conditions can demonstrate different behaviors, including self-organized emergent behaviors (Sterman 2000).

Research on real-life complex systems examines, for instance, networks of interconnections, such as hyperlinks between documents of the World Wide Web

[5] Wolstenholme archetypes: 1. Fixes that fail, 2. Escalating, 3. Success to successful, 4. Limits to success.

(Barabási & Bonabeau 2003). Such empirical networks often consist of few highly-connected nodes and a long tail of less-connected nodes. These types of networks tend to follow a power law distribution regarding the nodes and number of connections per each node (Newman 2003). Recently, also less systematic node distributions have been observed, noting also the influence of the data-gathering process (Meusel et al. 2014). Structures in random networks consisting of nodes with randomly placed connections follow a Gaussian distribution.

Power law distributions are found characteristically in recent value creating systems, where a decentralized crowd produces new products and provides new services through a voluntary collaborative network. Availability of open-source tools and platforms has enabled active people to complement the role of a consumer by a new role of a producer, i.e. becoming a "prosumer", often yielding the long tail of distributions related to multi-mode actors in those networks (Anderson 2006). Scarcity of one or more key resources efficiently limits the emergence of these crowds. In such situations, only a limited number of players can participate, which results in a kind of truncated power law distribution or other types of distributions. Recently, the commonality of power law characteristics in real life networks has been challenged, for instance, in (Broido & Clauset 2018), indicating that further studies in this field are needed.

In complex networks, there are multiple different feedback mechanisms. One of those is the growth pattern through preferential attachment (Barabási & Albert 1999). The strength of preferential attachment may be linear or nonlinear. In scale-free networks, preference depends linearly on the number of existing nodes in the networks. When the preference grows faster, the exponent becomes larger than 1. This kind of network is likely to experience the "Winner takes all" behavior (Barabási & Bonabeau 2003). The initial unstructured nature of networks created by people has induced a challenge in managing the World Wide Web (WWW) of hyperlinked pages (Berners-Lee et al. 2006). As a solution, powerful search engines crawl the web without understanding the semantics, explore the unstructured content, and as a side product, they navigate and map the man-made interlinkages of the web pages. Web science studies the "social machine" created by the information networks of the web, extending the scope of computer science to multiple interdisciplinary strategies (Shneiderman 2007). Web science is helpful in understanding the emerging macro level interactions of the people (Hendler et al. 2008; Kane 2009). Analysis of social networks is a tool for linking simple micro level characteristics, like the local connections of each network node, to macro level behaviors, such as diffusion of information and influence (Granovetter 1973).

2.2 Value systems

Value chains and value networks provide a useful theoretical view when financial value creation and value capturing are important (Porter 1985), for instance, in the case of mobile communication value networks (Peppard & Rylander 2006). Value system actors form a dynamic network of competition and collaboration (Porter 2001) and utilize, for instance, open innovation models

(Vanhaverbeke & Cloodt 2006) that may include a role for the consumer as a contributor (Norman & Ramírez 1993).

The value chain is a simple representation of a structure showing value creation as a pipeline. Practical ICT-driven value systems, like internet value systems, where structures of value creating networks emerge, utilize a set of raw materials, and implement a set of value-adding actions to create a finished product or service provided to the customers (Stabell & Fjeldstad 1998), are complicated (Porter 2001). In value network theory, digital value networks encompass more than flows of visible products, services, and revenues. They build on the exchange of knowledge and information, and intangibles become mediums of exchange in their own right (Allee 2000).

Developing value system theories utilizes system thinking and other concepts of complex systems in several different ways. Positive feedback loops create nonlinear effects, increasing returns in unpredictable ways (Arthur 1990), and facilitate growth of the value systems, which may become complex, and their observed behaviors may become comparable to ecosystems found in nature (Moore 1993; Iansiti & Levien 2004). As an example, positive feedback dominates when the communication network provides more connection opportunities at lower costs as a function of the number of the subscribers. On the other hand, negative feedback due to the lack to physical resources will limit the growth (Casey & Töyli 2012).

Value system evolutions from a simple value chain toward continuously morphing ecosystems have been extensively studied, for instance, to understand the role of new technology as a driver which disrupts value systems (Tushman & Anderson 1986; Kilkki et al. 2017), or makes industry platforms to emerge (Gawer & Cusumano 2008), and consequently, makes earlier technology capabilities and business models obsolete. In traditional value chains and networks, companies develop strategies and utilize different company-specific business models, while in highly collaborative ecosystems, strategies and value creation become sensitive to different structural issues such as connections between the ecosystem participants, also beyond the focal role of the platform leader (Adner 2017).

New firms often initiate competence-destroying discontinuities, while existing firms drive the market by building on the existing competences (Tushman & Anderson 1986). Industry architecture defining the sector-wide division of labor may experience several phases before the dominant design (Anderson & Tushman 1990) emerges and hence, industry architectures are usually partly designed and partly emergent (Jacobides, Knudsen & Augier 2006). Furthermore, internal structures of the stakeholders include architectural elements, which are also implemented in business models and are influencing capabilities to innovate and create value. Different emphases on technological changes drive evolution and disruption in value systems in four different ways: incremental innovation, modular innovation, architectural innovation, and radical innovation (Henderson & Clark 1990).

Network-oriented value creation blurs the borders of participating companies and requires a mixture of internal and external value creation. In such an environment, companies must consider the dynamics of the larger value network (Iansiti & Levien 2004; Haaker, Bouwman & Faber 2004). For instance, decision making in a single significant company (Li 2009) relates strongly to the specific ecosystem it operates in. Large value-creating systems can have many different characteristics, like in the case of geographical industrial clusters in the USA (Saxenian 1996) or in Europe (Crespo, Suire & Vicente 2014). Value creation in various networks is always a multifaceted issue, but the body of knowledge is limited how to assess the system state in such networks as defined in complexity theory. When practical value networks such as supply chain management develop more adaptive and versatile structures, complex network related systems models becomes useful (Pathak et al. 2007).

The business ecosystem as a concept introduces a model of value creation, capturing, and sharing as a system (Iansiti & Levien 2004) where solid boundaries do not limit evolution. When value creation includes collaboration and co-creation, like in the innovation ecosystems, the paradigm develops toward a system with even more complex dynamics (Smorodinskaya et al. 2017). Another ecosystem type has been recognized as the knowledge ecosystem, where the focus is on knowledge creation. The conceptual value creation of knowledge, innovation, and in different business ecosystems enables multiple different and concurrent roles for stakeholders to choose from (Valkokari 2015).

Value systems require dynamic capabilities, which enable companies to create, deploy, and protect their intangible assets. Strong dynamic capabilities allow actors to shape the value system through innovation and collaboration with other actors. Ultimately, the constraints set by regulators, standard-setting bodies, laws, social mores, and business ethics form the basis, where the final set of “rules of the game” is the result of co-evolution and complex interaction between the ecosystem participants (Teece 2007).

As a summary, the simplest model to create value is a disconnected stand-alone actor, such as an early-stage startup. Sometimes, a large monopolistic organization can behave like there was no other actor relevant in value creation. Value chains and value networks represent more versatile but still somewhat limited ways of value creation. Continuously evolving ecosystems represent an open collaborative value creation model, with observed similarities to the ecosystems in nature as a metaphor. Table 1 below is a simplified categorization of the reference terminology.

Table 1. General value creation models

VALUE CREATION MODELS/ KEY CHARACTERISTICS	**Independent, closed value creation**	**Value chain, Value network**	**Ecosystem**
Structure	Stand alone, Closed	Simple chain or hierarchy with selected openness	Many open and closed interfaces
Dynamics	Fixed, Hierarchical decision making	Flexible with some centralized coordination in decision making	Multiple, mainly decentralized or loosely coordinated decision making
Evolution	Static or Survival game	Growth within the structures and dynamic constraints	Continuously evolving structures and dynamics

The terminology requires further work (Oh et al. 2016; Ritala & Almpanopoulou 2017). Even if there is a substantial body of ecosystem research (Mäkinen & Dedehayir 2012), a systematic categorization of different system dynamics is rare (Valkokari 2015), and such studies often overlook the multidisciplinary nature of the ecosystems (Aarikka-Stenroos et al. 2016).

This research examines value creating systems to gain some further clarity and to characterize the value creating systems based on systematic modelling, including the needs to have some level of systemic alignment (Adner 2017). Taking the idea of conceptual alignment further, this research makes a difference between situations when the system state is known and internally aligned versus situations when the system is in a transition phase between states without such an alignment. Ecosystem literature pays little attention to separate growth and disruption periods, and therefore, instead of transitions, ecosystems are considered to evolve continuously. Furthermore, as it relates to traditional value network studies, the role of boundaries is important, while boundaries of ecosystems are often less clear.

Conceptual thinking referring to ecosystems in nature is an important source of inspiration. However, for value creation through innovations and industrial processes, the laws of the jungle are superseded by laws and man-made rules. One way to categorize value creating systems in communications is based on their hierarchical structure, the level of centralization and openness (Levä, Hämmäinen & Kilkki 2009), or similarly, on their centralization and horizontalization (Heikkinen, Casey & Hecht 2010).

2.2.1 Value systems and complexity

When observing complex value systems (Porter & Millar 1985), concepts of complexity theory provide a possibility to examine and classify value creation constellations based on their boundaries, internal structures, and related dynamics. Such systems experience periods of growth and disruptions, while the roles and interplay of external and internal factors are difficult to understand. This research takes initial steps to categorize the value systems using the complex attractors as references and to assess the system state in terms of complexity, while the original value system concept includes complexity often only implicitly. Therefore, complex value system in this research refers to value system modelling where the type of embedded complexity defines the system state. In other words, complex value systems include systems where the complexity can vary, and therefore, complex value system modelling includes also value systems with low or no complexity. This challenging definition aligns with the problem that a system may be erroneously considered complex if it merely exhibits certain hallmark patterns of complexity (Manson 2007).

There are some earlier conceptualizations which categorize different value creation models and their interplay. For instance, the Cynefin framework (Kurtz & Snowden 2003), Triple Helix (Etzkowitz & Leydesdorff 2000), and more recently Quadruple Helix (Arnkil et al. 2010) models recognize the different actor types and their characteristic ways of working. These concepts raise the importance of the specific characteristics of different actor types, e.g., public actors, private companies, universities, and individual people when considering both the benefits and challenges [6] of their collaboration (Wilson 2012). Organizational archetypes are useful in examining multi-stakeholder value systems, such as Public-Private Partnership (PPP).

As a clarification, different “helix models” are popular and have a tendency to grow, including components, adding no new type of system dynamics (Carayannis & Rakhmatullin 2014). Separately, the Double Helix model visualizing the dynamic transitions through different system states is another helix model for a completely different purpose (Fine 2000). The double helix model, however, is a useful high-level concept to bind together the value system fluctuations through the space spanned by the system states.

For the sake of clarity, another completely different value system concept refers to a set of base values prevailing in a group of people (Camarinha-Matos & Macedo 2010). Specifically, characteristics such as adaptability, affinity, reliability, and agility form a shared value set for a collaboration network. *A discipline of CNs* (Collaboration Networks) *shall focus on the structure, behavior, and evolving dynamics of networks of autonomous entities that collaborate to better achieve common or compatible goals* (Camarinha-Matos & Afsarmanesh 2005). Such shared base values obviously influence the dynamics and dimensions of the ecosystem they dominate. However, the term “value system” as used in this thesis is a different concept, connected to the added financial value or benefit that the business value system produces. This research does not consider the set of ethical or moral base values as such but recognizes the fact that for successful operations each real-life business value system needs to be aligned including the base value set and the other such characteristics within the system.

2.3 Regulating value systems

The laws of physics set the ultimate limits to value systems, for instance through propagation characteristics of the electromagnetic radiation. One level down, national governments control the value systems through legislation, policies and regulation defines one significant factual boundary for the ICT driven systems. The theory of regulations is broad, and only a limited set, relevant for ICT oriented use, of cases is considered in this thesis. Changes in regulation, customer needs, or business strategies drive the innovations parallel to technologies, enabling value systems to emerge, grow, and from time to time disrupt. Value system structures build interdependences and drive network effects, which make the radical and architectural innovations difficult for incumbent companies to tackle (Christensen 1997) and the overall value system transitions unpredictable (Arthur 1990; Sterman 2000).

ICT regulations are often coordinated internationally, while there are still many national variants also. The role of regulations can be both enabling (liberalizing) and limiting (controlling). Regulations may relate, for instance, to technical standards, consumer protection, network externalities, and rules for

[6] http://blog.bearing-consulting.com/2012/03/22/beyond-triple-helix-towards-quad-helix/. Accessed June 17, 2016.

industry competition and collaboration (Hix & Hoeyland 2011). Traditionally, regulations set sector-specific (agriculture, energy, health, telecommunications, transport, etc.) rules, which today creates tension, since digitalization and the use of ICT are gradually adopted in all sectors of society. The capability of industrial ICT-driven value systems to invest, innovate, and produce new value is in many ways in the hands of government policy-makers and regulators (Fransman 2010). They will need some clear anchoring points for more adaptive decisions in fast moving and dynamic markets (Clark & Claffy 2015).

Telecommunications value systems are regulated on a detailed level with sector-specific requirements, while Information Technologies (IT), for instance, are covered by less stringent horizontal rules. Regulation is considered to be a critical factor in telecommunications, influencing willingness to invest and, therefore, influencing opportunities for value systems to grow. Governments review their national policies to respond to new consumer needs, new technology opportunities, and competing actions by other countries and regions. A problem arises how to control this highly dynamic, adaptive system (Bauer 2010). The impact of national policies to global markets are important if the national governments decide to act in alignment, like in the case of 2G mobile communications in CEPT countries (Steinbock 2003).

Regulations in general have developed from monopolistic government-driven models to more liberal settings. Gradually different co- and self-regulative models have emerged (Marsden 2008). A fully uncontrolled "Laissez-faire" approach is considered impractical for ICT-driven value systems. As the liberalized global markets develop complex behaviors, the role of policies and regulations has shifted toward defining the boundary conditions and desired behaviors in the value systems. A specific interest in policy making is to incentivize investments and accelerate the adoption of new technologies, as noted in the case of broadband access (Cambini & Jiang 2009). Controlling the availability of and access to scarce resources, such as land or radio spectrum, is a powerful mechanism to control growth in value systems (Lemstra, Anker & Hayes 2011; Basaure, Casey & Hämmäinen 2012). Therefore, new, different, innovative, and technology-oriented regulative approaches can improve utilization of the resources significantly (Webb 2009). For example, as governments ultimately own the radio spectrum, they can sell licenses for a fixed period, often for twenty years, to mobile network operators, who can then fully control the radio spectrum they have licensed. The government can also allow use of the spectrum without a specific license but instead to define a set of generic rules for spectrum use, the approach applied, for instance, in the case of short-range radios in Wireless Local Area Networking (WLAN). Competition, unbundling, open access rules, and network neutrality are considered as option values affecting investment incentives (Bauer 2010) and innovation (Weber 2014; Vogelsang 2017). Such considerations require continuous re-evaluation as the technologies evolve (Wu 2003).

Regulations related to standards and interoperability form another structural element for value systems. Setting positions and rules for formal standardization organizations and consortia (Blind & Gauch 2008) and requiring international (Sutherland 2001; Infante & Vallejo 2012) and national roaming of services (Basso & Crocioni 2016) drive related value systems to rebuild their structures of competition and collaboration. Innovative new regulations created fundamentally new market dynamics for second-generation cellular mobile communication (Hillebrand 2013), and similarly, the role of the government in transportation and related technologies cannot be over-estimated (Geerlings et al. 2009) in the future. Since the launch of deregulated mobile communications, ICT-driven markets have quickly evolved toward global value systems, while public policies and regulation models have developed slowly. For instance, the regulatory framework for voice services was less than optimal as the industry transformed toward the data-centric mobile multi-media services (Vesa 2005). However, if the telecommunications sector and the legal and policymaking institutions are viewed as coevolving and complex adaptive systems, there are important implications for regulatory policy (Cherry 2007). System characteristics like resilience and resistance, as a result of positive and negative feedback loops through different types of connectivity, become points of concern (Longstaff 2003). Furthermore, the emerging ideas to utilize complex adaptive systems as a framework in regulative issues have influenced concepts of self-regulation and de facto regulation through strong multi-sided platform leaders (Boudreau & Hagiu 2009), reflecting the applicability of complex system archetypes beyond the traditional models of regulation.

Regulations related to value sharing, such as price regulation, are important in enforcing structural rules. However, the possibility of creating value from innovation is best viewed as the first imperative, whereas problems relating to value sharing can be seen as a second-order qualifying condition (Jacobides, Knudsen & Augier 2006). In this research, value sharing is noted only indirectly, e.g., by considering sharing of infrastructure and other assets.

As a summary, national regulations influence ICT-driven value systems directly through the policies for key resources, rules of competition and collaboration, as well as through different interoperability requirements, which indirectly create different dynamical behaviors through feedback structures of information and value. Smart, agile, market-oriented regulation can facilitate and limit value system dynamics, which raises the question whether regulation should be considered as a genuine boundary or as an elementary part of the system itself. National regulations form a relevant driver in global markets when there is a strong coordination in place between the national regulators. For the value systems studied in this research, the clock cycles of regulative measures are significantly slower than the clock cycles of technologies, products, and services, and therefore, regulation is considered an exogenic factor (Vesa 2005).

2.4 Standardization in value systems

The relationship between standards and business is intimate and leads to a broad body of multidisciplinary literature including economics, law, politics, sociology, strategy, as well as more practical perspectives like standardization operations, processes, and management (Swann 2000, 2010)[7]. Research related to standardization reflects the evolving issues in business. As value creation evolves from single-company models toward value networks and ecosystems, related standardization follows the paradigm and moves on toward collaboration in networks of standards instead of separate standardization activities. Collaboration between standardization activities becomes a paradigm of the system of systems. Consequently, research on standardization has started to study the interplay within and between the standards-setting organizations (SSO) (Wiegmann, de Vries & Blind 2017). This research focus on the interplay of interoperability standards and collaboration in standardization that drive the structures and dynamics of technologies and value systems. For instance, interplay between groups of like-minded participants has a positive impact on the performance of the overall system of standardization for mobile communication (Leiponen 2008).

Standardization is strategically important to the ICT industry due to the value of scale of the economy, compatibility, and interoperability between competing implementations (Shin, Kim & Hwang 2015). Interoperability between separate functions, modules, and products drives the dynamics in network economies (Katz & Shapiro 1985) and economics in general (David & Greenstein 1990). Network effects can be powerful enough to make the business system or consumer paradigm lock-in for a long time (Farrell & Saloner 1985), as has been noted for instance in the case of the QWERTY keyboard (David 1985).

Standardization and its relationship to businesses utilizing the standard forms a diffusion process of innovations. The multistage process spans from initial technologies and concepts through standardization to the tangible business and finally to adoption issues of intended end customers. Compatibility is one of the five critical diffusion factors related to innovation itself. (Rogers 1995). The time to market is shorter for radically new innovations when suitable existing regulation and standards exist (Ortt & Egyedi 2013), and in general, standardization removes market uncertainty (Gaynor & Bradner 2001) unless there are many competing standards (Gandal 2002). Standardization is therefore a significant control process for ICT-driven value systems.

Highly visible competition between standards and standardization activities initiated the debate on “Standards wars” (Shapiro & Varian 1999; Heinrich 2014; van de Kaa & de Vries 2015). These controversies have been studied in the case of video recorders (Cusumano, Mylonadis & Rosenbloom 1992), with later issues between formats of document files (Blind 2011), digital video disks (Christ & Slowak 2009; Daidj, Grazia & Hammoudi 2010), and the communications technology competition, for example, in home networking (van de Kaa 2009). Competition between different technology standards reached a climax when the race between mobile communications systems became a battle between regions of the world. The first round of this competition took place between the TDMA-based systems (2G); the second round between the CDMA-based systems (3G); and

[7] In the 2000 report, Swann covers close to five hundred articles related to standardization, which is further enhanced in his rather recent study, where he recognizes that another fifteen hundred new references have been published during the ten years between 2000 and 2010.

finally, the third round between the OFDMA-based systems (4G). The visible competition between radio technologies is in reality a part of a far more sophisticated competition between the global economic regions of the USA, Europe, and China (Glimstedt 2001), as the technologies themselves are rather similar, especially in 4G (Chang, Abichar & Hsu 2010).

In many controversies on standards, the winners seem to emerge through an optimum balance between the level of openness and the level of coordinated decision-making. The winners utilize a combination of strategies such as first mover's advantage, economies of scale, and performance leadership of the key technologies. The static idea of complementing products has evolved to dynamic interplay with downloadable applications, and consequently, traditional one-to-one collaboration in commercial partnerships has developed toward self-organized or orchestrated ecosystems. Leaders actively utilize internal and external collaboration, which influence the network effects and define the scope of interoperability and, furthermore, exploit the flexibility in standardized systems and technologies (van den Ende et al. 2012; Daidj, Grazia & Hammoudi 2010). Network effects in one sector may be able to drive the system dynamics on closely interrelated sectors (Heinrich 2014). Therefore, the value systems utilizing the same technologies and standards often align, or "self-organize", their behaviors.

While standardization has a significant impact on the business systems utilizing standards, economics can have strong influence on standardization (Fomin & Keil 2000). Expected economic value of the businesses depends on the network effects driving the participating companies to choose different strategies (Economides 1996), which may influence their standardization contributions. The standardization process has become an element in the business model design and influences competition in and between the value systems (Hawkins & Ballon 2007).

The literature is developing to study broader collaboration aspects in standards setting, including information exchange and access to complementary assets (Bar & Leiponen 2014) and innovations (Delcamp & Leiponen 2014). The more systemic (e.g., high switching cost) the technology is, the less likely it is that firms will utilize a hybrid of committee and market-driven models at the same time (van Wegberg 2004) even if that could be desirable (Blind & Gauch 2008). Broader understanding of the principles of collaboration between multiple standardization organizations is in its early phase, where different types of forums and their collaboration needs are noted, but further work is needed, for instance, related to the evolution of the standardization activities (Farrell & Simcoe 2012), such as the multi-stakeholder platform (MSP) initiative[8] of the European Union. Choosing and developing the best approach to create standards in modern society is by far not a solved problem (Fomin 2012).

Earlier research has classified standardization systems based on the nature of the controlling actors and the anticipated openness of the standardization activity. Clarity of classification becomes necessary when multiple different

[8] Multi-Stakeholder Platform, a standardization coordination approach driven by the EU Commission. https://ec.europa.eu/digital-agenda/en/european-multi-stakeholder-platform-ict-standardisation, referenced January18, 2016.

standardization processes have proliferated, for instance, due to the problems and weaknesses of traditional formal standardization (Hawkins & Ballon 2007; Blind & Gauch 2008). Furthermore, the modern ICT-driven products and services utilize many different standards at the same time requiring business leaders to cope with many, often competing and even conflicting standards at the same time (Fomin 2012).

Standards often have direct references in national and regional laws and directives. Such standards are legally binding and business actors have no choice but to implement the standards in their products and services (de jure). De jure standardization was originally driven directly by formally authorized actors, typically governmental organizations. Over time, the role of mandated de jure standards has reduced and today, only selected standards related to national security and safety are often both defined and mandated by the governmental bodies. Still, the role of the de jure standards is defined through national legislation, policies, and regulation while the development of such standards has been delegated to specific national, regional and global standardization organizations. The de jure standards are typically adopted through regulation, like the licensed GSM system standard in Europe. Today, these standards are developed by collaborative, consensus-oriented standardization committees, which are formed to include also private sector contributors. In the latter case, the formal national or regional standardization committee in practice exercises a delegated legal mandate of the governments (Fomin 2012). In such cases, the interplay between regulation and standardization, as well as with the political actors, is tight. Especially in case of mobile communication, governments and firms have had a strong effect on creating global standards (Funk & Methe 2001).

Organizations without such a formal assignment may simply take an active role to develop or set a new standard for a market (de facto). Many of the de facto standards are results of open voluntary collaborative processes. Separately, there are also de facto standards which are rather dominant designs (Anderson & Tushman 1990) imposed on the market by a single strong company who does not need to seriously negotiate with anybody else (David & Greenstein 1990; Gandal, Salant & Waverman 2003).

As a summary, Table 2 shows the simplified classification of different ways to manage compatibility and to achieve interoperability. In this research, standardization is considered broadly to include all four different approaches.

Table 2. Simplified classification of the compatibility pursuits

FOUR TYPES OF COMPATIBILITY PURSUIT	Mandated/Non-Collaborative	Openly Collaborative
Driven by a public actor (Government)	1: Mandated de jure standard	2: Licensed de jure standard
Driven by a private actor (Companies)	4: Proprietary dominant design	3: Voluntary de facto standard

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Standardization is a technical but also highly social process. *While standards might aim at the creation of stability and sameness, standardization itself is a highly dynamic phenomenon. Even the stability of standards* *themselves has to be understood as the result of underlying dynamic processes*. (Brunsson, Rasche & Seidl 2012). The multiple dynamical relationships are either competitive, cooperative, or simultaneously both, i.e. "coopetitive"[9]. The dynamics of the relationships can be categorized as changes in the conditions (e.g., goals), processes (e.g., organizational structure), or mechanisms (e.g., interaction style) (Majchrzak, Jarvenpaa & Bagherzadeh 2015). Internal processes and participants in standardization are well known (Jakobs, Procter & Williams 2001; Jakobs 2003; Hillebrand 2013), including also open voluntary consortia and organizations (Grøtnes 2008; Lemstra, Hayes & Groenewegen 2011). In standardization, the actors, activities, and artefacts connect to the same structure (Fomin 2003).

The direct link between systems theories and standardization has been rather weak. Complexity in the context of standardization typically refers to multifaceted or ambiguous issues rather than to complexity as a phenomenon. Complexity in standard-setting is a growing phenomenon (Katusic et al. 2012), as it has been in diffusions of innovations (Rogers et al. 2005), but research on complex systems applied to standardization is rare. The connection between complex systems with attractors and network topologies has been seen, for instance, when comparing diffusion models of innovations to a model of complex adaptive systems (Rogers et al. 2005), which can enhance our understanding of system use over and above predictors from individual-level adoption research (Sykes, Venkatesh & Gosain 2009). Such considerations have been applied, for instance, to study influencing in de facto standardization (Techatassanasoontorn & Suo 2011). In general, studies related to weak ties in the flow of information (Granovetter 1973) implicate that diffusion of innovations is different in differently organized value systems.

Actions of competition and collaboration form social networks showing characteristics of increased complexity (Gençer 2007; Kwak, Lee & Chung 2012). However, there is a limited set of studies which model SSOs and their behaviors as complex networks (Fomin & Keil 2000) and even less of those which utilize Social Network Analysis (SNA) methodology. SNA has been used to identify, for instance, the controlling actors of standardization organizations in China (Kwak, Lee & Chung 2012), and similarly the cross references between standardization documents have been analyzed to discover aspects of collaboration and clustering of social networks of the Internet Engineering Task Force (IETF) standards (Gençer 2007).

Systems thinking is a mechanism to address the "big issues" such as social, economic, or environmental problems impacting society as a whole and is also related to standardization (Swann 2010). An important relationship has been found between the regulatory system, the innovation system, and the marketplace in the making of wireless services (Lyytinen & King 2002), hence, spanning the space for wireless value systems to operate.

[9] In this thesis, "coopetitive" refers to simultaneous collaborative and competitive behaviors while "competitive" refers to a stand-alone approach only. From the social network analysis perspective, collaborating-only and cooperating contributors form the set of connected nodes of a social network, while competing-only contributors refer to disconnected nodes.

A specific interest relates to the possible feedback loops, which interconnect the tangible value systems of products and services utilizing the standards and the standardization system creating those standards. Such influence is often difficult to assess. The role of companies with significant commercial success in developing and utilizing the standards in their products and services is meaningful in some standardization forums like IETF (Jakobs, Procter & Williams 2001). In general, however, there are many companies, often referred to as “implementers”, who mainly utilize the standardized technologies but have a low presence in contributions. They provide neither resources nor content to the standards and, therefore, their role in endogenic system dynamics in standardization is low, but they may still influence exogenically through boundaries, for instance, by demanding changes to rules related to membership, decision-making, or intellectual property rights of existing standardization organizations (Bekkers, Iversen & Blind 2012). Such external influence can have positive or negative impact on the existing standardization effort.

Another example of external perspective relates to forum shopping (Lerner & Tirole 2006), which has a possibility to impact dynamics in standardization, for instance, if many members join or leave a standardization initiative at the same time. When the governance of Internet standardization was changed, it invited many new private sector companies to enter the IETF between 1993 and 2001, and consequently the new dynamics emerged and created conflicts related to fast commercialization of the Internet (Simcoe 2012). Such changes in standardization are powerful but rare. Typically, standardization policies change at a slower pace than relevant value system regulations, for instance, decisions on radio spectrum. Therefore, all such slow influencing is considered through changes in the system boundary conditions.

In summary, the standard-setting landscape is challenging. Standardization must become more effective and efficient and produce better results faster. Innovations contributed to standardization provide the critical input energy to the process, while collaboration and competition during the standardization process and later in the markets influence the dynamics for new value creation. While innovation is a process to increase diversity, and additional diversity is a source of additional value, the compatibility pursuit, such as standardization reduces diversity and, therefore, destroys the direct value of innovation. However, the broader impacts of standardization, such as speeding up the innovation diffusion through compatibility, creating network effects, reducing costs and market uncertainty, and providing benefits of economies of scale, bring balance to the dynamic equilibrium. Standardization forms a pre-competitive and pro-competition phase, a boundary to control, transfer, and consolidate scientific and technical knowledge for the tangible value systems which are competing and collaborating in providing products and services to their end users. This research focuses on compatibility standards due to their systemic nature and considers other types of standards indirectly only.

2.5 Modelling of value systems with complexity

Systems thinking (Senge 1990) introduces the systemic thought process and mental models, whereas system dynamics take the modelling further and provide a mathematical methodology to model and to understand the related complex real-world issues (Forrester 2007; Fowler 2003). Analytic thinking, where the system outcome is a sum of independent variables, fails to address behaviors of complex systems, where the local variables have many different interdependences that create path dependency on the system level (Gharajedaghi 2007).

Research on complex value systems sets a specific role to modelling as a tool between theories and reality. The model can build the linkage and capture the complexity of both (Manson 2007). One way to connect the role of theory, model, and reality is shown on the next page in Figure 5 as an adaptation from the modelling of geographic complexity.

The semantic diagram in Figure 5 positions the *Value System Complexity Models* in the middle to interconnect the theories and real-world observations rather than building theories from empirical observations only. The research process shown in Figure 3 includes phases of modelling and evaluation, which in the context of Figure 5 are illustrated by arrows of modelling based on theory and modelling based on reality, reflecting on sections 2 and 3 and setting the frame for modelling in section 4, and by arrows of evaluating, reflecting the studies of section 5 of this thesis.

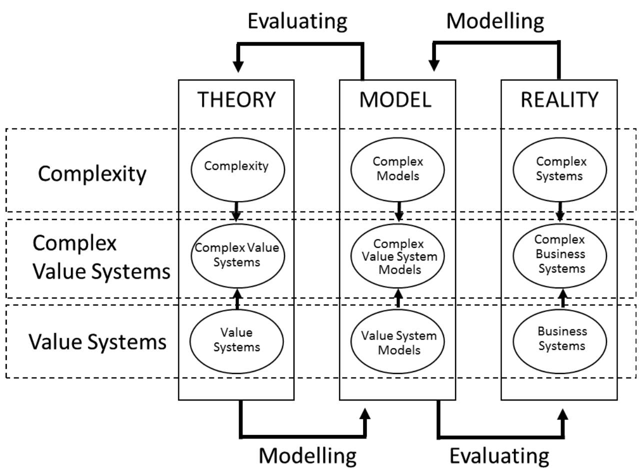

Figure 5. Semantic diagram of modelling of systems with complexity
Adapted from Steven M. Manson (Manson 2007)

In more details, *Complex models* provide a tool to examine the relationship of *Complexity Theory* and real-life *Complex Systems*. The nonlinear nature of complexity in theory and in practice requires computational modelling to provide the insights that are important in understanding the systems and their behaviors, as noted in case of geographic complexity (Manson 2007).

2.5.1 Consolidating the theories through the modelling

The semantic approach to study geographic complexity is applied to consider aspects of complexity in ICT-driven value systems. The modelling integrates the relevant existing theories on value systems discussed in sections 2.1.-2.4. with the aspects of complexity. The traditional theories of value chains, networks, and systems (*Value System Theory*) consider, for instance, linear and non-linear structures (Porter 1985; Stabell & Fjeldstad 1998; Norman & Ramírez 1993; Allee 2000), which sometimes are studied through the lens of complexity (*Complex Value Systems*), like in the case of supply networks (Pathak et al. 2007). *Value System Models* typically provide a static, system level view of the real-life *Business Systems*, for instance, in (Levä, Hämmäinen & Kilkki 2009; Heikkinen, Casey & Hecht 2010) or focus more specifically to business models of individual companies in sophisticated environments from service, technology, operational, and financial perspectives (Bouwman et al. 2008).

Value System Complexity Models consider *Business System Complexity* which is a relevant indicator for the type of dynamic behavior in the business systems. Simple metrices, like the number of the actors, or the links between the actors, do not directly define the system state, but more sophisticated methods are needed. Furthermore, if the system states vary over time, it is useful to assess them separately for each period. Complex value systems provide a perspective to value systems using complexity as a factor in theory, in modelling, and in reality, indicated by small vertical arrows in Figure 5.

As it related to complex value system modelling, centralization of the decision making and openness of the access to information set often the dimensions and, therefore, define the basic characteristics of value system (Levä, Hämmäinen & Kilkki 2009). Modelling a complex value system requires analysis to cover the system, including its relevant boundaries and the details of the subsystems and modules, to examine the state of the system. Availability and accuracy of empirical data set the limits to the modelling and, therefore, the modelling often becomes an iterative process, as indicated by the arrows connecting theories and reality through the model. Available empirical data sets limit this research to model the high-level structures only.

Qualitative modelling in Section 4 combines the existing theories with the additional element of complexity while using the observations and data from the real world to produce a *Complex Value System Model.*

2.5.2 Methods to evaluate the modelling

Section 1 introduced the structure of the thesis that consists of two main sections, modelling and model evaluation as depicted in the figure 2. Models in general are used to produce relevant information of the real world, often needed for planning or scenario building. When the model produces credible information with reasonable alignment with the real-world data, the value of the model become visible.

System dynamics connect micro models to large system behaviors with the aim to close the causal loops and logic as depicted by the arrows between theory, model, and reality. For instance, in Agent-Based Modelling (ABM) simulated actors (agents) using only their localized non-systemic logic yield system level information through a digitized model of reality. ABM is used to address complexity and dynamic behaviors in several areas like control theory, economics, and games (Holland 2006). ABM addresses dynamic phenomena through cumulating actions of individual actors while traditional approaches such as (Bass 1969) rely on dynamics on the system level. Complex models are an appealing but challenging approach due to their nonlinear, even chaotic nature (Manson 2007; Grösser 2017). Contradictions like "defining ecosystem boundaries is impossible (Iansiti & Levien 2004) while modelling of complex adaptive systems requires boundaries to make the selection of the fittest possible (Holland 2006)" demonstrates one of the key challenges. Therefore, focusing on value systems with recognized boundaries instead of broad ecosystems is a relevant approach for this thesis, especially when dynamic system simulations are used.

Social Network Analysis (SNA) is a methodology to address structural issues in networks with many actors. SNA is a tool to connect the real-world networks to several theories of complexity discussed in the section 2.1. SNA tools provide quantitative information about the networks, their structures, and other characteristics such as centrality measures and path lengths (delays) of the information flows (Wasserman & Faust 1994) , which have both local and global implications (Hanneman & Riddle 2005). Visualization of social networks provides a useful complement to qualitative case studies (Basole et al. 2012). Time-variant developments can be studied if the data on social networks include information on connections with time stamps like in case of FLOSS[10] repositories (Martinez-Romo et al. 2008). Social networks are often studied by focusing on structures or behaviors of the actors or as a combination (Jiang & Jiang 2014). This research focuses on the structural analyses. Aligning the discoveries in network topologies and dynamics in observed value systems related to technologies, businesses and action of the people provides another powerful mechanism to evaluate the complex value system model.

Section 5 address the model evaluation in detail.

2.6 Propositions for modelling

This research has a system-level focus on real-world businesses using complexity as a high-level conceptual framework and the traditional value system theories, models, and reality as the baseline to examine and model value systems with different levels of complexity, i.e. *Complex Value Systems*[11]. Granularity of the modeling is defined and limited by the visibility to the interfaces between the system actors, i.e. governments, private companies, communities or individual people.

Complexity theory characterizes real-world complex systems through their network structure by examining the system actors and their interactions.

[10] FLOSS in general refers to Free/Libre and Open-Source Software. There are many such data bases with embedded social networks of developers.

[11] Complex Value Systems is used parallel to Value Systems with Complexity, both including any levels of complexity characterized by the related system attractors.

Individual behavior and characteristics of the system actors make the overall system show specific time-dependent behavior. The system dynamics of networks fall into four basic archetypes (Strogatz 2001; Fowler 2003). When such archetypes are applied to value systems with different levels of centralization and openness, similar conceptual complex value system archetypes or value system states can be defined. In this research, these archetypes are applied to examine business systems where complexity is expected to have an important role.

The complex value system archetypes characterized by the conceptual attractors introduced in section 2.1 are defined as follows[12]:

Value system with Fixed attractor. Centralized decision-making with no external interaction. Monopolistic decision-making with closed technical and operational interfaces where only internal innovation is possible. (System type 1)

Value system with Limit-cycle attractor. Centrally coordinated decision-making with limited openness. Comprehensive set of requirements defines technical and operational interfaces allowing multiple actors to collaborate as pre-defined. Small number of key decision makers influences the system behavior significantly. (System type 2)

Value system with Strange attractor. Loosely coordinated decision-making with broad openness. Loose set of requirements allows large number of actors to participate based on their own judgement. (System type 3)

Value system with No attractor. No external requirements set. Fully independent decision-making lets the actors maximize their individual opportunities. In case of no common goals, the system becomes fully disconnected and fragmented based on random interactions. (System type 4)

Boundary conditions set the frame and functional rules for complex systems and their evolution. In practice, national legislation, policies, and regulations set the overall framework for all value systems in business. Regulators have the power to control the natural resources within the constraints of the laws of physics. Access to critical raw materials and other essential resources is a powerful tool for influencing value system dynamics. Furthermore, regional and global harmonization initiatives drive and moderate the business environment with a set of liberties and constraints, including requirements to interoperate. Governments set the scene for competition and collaboration and sometimes define the expected roles for the actors. For instance, in a value system with a limit cycle attractor, strong contractual or regulatory requirements tightly interconnect the group of actors, while a loosely coupled group in a value system with a strange attractor is connected through weaker, voluntary, often preferential ties. Regulation can directly control the feedback loops, for instance, by separating actors into groups, by disconnecting and unbundling functional entities, and consequently influencing network effects in the value system.

As it relates to standardization, there are four principal ways to standardization as defined in table 2. Standards define, for instance, the technical

[12] Numbering of the attractors and system states follows the numbering used in publications, as the related literature is using several different ways to number the attractors.

interfaces for the interoperability in the value system. For this purpose, standardization process picks and chooses relevant technologies, develops them further and formalizes the standards the value system will utilize. Therefore, standardization influences technology providers when they promote their offerings to ICT-driven value systems.

Four different system archetypes characterized by the four different complex attractors span the dimension of centrality and openness for the complex value systems and at the same time they define the framework for the relevant options of regulation and standardization as listed in Table 3.

Table 3. Aligning boundary considerations toward complex attractors

SYSTEM ARCHETYPES/ BOUNDARY OPTION	**Type 1**	**Type 2**	**Type 3**	**Type 4**
Attractor type	Fixed	Limit cycle	Strange	No attractor
Regulation option	Assigned, Mandated	Licensed	License Exempted (Unlicensed)	Laissez faire
Standardization option	Mandated de jure	Licensed de jure	Collaborative de facto	Proprietary de facto

In summary, this research examines the ICT-driven value systems that include elements of complexity, builds a model which can be used to examine and explore such systems, and contributes to the theoretical understanding and methods related to complexity in value systems. Existing literature on systems research encourages to focus on structures and impact of boundaries, to study and characterize systems and their dynamic behaviors. The four complex system archetypes set the framework for complex value system state modelling that utilizes the set of attractors as a reference.

The framework is applied to the empirical ICT-driven value systems to define a process and a model which can be used to examine value systems with different levels of complexity. To address the research question RQ1, the following detailed propositions are derived:

P1: Boundaries influence the resulting system state of the ICT-driven value system.

P2: Structures and dynamics characterize the state of the ICT-driven value system.

P3: State transitions restructure the ICT-driven value system and drive new dynamics.

The propositions are taken forward qualitatively in section 4 and in more detail for two specific cases in section 5.

3 ICT-driven value systems

The new era was ignited by multiple innovations around 1970, when the first commercial microprocessor (Intel 4004), the first Internet specification (RFC 1 Host software), and the first integrated CMOS [13] Analog-to-Digital converter (Analog Devices AD7520) surfaced[14]. At the same time, breakthroughs in software, networking, and signal-processing technologies took place on an algorithmic level, laying down the foundations for the modern ICT.

Technologies have developed exponentially[15], supporting each other, and digitalization of information has gradually superseded analog processing. Today, ICT focus areas include virtual software clouds running algorithms of artificial intelligence, networks developing toward 5G and broad use of IPv6, as well as augmented and virtual reality applications running on devices that enable end users to utilize the new capabilities. Ubiquitous connectivity enables billions of sensors to collect massive amounts of data for the ICT machinery, which as a reward runs society through automated processes applied to all sectors of our life.

ICT-driven value systems are overwhelmingly large and versatile, and they drive society by bringing new capabilities and functionalities to traditional industry sectors. Beyond the direct technology influence, ICT-driven value systems impact the system dynamics of other industry sectors through network effects (Heinrich 2014). It is an open question whether the ICT rules will evidently apply to all industry sectors or whether other sectors and industries are able to define the ICT based systems to follow the traditional rules. Harmonized modelling of the ICT and other interrelated value systems is therefore relevant.

Section 3.1. discusses the high-level structure of the ICT-driven value systems. Section 3.2 considers two mature ICT-driven value systems, mobile communication and internet, and section 3.3. focuses on their convergence. Section 3.4 briefly addresses the traditional value system of transportation under the influence of ICT. Transportation refers to any type of value system transporting people or goods, while Mobility as a Service (MaaS) is a specific

[13] Complementary Metal-Oxide-Semiconductor, a technology to produce integrated circuits for mass market

[14] At the same time in 1969, in the remote Nordic town of Helsinki, Nokia developed their first data modem (200 baud) to be used in the data network of the Finnish Universities (later FUNET), utilizing the connections provided by Suomen Posti ja Tele. This system connected university research, private, and public actors in collaboration for advanced telecommunications using a collaboration model, which now after fifty years is better known as Triple Helix of PPP.

[15] Referring to heuristic nonlinear laws such as Moore's law and Metcalfe's law and other similar observations.

emerging ICT-driven concept shaping the value systems, possibly toward value systems of mobile communications and internet. Section 3.5 consolidates the landscape and defines the context for the thesis.

3.1 Structures of ICT

Technology development enables new services, and new service ideas require new technologies. Adoption of new technologies, business models, and strategies often involves sophisticated and multifunctional transitions, broader shifts from one policy regime and a set of market signals to another alternate policy regime and another set of market signals (Zysman et al. 2010). These shifts in regimes are often regional, service- or technology-specific, and therefore, the overall market experiences multiple states of equilibrium and transitions between them. The importance of end-to-end requirements and fast development and diffusion of technologies pull the stakeholders together and encourage collaboration and not only competition. Well defined system borderlines and boundaries are important in understanding the value systems developments, such as the transition from GSM and UMTS (Hillebrand 2013), mobile radio spectrum issues (Basaure, Casey & Hämmäinen 2012), mobile services (Vesa 2005), or the unbundling of network and services in national markets (Davies, Howell & Mabin 2008). Over the years, ICT-driven value systems have grown and developed sophisticated networks and structures. The structures include different layers from the societal level through industries and technologies to science. For the technology-oriented "lower layers" (science, R&D), it is often possible to define clear roles of actors while for "upper layers" the situation is fuzzier (Kilkki et al. 2017).

In a complex system, the different pace of change virtually divides the system into separate subsystems (Hyötyniemi 2006). Therefore, separation of the fast-moving technologies into their own lower-layer entity is a practical choice which has only limited impacts on the big picture. To manage this properly, a solid borderline is needed to define the boundary between the ICT value system and a pool of all possible technologies. Innovations on the lower layers are important to upper-layer actors for enabling the value system evolution. Standardization, including all the options of Table 2, is one of the key mechanisms driving and controlling technology diffusion from research to operational ICT-driven value systems. Consequently, standardization forms a solid boundary between ICT-driven value systems and fast-moving technology layers.

As it relates to upper layers, the pace of change can be used similarly to bring further clarity to the fuzziness. The upper layers consist of entities with three different characteristic clock cycles. Businesses in the ICT-driven value system aim to match consumer needs including the equal pace of change. Governments, however, representing the higher societal layers, change their positions slower and, therefore, form a separate entity from the ICT-driven value systems and their customers. Therefore, policies and regulations form the boundary to manage the interface between governments and ICT-driven value systems. Finally, the laws of physics change even slower, and the physical constraints form a rather static boundary for the ICT-driven value systems, where scientific discoveries may occasionally introduce some changes.

In summary, the different pace of change sets boundaries (shown as arrows) for the ICT-driven value systems and sets the framework for this research as depicted in Figure 6. The high-level system boundaries are recognized by defining the five high-level entities as domains, reflecting their different systemic nature, i.e. laws of physics, government domain, consumer domain, technology domain, and finally the ICT-driven value systems in the middle.

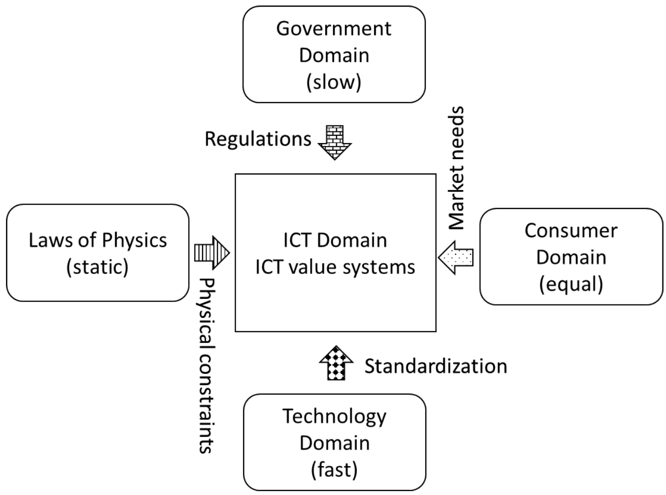

Figure 6. Principal boundaries of ICT-driven value systems

Due to the frequent interaction between the ICT-driven value systems and their consumer customers (conceptually operating roughly on equal cycle time), the borderline between these domains is blurred. The intimate relationship between the ICT-driven value systems and their customers, i.e. the relationship between market needs and provided products and services, pulls the domains together regardless of the generic regulations, such as consumer rights and privacy protection. Furthermore, consumers are considered also to be systemic actors in the ICT-driven value system. For instance, consumers and other end users are merging the roles as prosumers, private content providers (Prahalad & Ramaswamy 2004).

To limit the scope, some simplifications are used. Influencing through the boundaries is often two-directional, but for this research, the boundaries are considered one-directional, shown as unidirectional arrows. That is, actors in the ICT-driven value system are incapable of significantly influencing governments, science, or laws of physics, as their influence materializes through long and slow feedback loops, such as lobbying, fundamental research, and legal processes. Therefore, this research focuses only on boundaries set by regulation and standardization, while the laws of physics are considered fully static, and consumers are included as value system actors.

3.1.1 ICT-driven value system

As it relates to the ICT-driven value system between the two relevant boundaries, the "ICT ecosystem" consists of four important "layers" in a reference model described by Martin Fransman (Fransman 2010). The layers in this context refers to four groups of players, i.e. networked element providers, network operators, content and application providers and consumers. Multidimensional analysis in defining solid boundaries for the actor groups is important in long term strategic considerations since perceived structures based on value creation only (Sabat 2002) may lead to temporary conclusions.

In this research, layers are referred by a neutral word, cluster, to avoid any preference between layers, actors, or actor groups but still indicating a certain amount of similarities between the entities. Also, instead of referring to all ICT-driven businesses as ecosystems, value system terminology is used as discussed in section 2.2. Clusters are referenced using the name of the technical asset, such as "network", instead of the legal operative entity "network operator" controlling the asset. With these clarifications, a set of recognized clusters and the interfaces between them form the high-level structure for the ICT-driven value systems as an adaptation from Fransman (Fransman 2010).

The clusters of the ICT-driven value systems are as follows:

Cluster 1: (Content) This cluster includes all possible elements of aggregated digital content. Examples include music and movie libraries of major content brands. Gradually all the public and private databases (big data) of healthcare, education, and more are becoming part of this cluster. Content is managed by content and application providers.

Cluster 2: (Network) This cluster includes all the means to transport the digital content and connect the stakeholders. The most notable parts of the network cluster include the global mobile and fixed communication networks. Control functions of the network cluster are normally embedded while the implementation technologies have recently become more and more cloud-based. Licensed network operators as well as other actors operate the network entities and systems.

Cluster 3: (Device) This cluster includes all consumer products and gadgets that are connected through Cluster 2 and which can be used to consume, control, and complement the content in Cluster 1. In a simplistic view, consumer products provide also the physical (user) interface for a human being to access the capabilities of the clusters. Smart phones, automobiles, TV sets, and white goods at home, medical equipment in hospitals are examples of end-user or consumer devices which may be locally connected to each other.

Cluster 4: (Personal Data) Consumers own their personal data. Until recently, the role of personal data has been rather underdeveloped, but with the growth of the Internet of Things and other data-age phenomena, the situation is changing rapidly. Control rights and ownership of personal data are under implementation in Europe[16]. Examples of personal data include data on SIM cards and similar data independently of the physical storage media. Personal data include any data which are identifiable to a person, such as consumer-created content in social networks. Separation of personal data from the person is identical to separation of the network operator and the network.

These clusters have been identified from several perspectives, as using generic degrees of freedom in knowledge generation (Fransman 2010). Using the opposite way, lack of freedom, produces a similar structure. Control mechanisms imposed by regulation have been broadly studied, for instance, in the case of network neutrality (Wu 2003; Bauer 2010) and in the case of mobility of the roaming subscribers in the Universal Mobile Telecommunications System (UMTS[17]), using either Mobile Station (MS[18]) roaming or Subscriber Interface Module (SIM) roaming (Rapeli 1995) with aligned results.

Earlier studies address behaviors of actors as individual decision makers in each cluster. Cross-cluster studies find that agile regulation of the critical interfaces influences market dynamics significantly, for instance, in case of handset bundling and mobile data usage (Tallberg et al. 2007). From system dynamics perspective, such regulation considers the acceptable or optimal strength of the positive and negative feedback loops in the system. Holistic studies on value systems require recognition of the cluster-level factors as well as inter-cluster issues like the role of actors (companies) operating in several clusters at the same time as they in this way influence the strength of the system level feedback loops. All ICT-driven value systems include elements from all clusters, but the implementations vary case by case.

The four clusters impose (4 – 1)! = 6 interfaces, symbiotic relationships (Fransman 2010), between the clusters. From the system dynamics perspective, the role of the interfaces is naturally as important as the role of the clusters.

The interfaces between the ICT clusters are as follows:

Interface 1: between Content and Network defines a borderline and limits bundling between the clusters, e.g., how to provide quality of service to specific content services (Recognized, for instance, as Net neutrality).

Interface 2: between Network and Device supports device interoperability and limits technology-based lock-in possibilities (Recognized, for instance, as an open-air interface).

Interface 3: between Device and Personal Data separates the identities of the device and the end user. The interface limits possibilities to bundle mobile devices and mobile subscriptions among others (Recognized, for instance, as an

[16] Personal Data has been recently strongly recognized, for instance, in the new European directive General Data Protection Regulations. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0679&from=EN.

[17] Universal Mobile Telecommunication System refers to the European initiative to develop system and technologies for the 3rd Generation mobile networks. http://www.etsi.org/technologies-clusters/technologies/mobile/umts. Accessed January 15, 2018.

[18] Mobile Station and Subscriber Identity Module refer to functional modules of the 2nd generation system in Europe.

MS/SIM interface with programmable SIM lock[19] functionality as a mandatory regulative requirement).

Interface 4: between Content and Device is weakly defined (Various models to build bundles over the interface exist without balancing recognition to drive openness and competition).

Interface 5: between Content and Personal Data is weakly defined (Various models to build bundles over the interface exist without balancing recognition to drive openness and competition).

Interface 6: between Network and Personal Data focuses on the Personal Data of the end users (Recognized, for instance, as number portability and related regulations).

Four (1, 2, 3, and 6) out of these six interfaces are systematically recognized, i.e. the rules of openness and bundling over the interface have been defined through institutional elements such as laws, regulation, standardization. Especially interfaces 1 and 2 are quite broadly adopted[20]. Each key interface plays a role when market actors are seeking new possibilities, for instance, using bundling of functionalities from different clusters for enhanced value creation and capture. As examples, the interfaces with weak regulative requirements are sometimes diluted by highly competitive service, product, and technology bundles, observed in the case of the Amazon Kindle[21] device and content bundle, for example, or in the case of Facebook[22] providing identity federation as part of their social media service.

The clusters are often presented in a logical vertical stack of layers separated by horizontal interfaces (shown as pairs of arrows pointing at the interfacing clusters, with de jure unbundling shown as solid lines, and possibilities for de facto bundling as dotted lines) as in Figure 7 on the next page.

[19] A programmable mechanism to lock (and unlock) the connection of a SIM card to a specific mobile device

[20] For Net Neutrality see, for instance, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2120&from=EN. For Air interface, Service provider and SIM interfaces see, for instance, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:51994DC0492&qid=1464079698636&from=EN. Accessed March 16, 2018.

[21] Amazon Kindle store. https://www.amazon.com/gp/product/B00I15SB16/. Accessed March 16, 2018.

[22] Facebook Identity federation. https://developers.facebook.com/docs/facebook-login . Accessed March 16, 2018.

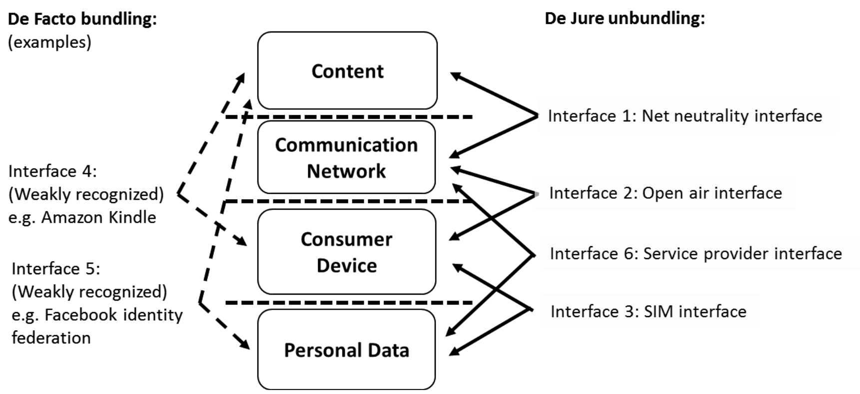

Figure 7. Recognized ICT clusters and interfaces between the clusters
Adapted from Publication V and (Fransman 2010). Copyright 2015 IEEE.
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For the future, the weakly recognized and weakly managed interfaces require similar attention as all the other key inter-cluster interfaces due to the growing influence of network effects between interrelated industries (Heinrich 2014). The mental model of the vertical stack with horizontal interfaces has contributed to a broader conceptual thinking such that, for instance, regulations and standards are addressing the market horizontally while companies often aim to build vertical businesses. This notion is partially misleading and deliberately undermining the importance of the interfaces 4-6, which in such a drawing are "not horizontal". Therefore, it is useful to redraw the stack and to show all the clusters as equally important. This provides a balanced view to the functional work split of the ICT clusters (Fransman 2010) positioned between their high level boundaries (shown as arrows), as presented below in Figure 8.

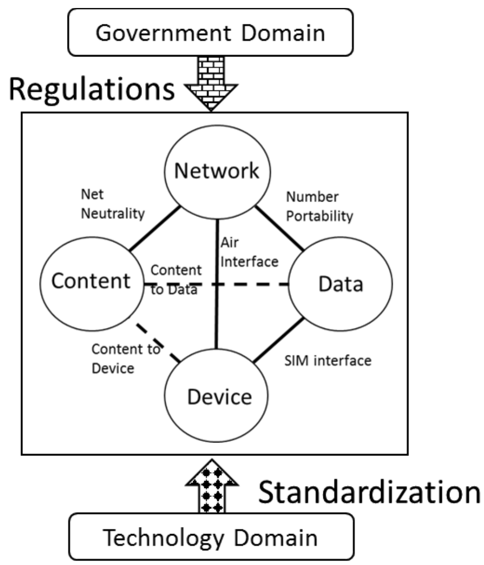

Figure 8. Symmetrical model of clusters inside the ICT-driven value systems
Adapted from Martin Fransman (Fransman 2010)

The currently well-defined interfaces are shown as solid lines, while dotted lines indicate the weakly recognized interfaces. This drawing allows the flexible use of the vertical and horizontal mental model. The symmetrical presentation of the clusters can be turned around as needed, and each interface can be observed in the “horizontal” position and related to potential bundling “vertically”. Each ICT cluster has many actors that provide competing products and services to the end users, but due to the systemic nature of the ICT, actors need to collaborate with their competitors and partners within their cluster and in other clusters.

3.2 Mobile communication and internet

Mobile communications and internet value systems range over the four clusters of the ICT-driven value systems. These two initially fully separate value systems have gradually developed toward convergence. Due to the initial separate starting points, the evolutions of the value systems are studied separately with additional convergence considerations. The research emphasizes developments in network and device clusters and the open interface between them.

3.2.1 Mobile communication

Wide area cellular mobile communication has its roots in Bell Labs[23], where the idea of geographical re-use of radio frequencies was introduced (Manninen 2002). Since the early days of radio communication, national governments have noticed the special role of radio spectrum, and for this purpose, the International Telecommunication Union (ITU[24]) was set to coordinate the use of this resource globally. The ITU effort utilizes voluntary decision-making by national governments, and the effort is organized into three regional subgroups. The coordination decisions reflect local interests of the regional groups. Political and commercial path dependences have influenced the regional groups and consequently the boundaries of the mobile communication value system in each region. ITU regional groups include Region 1, consisting of Europe, Russia, Mongolia, the Middle East and Africa, Region 2, covering the Americas and Greenland, and Region 3, comprised of high population areas of Asia and Oceania.

Liberalization of telecommunications gained momentum through the decision of the U.S. Department of Justice to break the vertical monopoly of the American Telephone and Telegraph Company (AT&T) in 1972. This decision lead to establishment of Regional Bell Operating Companies in 1982. Similar steps were taken in other countries, like in the United Kingdom, where the government decided to privatize British Telecom through the Telecommunications act of 1984. These legislative decisions set the basis for other countries to follow the model. When the public telecommunications services were opened for competition, regulation and consumer protection remained the governments’ responsibility.

[23] Bell Labs refers to the laboratory created by Alexander Graham Bell. https://www.bell-labs.com/about/history-bell-labs/. Accessed March 4, 2018.
[24] International Telecommunication Union is the United Nations specialized agency for information and communication technologies (ICT). https://www.itu.int/en/about/Pages/default.aspx. Accessed January 25, 2018.

During the first half of the 1980s, the first generation (1G) of mobile communication technology development and service deployment took place in a rather fragmented and unsynchronized manner in different parts of the world. National administrators assigned key resources, like radio spectrum and telephone numbering schema for public networks, to the leading national telecommunication companies, which gained a monopoly market position in the provision of the simple Plain Old Telephony Services (POTS) to the mobile users. Mobile communication was considered an extension to the fixed telephony with the same services and only wireless mobility of the subscribers added. Mobile network operators (MNO) defined proprietary specifications without paying attention to the emerging ICT clustering. Air interface between the network and mobile station was the only interface with publicly available specifications. The value system and the roles of technology companies, device and equipment suppliers, as well as end users were fully controlled by the MNOs and indirectly by the governments. The Advanced Mobile Phone System (AMPS) developed in the USA was the most popular technology during the 1G era (Funk & Methe 2001).

The first semi-open system was developed in the Nordic countries. The Nordic Post and Telecommunication authorities realized that building separate independent networks and technologies for such small economies would waste resources. The first mobile communication system with international roaming was launched in 1981. Coordinated but still monopolistic decision making in all Nordic countries facilitated harmonized radio spectrum allocations, and the behavior extended to common service requirements and technology development. Coordination between Nordic operators ensured a long-lasting collaboration model for the future (Lehenkari & Miettinen 2002). The Nordic Mobile Telephone (NMT) system was implemented in all Scandinavian countries including international roaming between the countries. Later some European and Asian countries adopted the NMT technology also.

Only a few years after the service launch, the 1G mobile communication experienced severe congestion due to limited radio spectrum. It became obvious that the 1G networks will fail to support the growing demand. At the same time, digital signal processing, software, and silicon technologies were taking fast steps forward. It became obvious that the second generation (2G) of mobile communications will be digital. The only question was what kind of digital system would be most suitable for each national market.

A major system transition took place, especially in Europe, when the national telecommunications authorities in their coordination organization, the European Conference of Postal and Telecommunications (CEPT), decided to develop one single pan-European system with open standardized solutions (Steinbock 2003). In 1982, CEPT[25] established a Special Mobile Group (Groupe Special Mobile, GSM[26]) to explore European alternatives to build a pan-European mobile service in the spirit of the expanding European Union.

[25] Conference of European Postal and Telecommunication Administrations (CEPT). http://www.cept.org/. Accessed March 6, 2017

[26] Group Special Mobile (GSM), a dedicated mobile working group of the (CEPT) initiated in the early 1980s. http://www.cept.org/. Accessed March 6, 2017.

The specification development process covered four of the six interfaces between the ICT clusters. As part of the process, the authorities decided to promote competition between MNOs in each country by liberalizing the use of the radio spectrum and device ownership. The encouraging experiences of NMT drove the requirements for international roaming within all CEPT countries (Haug 2002). All these new regulations created a fundamentally new set of market dynamics for the second-generation cellular mobile communication. The European model implemented in the GSM system was exported to almost all countries in the world (Hillebrand 2013). However, other administrations outside of CEPT countries adopted a less demanding vision without strong interoperability requirements between the national networks. In the GSM system, novel protocols (GSM MAP, Mobile Application Part) provided mechanisms for secure roaming of the mobile stations between the networks, beyond the mobility within one network. Through the radical requirements for interoperability, the CEPT countries gained leadership within ITU Region 1, while USA was the leader in ITU Region 2. In ITU Region 3, only Japan developed their own national approach for 2G and, in a broad sense, the role of Region 3 became important only later.

The GSM service was launched commercially in 1992. The GSM-driven mobile communication value system focused initially on end-to-end voice service. Basic low-speed circuit-switched data services fail to provide compelling support for an Internet-style client-server paradigm. A packet-switched data service using the General Packet Radio Service (GPRS) protocols was introduced as a steppingstone toward the next generation, but it failed to change the POTS-oriented service paradigm of GSM. During the 2G era, all attempts to create significant value in the content cluster were quite unsuccessful, and separate content cluster actors in the 2G mobile communication value system were rare. The content-oriented services, such as voice mail and Short Message Service (SMS), were fully integrated into the mobile network functionalities and operated by the MNOs. Therefore, the 2G mobile communication value system consisted of three key types of actors: end users, network operators (with their integrated content services), and companies providing devices to end users.

In the GSM-driven mobile communication value system, the dedicated radio spectrum licenses allow MNOs a unique position. The spectrum licenses give full access for each operator to the limited natural monopoly resource in each market. As the regulators award parallel licenses in each country, they facilitate limited competition between the MNOs. MNOs have a set of other privileges, such as the right to offer a bundled service including the subscription and mobile device (ME/SIM bundling) to the consumers. Regulators balance the privileges by a set of service obligations related, for instance, to minimum coverage requirements, support of international roaming, emergency services, and legal intercept requirements.

Toward the end of the century, fast growth in 2G services parallel to the emerging paradigm of data networking and internet technologies motivated investments in the third generation (3G) of mobile communications. The success of the GSM system had validated the importance of international roaming of mobile services, and the interest to build a global mobile communication service was strong. This need was recognized both on a national and international level in ITU, and it was strongly supported by the operators and suppliers of the 2G systems. Availability of the harmonized radio spectrum became the key challenge in 3G due to the technology limitations of radio frequency subsystems in mobile devices. The radio spectrum coordination in ITU set the basis for global collaboration in building the 3G systems, technologies, products, and services. The first 3G services were launched in 2001. Circuit-switched voice remained the mainstream service, and the growth of data services was slow. There was no obligation to enable data services in 3G to follow the internet value system paradigm, which was gaining the leading position for data services in fixed networks outside of the mobile communication value system.

Two parallel 3G systems were developed for the global market, both using Code Division Multiple Access (CDMA) radio technology in their radio subsystems but with fundamentally different configurations and with fundamentally different core network subsystems. In China, a specific local adaptation, optimized Time Division Duplexing (TDD), was defined for national use. As the technical capabilities improved, the use of 3G data services gained momentum, and the next-generation technologies (4G) were optimized for packet-switched data services with circuit-switched services as a fallback only. The leading 3G system inherited the GSM system model by adopting the core network protocols and technologies as well as other specific key features such as SIM cards from GSM. Dual mode GSM/WCDMA operation and ETSI sponsoring the 3rd Generation Partnership Program (3GPP) in 3G standardization finalized the smooth evolution all the way from GSM/GPRS toward 5G.

As it relates to the USA and Japan, the development from 1G onwards had some specific deviations. The regulators set fewer demanding requirements for MNOs to interoperate. For instance, operators could develop separate non-interoperable systems for messaging and other value-adding services. Instead of a holistic system transition from a monopoly model to an interoperable licensed model, the systems transformed from one monopoly operator approach to three almost separate monopolies. This significant decision maintained the system fragmentation in those markets which included significant consequences also related to the adoption of later generation technologies.

The different market dynamics in different countries have influenced the mobile communication value systems, especially related to the convergence of Mobile Communication with the Internet, giving temporary advantages to first movers in ICT and innovative business models (Steinbock 2003). Generations of licensed mobile communications from 1G through 2G, 3G, and 4G toward 5G define the line of major changes, including changes in technologies, architectures, and ways of working. Regulatory decisions to allocate new radio spectrum for mobile communication have been one major driver to make the difference between the generations, specifically for the licensed value system, as expected (Steinbock 2003).

The generations of mobile communications are as follows:

1G: Era of the emerging public mobile communications services with new wireless technologies like cellular mobile networking, driven by leading national innovator companies. Analog national systems and networks dominated the market (NMT, TACS, AMPS and others).

2G: Regional consolidation of business systems with related technology choices to create significantly more value, including larger network effects. Digital technologies drive the system performance far beyond that of the previous analog methods. Regional digital networks with roaming necessary only in Europe (supported initially only in GSM; other networks like D-AMPS, CDMA, PDC implemented advanced core network functions later).

3G: Global consolidation of technologies toward a single main stream. Deviating regional ambitions disabled full platformization (3GPP-driven WCDMA gained leadership over other value systems like 3GPP2-driven CDMA2000).

4G: Full platformization. High-performance radio complemented with a flat network architecture allows separate business systems to emerge on top of the mobile platform (3GPP-based LTE/SAE networks dominate mobile communication, and internet services emerge Over the Top (OTT) of the mobile communications).

5G: Performance needs of a new type of vertical businesses drive the platform to provide multiple different types of quality of service while maintaining full interoperability within the system (3GPP-based 5G will provide segmented services using, for instance, network slicing).

6G: Communication and network technologies are expected to become mature, which will move the focus of innovation and value creation to the digitalization of society in general.

In summary, the generations from 1G to 5G can be visualized in Figure 9 by using the eternal cycle or double helix model developed by Charles Fine (Fine 2000) (arrows show the direction of the evolution). Development of mobile communications is driven by environmental changes complemented by multiple types of innovations. Paradigm shifts require multiple changes in value systems (Keeley et al. 2013).

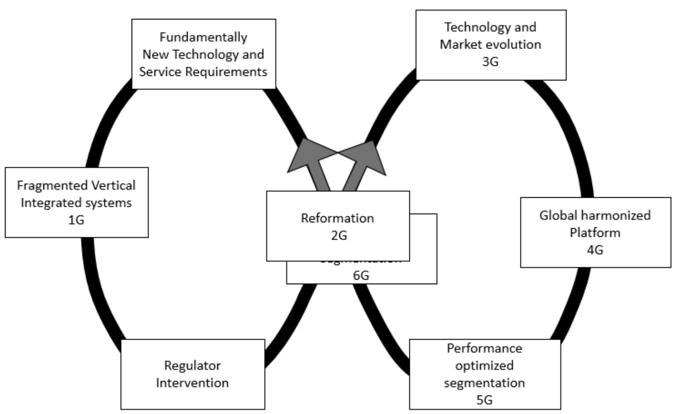

Figure 9. Double Helix of mobile communications
Applied from Charles Fine (Fine 2000)

In the drawing, the cycle through multiple service and technology paradigms (generations) begins when fundamentally new market requirements (mobility) are enabled by new technologies (wireless) and a new critical resource (radio spectrum). The vertical closed value creation of 1G with centralized decision-making forms the first extreme paradigm on the left. Liberalization drives decentralization and technology horizontalization through 2G and 3G to the other extreme in 4G on the right. Optimization of the ICT capabilities for specific business verticals such as IoT reduces interest in horizontalization and encourages abandoning net neutrality in 5G and toward 6G[27].

Dynamic systems analysis requires that the system borders be well defined. For mobile communications, this requirement is implementable by noting that critical system boundaries are set by laws of physics and, in more detail, by explicit regulations related to boundary conditions, especially the availability of radio spectrum, and to rules of competition and collaboration, obligations of MNOs to provide interoperable services and requirements to provide a set of well-defined interfaces. The speed of change in technologies is fast, and for each generation of mobile communication, the set of technologies is developed or defined in detail in standardization, which defines the other boundary for the observed value system.

3.2.2 Internet

The first conceptual ideas for the system that later became the Internet were developed in the context of the Advanced Research Project Agency (ARPA[28]) of the United States Department of Defense (Leiner et al. 2009). Internet development started as a novel and simple packet-switched protocol design with an ambitious vision of a “Galactic Network”. The initial ARPANET[29] consisted only of the Interface Message Processors (IMP) and the protocol between the processors. The development took place as a scientific project, and the first operational node was set up in the University of California Los Angeles. Other universities joined the project and connected their host computers to the network.

The original host-to-host Network Control Protocol (NCP) had limitations, and it was superseded by a new protocol developed for an open multivendor environment. This work yielded the first version of the Transport Communication Protocol/Internet Protocol (TCP/IP). The new protocol suite implemented all the key characteristics of the Internet as we can observe it today, including computing platform independence, best-effort communication, and retransmission in case of a packet failure. For the TCP/IP, black box devices (routers and gateways) maintain no information of the individual data flows, and the connections operate without any centralized control. Formal architecture specifications of the Internet are simple, as the system consists of fractal subsystems connected to each other

[27] Speculatively, the model predicts the needs for fundamentally new requirements (digital society) enabled by new technologies (machine learning) and new critical resources (personal data) to initiate a major next era to begin. Predicting the future is challenging and beyond the scope of this research. However, the model aligns with other similar models such as phases of K-wave.

[28] The Advanced Research Project Agency has been renamed as Defense Advanced Research Project Agency DARPA. https://www.darpa.mil/. Accessed October 17, 2017.

[29] The initial name of the network technology connecting the computers was ARPANET.

as they prefer. From the innovation diffusion perspective, the same principle applies, and the decision to incorporate the TCP/IP into the Berkeley Software Distribution (BSD) Unix system made the protocols available for voluntary adoption to the research community in the USA.

Governmental guidance for the Internet was simple. Initially, however, the use of the TCP/IP was mandated as a defense standard, which led to two versions of the protocol use cases: MILNET supporting the defense needs and ARPANET supporting the research. The National Science Foundation (NSF) decided to adopt the TCP/IP for their networking needs, and other similar voluntary TCP/IP networks were built for other similar purposes. The Federal Networking Council (FNC) coordinated the sharing of costs of communication infrastructure including intercontinental cables and interworking with networks in other counties. The close co-operation of the NSF and the FNC promoted the use of the TCP/IP beyond national borders (Leiner et al. 2009). The voluntary nature, sponsored by governmental actors, has "donated" the fundamental operative characteristics to the Internet, its protocols, and to the collaboration in the network deployments. At the time of these early developments, commercial computer networking solutions were all fragmented, different companies driving their own technologies, which were vertically integrated into their computing platforms, including, e.g., SNA[30] (International Business Machines, IBM) and DECNet[31] (Digital Equipment Corporation, DEC).

The Internet community initially ignored the importance of mobility. All the internet protocols assumed fixed connections between the computers connected to the network (the personal computer paradigm was yet to come). Separately, the ITU decision to allocate a small amount of radio spectrum for Industrial, Scientific, and Medical (ISM) use was further promoted by the Federal Commission of Communications (FCC) in the USA through the recommendation to use spread spectrum technology for shared communication on these bands. These decisions were noted, which spurred development of the Local Area Networking (LAN) system of limited wireless mobility for devices connected to the Internet. The internet value system adopted the Wireless LAN (WLAN) as a new access method without any disruption to the value system structure or dynamics. The protocols and technologies for wireless LAN were originally developed in many competing teams and organizations. Over the period of fermentation (Anderson & Tushman 1990), the working group 802.11 of the Standardization Association of the Institute of Electrical and Electronics Engineers (IEEE-SA) gained the leadership in developing a wireless access network solution for the internet value system using the wired Ethernet technology already in use in the internet value system as a starting point.

Spectrum rules for wireless access to the Internet are referred to as unlicensed because there is no need to acquire any spectrum license. However, since the devices using those frequencies are considered "license-exempted" (they need no device-specific license, but instead compliance with a set of technical requirements is required) this combination of spectrum and device regulation is

[30] Systems Network Architecture.
[31] A Suite of network protocols developed for the PDP-11 computers.

considered in this study as a *license-exempted* model. Fully unlicensed use of radio spectrum and devices is possible only on frequency bands with no ITU attention[32]. Within this approach, the actors who operate the computers in their premises have the possibility to decide the level of openness and interoperability they want to provide. Only a few regulatory service requirements are set for these actors, and this liberty has led to a large set of technically similar and sometimes interoperable networks and services. Technical requirements related to ISM use include formal rules, like a maximum level of transmitted power within a certain radio spectrum mask. Also, listen-before-talk (ALOHA protocol) is mandated (Lemstra, Hayes & Groenewegen 2011). From the perspective of value system dynamics, it is quite important to note that administrations have the legal power to enforce the rules of the internet value system if the basic ground rules are neglected.

Internet and mobile communication value systems consist of similar actors, but their interrelations are quite different. The most important actors in the internet value system are companies, institutes, and service providers that control their own domain names and address space and operate their sub-networks autonomously. They can also control the interconnection of their network to other similar networks through a hierarchy, where a small number of large Internet network operators (Tier 1) interconnect all the subsystems together through so called peering points governed by a set of peering agreements. Peering through the hierarchy is voluntary, allowing the individual sub-networks to interconnect also locally as they prefer.

The internet value system initially paid little attention to the content cluster. It was important to provide the connectivity to support basic applications such as email and file transfer. With the emergence of browser technologies, the vast range of web content started to develop. Fast progress of browser technologies made the client and server bundling tighter, and vertical connections between the end-user device software and the content cluster services became characteristic to the internet value system. This development raised concerns of anti-competitive bundling, for instance, in the case of personal computer operating system and the web browser application[33].

As it relates to other ICT clusters, the end user devices and the end users' personal data, the internet value system is straightforward. The end-user device cluster (client) consists of computers, typically personal computers and later devices which operate like computers, such as smart phones and pads. The role of Personal Data (and identity) of the end users is very loose. Internet users have been able to create as many identities as they have wished and often, e.g., an email account has been used to verify the identity and share their data (like social media) quite freely.

Over the years, the Internet technologies have developed to support a large range of functionalities. Services in the Internet are defined by the supporting

[32] ITU definitions in https://www.itu.int/dms_pub/itu-r/opb/hdb/R-HDB-21-2005-R1-PDF-E.pdf. Accessed November 8, 2017

[33] Microsoft Windows and Explorer bundling.

protocols developed in the Internet Engineering Task Force (IETF)[34]. The IETF has specific working areas for Internet, Transport, Routing, Security, Applications and Real Time, and Operations and management. Internet services are provided between the communicating endpoints that support the needed protocols. There is no mandatory requirement for a specific protocol set, which sometimes causes problems. The Internet as a transport network aims to be transparent and provide fallback options, making the best effort to support the needed services. Applications on the top of the Internet are provided using either proprietary technologies or quite often using protocols and concepts developed in the World Wide Web Consortium (W3C)[35].

"Internet services" is a rather loose definition. Any digital service or application, which utilizes Internet protocols, is considered an "internet service". Gradually, all sectors of life have started to provide their digital services over the Internet. More specifically, internet service providers are specifically those companies providing the internet access, transport, and basic applications, such as email. Furthermore, internet services are decentralized. Each service provider provides services on a best-effort basis, and for the end user, the visible part of the service is typically the client-server connection with either a browser-based or native software application or a versatile combination, a mash-up of multiple services.

For the internet value system, the interface between the content and network cluster (Interface 1 in Figure 7) is controlled by net neutrality regulations enforcing the separation of the content cluster from the network. Net neutrality regulations, however, restrict bundling only between the content and network, while all other interfaces between the ICT clusters in the internet value system lack mandating regulatory guidance. This has enabled, for instance, companies providing operating systems and other important software to bundle their services in the content cluster with the client software of the end-user devices. The recent General Data Protection Directive (GDPR[36]) has raised the importance of the personal data cluster in the internet value system in the European Union.

The different models of vertical separation in the mobile communication and internet value systems have been one driver keeping the value systems at arm's-length distance from each other. Furthermore, specific system technology generations characteristic to the mobile communication value system are difficult to observe in the internet value system as technologies have evolved without holistic coordination.

[34] Internet protocols are developed in the IETF working groups. https://datatracker.ietf.org/wg/. Accessed October 29, 2017.
[35] Web services protocols are World Wide Web Consortium working groups. https://www.w3.org/Consortium/activities#Working. Accessed October 29, 2017.
[36] European Commission 2018 reform of data protection rules. https://ec.europa.eu/commission/priorities/justice-and-fundamental-rights/data-protection/2018-reform-eu-data-protection-rules_en. Accessed May 25, 2018.

3.3 Convergence of mobile communication and internet

The convergence of mobile communication and internet value systems has progressed slowly. In the mobile communication value system, the mobile network operators dominate the value system due to their specific regulatory position. These privileges have enabled the MNOs to extend their role to other clusters in the value system, to provide operator-specific services and operator-branded mobile devices and to bundle the subscriber to the mobile network.

The internet value system separates content and services from networks. The convergence of the value systems drives the separation of content and network in the mobile communication value system, which has only reluctantly adopted the model. When the interest in internet services emerged, the mobile communication value system started to provide semi-integrated services instead. Semi-integrated services, such as I-mode in Japan and Wireless Application Protocol (WAP) based services in Europe became popular when the network capabilities were scarce (Peppard & Rylander 2006). These specific mobile internet services were optimized for mobile use in multiple ways, enabling large market potential, including those users who had access only to phones with limited processing and memory capabilities. These dedicated internet-like services for mobile communication failed to gain acceptance globally due to their tight bundling with local network operator business needs, which limited the performance and competitiveness of the cost structure. The walls of the garden protected – and limited – the business, i.e. they worked in both directions (Tee & Gawer 2009).

To overcome the problems of convergence, the key actors, especially the MNOs in collaboration with other mobile communication value system actors, invited other relevant stakeholders, such as IT companies, to create tightly coupled services and applications for the value system. On the other hand, separate Over the Top (OTT) services[37] emerged gradually and only loosely coupled with the network functionalities, which allowed a broader developer community to contribute in a less controlled innovation environment.

The tightly coupled services, such as Multimedia Messaging and Push to talk over Cellular (PoC), were introduced parallel to the emerging 3G technologies. Complementing new functionalities were developed for the 3GPP standards also to enable the specific PoC features such as the fast call setup for half-duplex service. The deep co-implementation required many new or updated standards and product designs and affected the component and platform providers, product companies, as well as MNOs and service providers. In most markets, also the end customers were supposed to learn the new service paradigm. The cognitive challenge in building a new successful mobile service bundle was significant (Bouwman et al. 2007). As it relates to the content cluster, regardless of the early confusion, the services and applications of the internet value system dominate the market today. It is still possible to use voice mail, SMS, and some critical integrated services such as Device Management, but the majority of the network traffic is created by fully independent OTT services and applications.

[37] Separate internet services in the context of the mobile communication value system.

The network cluster in the mobile communication value system has adopted internet technologies in two areas. While the mobile communication network takes care of the global wide-area radio access and mobility, internet protocols as specified in the 3GPP Internet Multimedia Subsystem (IMS) and Voice over LTE (VoLTE) are used to make the session-level end-to-end connections in 4G. For data services, the network-level internet protocols connect the clients to the servers through transparent mobile networks.

Separately, the internet value system utilizes generations of license-exempt technologies, mainly based on the IEEE 802.11 standards, to complement the capabilities of the 3GPP mobile communications. Standardized technologies developed in IETF, W3C, and in other internet-oriented communities connect people, devices, and data in the clouds independently from the underlying mobile and fixed transport networks. During the 2G era, the separation of IEEE 802.11 a/b from the early mobile communications packet radio systems like GPRS was clear. The IEEE 802.11g specification was developed to address the performance requirements of the 3G era. Furthermore, the IEEE 802.11n and its parallel wide-area technology, the IEEE 802.16 (WiMAX[38]), emerged to compete with the 4G mobile communication systems.

The juxtaposition continues as 3GPP is considering the use of the license-exempt spectrum and device regulations for 5G. Technology interworking for these two value systems has been specified in multiple ways and multiple times, but the successful hybrid deployments have been limited. This continuous incompatibility has been partially circumvented by designing consumer devices with dual functionality. End-user devices include two separate sandboxes for functionalities of mobile communication and internet value systems. Network-related user identity and data are in most cases fully separated between the value systems. There are some limited services where, for instance, the SIM card and operator billing can be used to access the Wi-Fi service.

The convergence continues at a much slower pace than expected in the mobile communications and internet value systems (Steinbock 2003), and the value creation moves on to new areas, shifting the convergence to horizontalization. The final decisions are made through consumers' choice instead of the choice of policymakers or corporate managers.

3.4 Transportation and mobility

The value system of transportation of people and goods has developed independently from the mobile communication and internet value systems. Recent innovative concepts like Mobility as a Service (MaaS[39]) have adopted an ICT-driven approach to re-design the traditional value system, introducing radical

[38] Worldwide Interoperability for Microwave Access, a technology developed in the IEEE 802 community to provide Internet-oriented radio connectivity for wide-area deployment. Trademark owned by WiMAX Forum. WiMAX Forum is a non-profit organization that promotes WiMAX technology and certifies WiMAX products

[39] Mobility as a Service Alliance sponsored by ERTICO – ITS Europe. https://maas-alliance.eu/. Accessed January 5, 2018.

innovations (Sochor et al. 2017). The development is still in its early phase, including unsettled terminology. Mobile communication and internet are truly global value systems, while transportation and especially new mobility as a service are rather fragmented due to strong national priorities. This research focuses on transportation and mobility value system developments in Finland. Emerging local transportation value system provides only limited possibilities to observe developments compared to the mature global communication value systems. However, the additional benefit of examining the transportation value system is at least three-fold. First, the starting point for the digitalization is domain specific and includes long historical roots in technology, regulations, business behaviors, and consumer expectations. The transportation value system provides opportunity to examine structures and dynamics that may have never existed in the ICT value systems before. Secondly, the current developments in the ICT driven transportation appear to be in many ways in the situation of the initial 1G of the digital communications, including multiple separate national initiatives. Thirdly, the role of ICT in the transportation value system is expected to be disruptive in the near future. Therefore, analysis of the transportation value system complements the broader analysis of the ICT value systems.

Transportation and mobility are critical for modern society, representing typically the second largest cost item for households and a significant cost for enterprises. The transportation value system is considered to be a stable environment, where significant investments in network infrastructure (roads, railroads, ports, etc.) and transportation hardware (vehicles, trains, etc.) have created a legacy, which is difficult to change. Furthermore, in many areas of transportation, regulative requirements effectively slow down technology development. A new approach is needed to create a sustainability-oriented technology development and paradigm shift in transportation. The role of governments is important in driving the market and technology transformations (Geerlings et al. 2009).

The current transportation value systems are isolated and fragmented. Transportation services are provided by either fully vertically operated, isolated large companies and public transport authorities, or they are provided as fragmented initiatives by competing innovative start-ups and companies seeking platform leadership. The fragmentation of technologies and service provision provide low interoperability.

Historical value system models of transportation operate with physical (Materia) objects, while ICT-driven value systems address information (Data). Therefore, making direct comparisons is challenging. Still, structural and functional similarities can be identified using the recognized ICT clustering structure (Fransman 2010). These similarities pave the way for a fluent adoption of ICT in transportation and provide guidelines for developers of MaaS.

The clusters of the transportation value system are[40]:

Cluster 1: (Content) This cluster includes all elements of services that are provided independently from the other clusters (demonstrating the difficulty to define the cluster as currently most of the services are vertically integrated). Examples include, for instance, support services, registers, and databases to help navigation and use of public transportation.

Cluster 2: (Network) This cluster includes the entire transportation network and its infrastructure. Most notably, the cluster includes roads, railroads, and immediate related infrastructure like traffic lights.

Cluster 3: (Device) This cluster includes all end-user devices for transportation, most notably vehicles but also boats, ships, airplanes, and similar.

Cluster 4: (Personal Data) This cluster includes information on people and goods transported.

Similarly, the interfaces between the clusters are:

Interface 1: between Content and Network. As an example, the roads and railroads are operated separately from services. Some limitations exist specifically for railroads.

Interface 2: between Network and Device. As an example, any vehicles fulfilling certain requirements can be used on the network, and networks and devices have different owners.

Interface 3: between Device and Personal Data is also recognized in case of, for instance, recognizing the roles of the owner, driver, and passengers from the vehicle identities.

Interface 4: between Content and Device is weakly recognized. Transportation service companies may have their own fleets of vehicles while there is no dominant platform bundle between services and vehicles.

Interface 5: between Content and Personal Data is weak. End users can use multiple service providers, and only voluntary loyalty mechanisms are used, but no data portability is supported.

Interface 6: between Network and Personal Data is undefined, and there is no bundling between the people and goods and the transportation network or infrastructure.

Regulation in transportation has long historical roots. In Finland, regulative measures apply to all clusters of transportation. Regulative licenses and requirements apply to vehicles and users of the vehicles. For instance, all the bus routes, taxicabs, long distance and local cargo transportation have different licenses, which limit the number of the service providers and disable competition between them. Regulations are often vertical, regional and cover, e.g., quality of services, competition (number of licensed service providers and vehicle characteristics), and even tariffs. Transporting people and cargo independently in the same vehicle is rather restricted, and likewise, separation of buses and taxis

[40] Note: Publication VI uses the word "layer" instead of "cluster".

into two different groups with different rules has caused confusion[41]. As a specific observation, the personal data element of the transportation value system (driver's license) is often recognized as a general personal identification card. Simultaneously, a high number of private vehicles is used for private transportation without coordination and ride sharing possibilities limited by regulations using fragmented ICT technologies provided by automobile companies with their subcontractors and competitors.

Such detailed regulation has aimed to create sustainable, reliable services and to protect the consumers and environment. Implemented regulations and related services have served the society well, but with the fast evolution of new technologies, the detailed and restrictive boundary conditions have become a burden, making both the end users and potential new service providers unhappy. Liberalization of the taxi service in neighboring countries, harmonization needs related to national and international cargo transportation, entry of global platform companies to offer personal transportation service, and the needs to address environmental issues like climate change have increased pressure to renew the value system operating model in Finland.

The aim of MaaS is to bring forward similar developments as in mobile communications and internet value systems by using interoperable technologies nationally and internationally to provide multiple service options to end users. Dominant design has not yet emerged, and experimentation continues (Anderson & Tushman 1990; Utterback 1994). Fragmentation of technologies does not yet support interoperability of services, which impacts negatively the diffusion of MaaS in the mass market. Systemic transitions in transportation are uncertain because of barriers such as slowly changing personal preferences for individual freedom and other social and cultural factors (Geerlings et al. 2009).

3.5 Consolidating ICT-driven value systems

In summary, the ICT-driven value system can be simplified to a process model, where the different value system clusters turn valuable resources to even more valuable products and services. Each cluster has their own internal value creating process, but clusters depend on each other in providing the "whole product"[42] to the end user. No cluster alone can provide anything meaningful, and the total value typically clearly exceeds the sum of the parts. This high-level conceptual process is illustrated in Figure 10.

[41]Expert opinion on competition in transportation of people and cargo. https://www.lvm.fi/lvm-site62-mahti-portlet/download?did=204535 Accessed October 30, 2017

[42] The Whole Product concept relates to the difficulties new product innovation experiences when entering the mass markets, popularized by Geoffrey Moore in his book *Crossing the Chasm*.

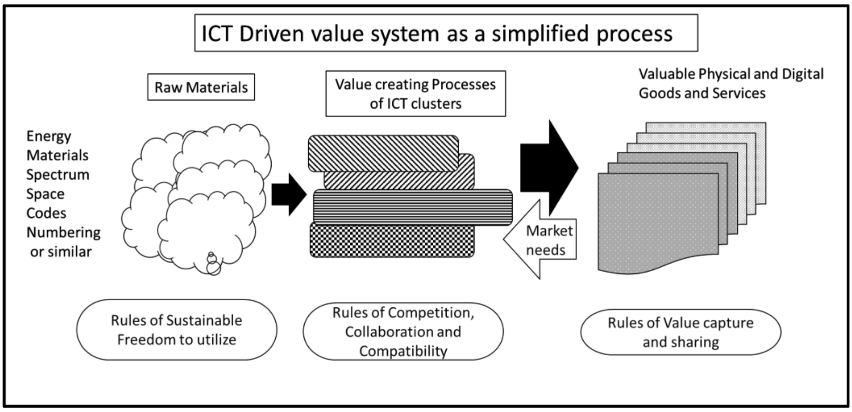

Figure 10. ICT-driven value system as a simplified process

Figure 10 shows the ICT clusters[43] in the middle partially overlapping to indicate the issues with interfaces as discussed in section 3.1. Each cluster is limited by the boundaries set by the laws of physics and man-made laws and regulations, which define sophisticated rules for how different resources are available. Regulative rules, even when they are loose, direct the operations of the clusters, define rules of competition and collaboration, and often encourage interoperability. In some clusters, there are even direct rulings related to value capture and sharing; for instance, in the case of the network cluster, tariff regulation of international roaming fees and spectrum auctions as a mechanism to collect entry fees for market access. The process shows the feedback loop created by market needs of the end users, while otherwise the process is considered to be unidirectional. The black arrows show the simplified value creating process, and the white arrow shows the feedback by the market needs. While the structural ICT cluster model described in section 3.1 shows the top-level time-invariant structure, the process view of the value system paves the way to study the time-variant, dynamic value system behaviors, as will be discussed in section 4.

The ICT-driven value systems have many parts and functions and interconnecting links, but the actual system state in terms of complexity is assessed explicitly quite seldom. This research examines the ICT-driven value systems with complexity by focusing on three high-level factors: availability of critical resources, internal competition and collaboration, and interoperable interfaces in the value systems.

3.5.1 Resources

All value systems need similar resources, but depending on the value system, some resources are more critical. The ICT-driven value system needs material resources and energy during deployment and production. Physical space becomes important when, for instance, mobile communication networks need more base-stations, cables, and other physical devices, which need energy also for cooling. It

[43] In this context, it is useful to separate the roles of the personal data of the consumer and the consumer him or herself.

is a common view that the most critical or scarce resource in mobile communication is radio spectrum[44]. This applies to the internet value system also when wireless access to the Internet is used. Therefore, the availability of radio spectrum influences value system dynamics significantly. Some other resources that are based on modest visionary thinking need consideration because the availability of such resources becomes thinner over time. Such resources include, for instance, signaling code space and fixed address space of the network devices. Quite recently, the IPv4 addresses were exhausted, and a network upgrade to IPv6 became mandatory.

Also, the ICT-driven value systems like MaaS transportation require resources, but their relative importance is different. In transportation, energy is a critical resource while, for instance, the role of radio spectrum has been low. Other scarce resources in transportation include, for instance, physical space needed for roads, streets, railroads, parking lots and similar, while so far, concerns related to physical infrastructure supporting mobile communication, such as base station sites, buildings for switching centers, communication cabling, and power lines are less critical. The transportation infrastructure includes technical facilities such as traffic lights that align with ICT-driven value systems in their resource demand.

Even if all the resources are important, the scarcest resource forms the bottleneck for growth and limits value creation and related dynamics. Therefore, the rules of freedom related to the use of the scarcest resource are so important. Furthermore, changes in availability or consumption of the resources move the bottleneck from one resource to another, causing sometimes radical changes to the system dynamics. Availability of all the resources is limited by the laws of physics with additional details defined by man-made regulations as discussed in section 2.3.

In ICT-driven value systems, the role of energy is growing but hitherto has not taken over the critical role of the radio spectrum. Looking toward the future, data about our environment and personal data on ourselves are assumed to become the new emerging critical raw material. Value systems under the influence of ICT go through reconfigurations, where the value of knowledge and information drives the system structure (Allee 2000). On the other hand, more extensive use of ICT may indirectly make the radio spectrum become the critical resource also in the future transportation and mobility value system. The new service models in 5G drive the development toward convergence in this context.

There are many other resources that the value system actors need, such as people, talent, and money. Their role is critical especially when value systems experience fast growth or a period of disruption. Availability of these resources is often company-specific rather than relevant for the value system in general.

3.5.2 Competition and collaboration

Competition and collaboration in value systems spans over the whole innovation and value creation process. Often the pre-competitive phase, focusing

[44] The total value of the licensed spectrum only in the USA (645.5 MHz) is about 500 billion dollars. http://www.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf

on research and standardization, includes more collaborative elements, while the later commercial phase is considered competitive. The regulations set the rules for competition and collaboration either through controlling the availability of resources or more directly requiring and limiting value system actors to collaborate to provide desired services and products to the end users.

Competition and collaboration in the mobile communication, internet, and transportation value systems have their specific characteristics. During the era of state-owned monopoly telecom operators, there was very little competition in the mobile communication value system, but the situation changed significantly when the liberalization of telecommunications opened possibilities for new companies to enter the market. Liberalization ignited competition, while related regulation directed the actors also to collaborate, especially to enable roaming and interoperability of the mobile devices.

The internet value system initially developed without competition within a public research environment. The situation changed when commercial companies entered the market. In the beginning, collaboration was very open in technology development, and with a growing number of participants, voluntary collaboration has developed different approaches in different parts of the value system. Today in the internet value systems, the roles are loosely defined, and from a regulation perspective, the market is open for anybody to enter.

The transportation value system also has a tight definition of roles, but there are several different sets of those rules and roles. The situation in the transportation value system is currently monopolistic for public transportation, while all the private vehicles are operated without coordination. Competition in MaaS takes place between the fragmented initiatives of different strongly competing MaaS providers. In general, collaboration in transportation is rather limited. Each actor has their own interests. The liberalization of the monopoly markets gradually proceeds in Finland indicating new opportunities for both competition and collaboration.

3.5.3 Compatibility and Interoperability

In ICT-driven value systems, the equilibriums and transitions materialize through the interfaces between subsystems and their components. Compatibility and more specifically interoperability of the features and functions over these interfaces is a critical factor in influencing the system dynamics through network effects (Katz & Shapiro 1985; Gandal 2002). Interoperability in technical interfaces and in business relationships in a value system is an internal, endogenic factor, while the boundaries set by regulations and other factors are considered primarily exogenic. Regulation, however, sets significant requirements for some internal interfaces and, therefore, defines a part of the structures explicitly.

One main approach to achieve interoperability is standardization as discussed in section 2.5. More precisely, technical interoperability is a precondition to operative interoperability. This means that technical features and interfaces specified in standards add value only if they are also implemented in business. Analysis of technical interoperability is, therefore, only an intermediating factor, and it requires a complementing view to look at the mechanisms of how technical interoperability is achieved through practical implementations.

For mobile communications and internet value systems, key interfaces have traditionally been defined by multiple standardization organizations and initiatives. The CEPT decision to align the 2G mobile communication services in their administrative domain as discussed in section 3.2 imposed a need to re-organize the way of creating relevant interoperability through standardization in Europe. European telecommunications authorities with the European Commission established the European Telecommunications Standards Institute (ETSI[45]) to continue the work initiated in the GSM[46] activity in the CEPT. ETSI has further delegated most of the specification development responsibilities to the 3rd Generation Partnership Project (3GPP[47]) in collaboration with other main de jure standardization organizations of the world while maintaining the power to formally ratify the relevant parts of the 3GPP deliverables as European Norms (EN)[48]. The 3GPP standardization further collaborates with other relevant organizations, such as Open Mobile Alliance (OMA[49]) to cover all the mobile communication-relevant clusters of the ICT-driven value systems.

The initially United States-driven developments for the internet value system utilize primarily standards developed in the IETF[50], W3C[51], and for wireless access functionalities in IEEE 802.11[52] communities. By today, these developments have reached a global scope and scale. Mobile communication and internet value systems have their internal interplay between technology research, standardization, and commercial deployments, which form a systemic collaborative continuum in both value systems.

Technologies, systems, and businesses related to Mobility as a Service are emerging in multiple ways. The aim in MaaS is to provide one interoperable system and set of services where end users can utilize the underlying capabilities seamlessly, as they are able today, to use the mobile communication and internet services. The key enabler in all MaaS services is the extensive use of ICT. A specific effort for MaaS is currently only emerging in the standardization arena. The

[45] European Telecommunications Standards Institute ETSI. http://www.etsi.org/about . Accessed March 6, 2017.

[46] Transfer of the GSM working group to ETSI enabled any ETSI member organization to join the effort. Later the meaning of the acronym was updated to Global System for Mobile communications.

[47] Third Generation Partnership Program 3GPP, a joint standardization effort by a number of regional formal standardization organizations like ARIB, ATIS, CCSA, ETSI, TSDSI, TTA and TTC. http://www.3gpp.org/about-3gpp/about-3gpp. Accessed March 6, 2017.

[48] European formal standards, European Norms are standards ratified by ETSI, CENELEC or CEN. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:316:0012:0033:EN:PDF. Accessed March 26, 2018.

[49] Open Mobile Alliance, a voluntary group developing standards for service enablers for mobile networks. http://openmobilealliance.org/. Accessed March 6, 2017.

[50] Internet Engineering Task Force, a voluntary group developing standards for the Internet. https://www.ietf.org/. Accessed March 6, 2017.

[51] World Wide Web Consortium, a voluntary group developing standards for web technologies. https://www.w3.org/. Accessed March 6, 2017.

[52] Institute of Electrical and Electronics Engineers working group 802.11 responsible for developing local area radio access technologies for the Internet. http://standards.ieee.org/about/get/802/802.11.html. Accessed March 6, 2017.

formal standardization for intelligent transportation systems and services has been ongoing in the International Organization for Standardization (ISO[53]) for decades. European standardization organizations, European Committee for Standardization (CEN[54]) and ETSI, started to focus on this area under the mandate of the European Commission and in collaboration with other relevant groups, including ISO. CEN Technical Committee 278 and ETSI Committee Automotive Intelligent Transport Systems (ITS) with other regional groups are seeking to build harmonized standards for the ITS for worldwide interoperability.

Parallel to the formal standardization activities, there are several voluntary organizations complementing and competing in providing the interoperable technologies and solutions for the actors of the emerging MaaS value system. The voluntary groups focus their activities, for instance, in services[55], local connectivity[56], wide area connectivity[57], software[58], and software platforms[59]. Additional coordination is needed to make all the voluntary systems work together and to create a whole product acceptable to the consumers. Automakers have traditionally been able to manage this challenge well (Takeishi 2001). In case of MaaS, this challenge goes beyond the limits of a physical product such as a car.

Convergence between mobile communication and internet value systems has a long history, but convergence with transportation and mobility is in its early stage. Network effects have shaped the ICT-driven value systems. Similarly, developing interoperability between ICT and transportation will enable further powerful network effects to emerge. Different scenarios related to interoperability alignment between the value systems is still an open question. The current 5G work plan in 3GPP has many features and functions under development to support transport and mobility solutions. As it relates to initial MaaS ideas, existing 3G and 4G networks can already support a large set of planned services.

Mobile communications, Internet, and MaaS require value systems with many stakeholders where interoperability will provide additional value. All different ways to provide interoperability as defined in Table 2 are relevant. However, collaborative standardization models are considered important, while mandated, government-imposed interoperability mechanisms as well as proprietary pursuits of dominant designs are considered less value-creating options in these complex value systems.

3.5.4 Summarizing factors influencing ICT-driven value system

ICT-driven value systems live their life between two important boundaries: regulation and standardization. ICT-driven value systems consist of four rather well defined systemic clusters, which are interconnected by six interfaces

[53] International Organization for Standardization, Technical Committee 204. https://www.iso.org/committee/54706.html. Accessed October 17, 2017.
[54] European Committee for Standardization. https://www.cen.eu/Pages/default.aspx. Accessed October 17, 2017.
[55] Mobinet. http://www.mobinet.eu/. Accessed October 17, 2017.
[56] Mirrorlink. https://mirrorlink.com/. Accessed October 17, 2017.
[57] GSMA. https://www.gsma.com/iot/automotive/. Accessed November 1, 2017.
[58] Open Automobile Alliance. https://www.openautoalliance.net/. Accessed October 17, 2017.
[59] GENEVI. Alliance https://www.genivi.org/. Accessed October 17, 2017.

(Fransman 2010). In each cluster, actors operate according to specific processes, where physical availability of raw materials and market input drive the innovations. The clusters are often separated, but vertically integrated companies can build bundles also over the cluster interfaces. Furthermore, when standardized technologies are used in different clusters, self-organized alignment may create bundling through network effects (Heinrich 2014).

Within each of these clusters, there is a network of actors which compete and collaborate when providing products and services to their customers. This network extends over the clusters, connecting actors from researchers in universities all the way to the sales person in a distribution outlet interfacing with the end user or consumer with multiple ties, which are often difficult to see. During technology disruptions, borderlines between the network actors are blurred (Afuah 2001). A new paradigm emerges when actors play multiple roles, building bridges to expand their business opportunities by complementing and bypassing the role of their own customers, sometimes by accident and sometimes as a strategic move (Valkokari 2015). Different types of mergers and re-organizations take place rather frequently when centralized and decentralized phases of industry evolution follow each other (Fine 2000). The "Five forces of competition" model still explains the local playing field for each actor in the value system (Porter 2008), while the value system level behaviors require a broader view (Teece 2007).

For instance, in the traditional value system model, the role of the end user is merely that of an adopter, while recently end users have developed new roles of prosumers, both consuming and producing services; e.g., a private car owner may occasionally provide transportation services to other car owners. Regulations reflect slowly the emerging trends in ICT-driven value systems. The role of the key end user, the consumer, is in general separated from the value system (specifically protected) rather than included. Regulations give consumers specific rights (e.g., protection of privacy) that have implications for the roles of consumer and prosumer related to value capturing and sharing.

Furthermore, different sets of rules drive value systems differently, which creates opportunities to bypass expensive service obligations in one value system by deliberately utilizing a less regulated approach, such as providing voice call over Internet without supporting emergency call requirements of the mobile communications. Table 4 summarizes the key external and internal factors discussed in section 3. These factors shape the value creation, capture, and sharing behaviors in ICT-driven value systems. Table 4 presents the general status, while section 4 focuses on the details of the systems and their evolutions.

Table 4. External and internal drivers of the value systems

VALUE SYSTEMS/ DRIVERS	Global mobile communication	Global internet	Transportation in Finland
Scarce Resources	Licensed, Especially radio spectrum, mandatory device type approval/certification	License-exempted, Radio spectrum unlicensed with certified devices	Exclusive and Licensed (some License-exempted, Free)
Competition	Tightly defined, exclusive roles	Loosely defined, open market access	Mainly tightly defined, exclusive roles (Undefined use cases allow market access)
Collaboration	Selected mandatory requirements, for instance, for using standards	Voluntary standards, multiple different consortia	Only implicit requirements, Mainly proprietary technologies
Compatibility Interoperability	High requirements to provide roaming, voice and set of other services	Loose interoperability on voluntary bases	No sector specific

Value systems include long and slow exogenous feedback loops through evolving regulations. If the share of the utility to society is considered too low or high, it may impact the regulative decisions, such as the way that raw materials are made available. This research focuses on the dynamics in the value systems, and therefore, such high-level and often slow feedback is considered a boundary.

Furthermore, this research focuses on value creation and drivers influencing the structures and dynamics in the innovation process within the boundaries set by availability of scarce resources and requirements for competition, collaboration and interoperability. Value capturing, sharing, and influence of customer feedback are considered indirectly only.

4 Qualitative modelling

The research question RQ1 in section 1.2 sets the goal to develop a model which can be used to explore the evolution of ICT-driven value systems. Theoretical considerations in section 2 produced three propositions – P1, P2, and P3 – to explore the research question in more detail. This section addresses the propositions through qualitative studies and summarizes the research path based on Publications I, II, V, and VI.

Section 4.1 presents the used methods and data and introduces the publications, while Sections 4.2 explains the modelling framework. Sections 4.3–4.5 present three case studies of different value systems and their developments. Sections 4.6–4.8 conceptualize the model to examine the value system states and their transitions.

4.1 Research methods, data and role of publications

Qualitative system modelling and qualitative reasoning study continuous aspects of entities and systems in human-like manner with the aim to capture their capabilities and enable robust reasoning. When working on high level models, for instance related to artificial intelligence, there is often not enough information to make accurate predictions (Forbus 2008) . Qualitative modelling includes multiple techniques to address the ambiguities from different perspectives. Such system tasks include for instance simulation, envisionment, mental models, diagnoses, and verification (Bobrow 2012). Section 4 focuses on building a structure for the model and observe (diagnose) the behaviors of the value systems including using the mental modelling to encapsulate the historical developments. Using the observed technical and operational structures as a starting point, this section envisions all possible value system states and behaviors by identifying and analyzing real world ICT-driven value systems. Section 5 complements the modelling using simulations to analyze dynamic behaviors and social network analyses as verifications that the observed operational structures in the value systems match with expected set of behaviors.

ICT-driven value systems are in a state of continuous change. Changes and transformations take place gradually in different parts of the value systems, shaping the internal and external borderlines, making the analysis of the value systems characteristics quite challenging. A case study approach is therefore a suitable methodology to study contemporary phenomena with unclear boundaries (Yin 2006).

Selecting the case studies for this research reflects the initial starting point to address the standardization priorities in Nokia Mobile Phones in light of the evolving theories of complex systems. Selection of the use cases was not random but guided by the set of theories discussed in section 2 and certainly not just a statistical sample (Eisenhardt 1989). Value system modelling examines two initially separate value system evolutions, mobile communication and internet access, which are characterized by multiple factors, for instance, different regulations related to the availability of radio spectrum. A specific mobile internet application, Push to talk over Cellular (PoC), is studied to examine convergence of the value systems. Modelling extends toward a contemporary policy question of future roadmap scenarios of ICT-driven services, such as Mobility as a Service (MaaS). MaaS is one of the key new services assumed to drive the investments and deployment scenarios of 5G networks[60].

During the research, several different empirical data and information sources were utilized. The data sources provided three different types of information: written, numerical, and mental data (Forrester 1980). Written data include descriptions of the architectures, module and system specifications, signaling flowcharts, organizational charts, process descriptions, and similar. As it relates to boundaries, information on related regulations, directives, mandatory requirements and service obligations, and other relevant data including the data related to spectrum auctions were used. Similarly, knowledge on standardization organizations, processes, and the actual standards was used. The descriptive documents are critical when mapping the mental and numerical data points onto the models. The numerical data consist of statistical and time series data on the business systems, for instance, market data such as the number of subscribers or users of services and products.

The third category of data consists of mental information and knowledge which became available through expert interviews. The correct mental information is often critical to gain higher-level understanding of the practical system behavior (Sterman 2001). The interviews took place in two main segments: During value system studies related to mobile communications and internet and separately in studies in Mobility as a Service, 18 and 14 experts were interviewed, respectively. The experts represented regulators (both telecommunication and transportation), telecommunication network operators, service providers, a public transport authority, a municipality, unions of bus and taxi companies, an insurance company, an emerging MaaS operator, ICT equipment, device and solution providers, and academia. In semi-structured interviews, research topics were discussed in an open and rather broad manner with a lot of freedom for the interviewees to express their views and opinions. The expected challenges of semi-structured research in achieving accurate or repeatable results turned out to be real. As the mobile communication and internet value systems, including their

[60] Finland is one of the leading countries where the government is driving the alignment of transportation and mobile communications value systems. http://www.exportfinland.fi/web/eng/maas. Accessed January 8, 2018.

convergence, are mature, it was somewhat easier for the experts to explain their views and to reflect the changes in the value systems over a long period of time. The transformation of the transportation value system is only in its early stage, and therefore, the discussions were more open-ended, especially those related to the future of the value system.

The studies complement each other, and together they address the value systems in alignment. Table 5 provides a summary of the qualitative studies and their scale, stage, and scope.

Table 5. Qualitative case study types

VALUE SYSTEM PROPERTIES/ CASE STUDIES	Value System Scale	Value System Stage	Value System Scope
Wireless Access	Large, Global	Mature	Backward looking
Push over Cellular	Small	Make or Break	Momentary
Mobility as a Service	Emerging, Local	Immature	Forward looking

The interviews utilized the framework of system archetypes identified in the earlier literature. The focus of the interviews was on the behaviors of actors, their known and anticipated strategies, roles, capabilities, and collaborative and competitive actions. The interviews aimed to identify systematically different elements in value system behaviors related, for instance, to goal setting, communication styles, trust and security requirements, and innovation creation. Case studies utilized the collected information, where the written technical and organizational information on structures, constraints, and requirements turned out to be suitable to construct the complex value system state models. The semi-structured interviews provided information focusing on practical ways of working in the value systems.

As the interplay of internal dynamics within the structures may also make the structures change, the usual systems-thinking problem arises: What is the system, and what is the environment? As the majority of the interviewees represented organizations in Finland, the cultural tendency in Finland to follow the rules was visible. This attitude may limit business innovations, but it surely served this research well by emphasizing the shades of grey in many areas.

Section 4 consolidates the four partially dependent studies. Table 6 below summarizes the approaches used in the original Publications I, II, V, and VI.

Table 6. Summary of qualitative Publications

PUBLICATIONS	Scope	Methods	Theories	Data
Publication I	Service adoption issues of PoC	Qualitative modelling of the innovation diffusion characteristics of the planned service	Theory on diffusion of innovations, Value network theory, Regulation and standardization theories	Qualitative: Publicly available technology, standardization, and business documents, information, and statistics.

PUBLICATIONS	Scope	Methods	Theories	Data
Publication II	Structural analysis of wireless access network evolutions towards GSM and Wi-Fi based systems	Qualitative modelling of complex value system structures and dynamics	Value network theory and Network theory, Complexity and Systems theories, Standardization and Regulation theories	Qualitative: Publicly available technology, standardization, and business documents and information. Expert interviews. Quantitative: Publicly available statistics on technology penetrations and standardization contributions
Publication V	Service adoption scenarios of MaaS	Qualitative modelling of the innovation diffusion scenarios based on value system characteristics	Value network theory, Network and Complexity theories, Platform theory, Theories of Innovation diffusion, Standardization and Regulation	Qualitative: Publicly available descriptive technical and business documents and regulative considerations. Expert interviews.
Publication VI	Analysis of potential MaaS value system models	Qualitative scenario modelling of complex value system structures and dynamics	Value network theory, Platform theory, Complexity theory, Regulation theory	Qualitative: Publicly available data on systems and technologies. Expert interviews.

In summary, qualitative modelling consists of four case studies in section 4 and two case studies in section 5 to address the modelling in those multiple different perspectives. Furthermore, also the nature of the propositions P1, P2, and P3 is qualitative. Through the case studies, this thesis examines commonalities and differences in the complex value systems and their developments over time to build one qualitative model.

4.2 Complex Value System modelling framework

The framework to model the value systems with complexity consists of three main elements where the ICT cluster model is used as a reference in identifying value system actors and their interfaces. Boundaries set by the regulators and standardization channel, the societal expectations and driving force of new technologies, respectively and endogenic innovations for bringing new products and services to the hands of the end users are all important factors influencing the behaviors of the systems. The value system structure sets the basis for analysis, examining the interfaces and modules (well specified subsections in the value system, actors or groups of actors operating devices, services or pieces of equipment with well-defined open interfaces) of the value system and its stakeholders, while the value system dynamics are used to consider the actions of the stakeholders to examine the resulting end state of the overall complex value system.

4.2.1 Structural model

ICT-driven value systems include multiple value creating subsystems, which are interconnected in multiple different ways. Through a systematic analysis, the different roles, drivers, and interrelations reveal key characteristics of each value system. Value system structural modelling follows the value chain principles (Porter 1985) and utilizes more sophisticated models, which focus on roles and relationships between different economic actors as they compete and collaborate to produce value (Allee 2000; Iansiti & Levien 2004; Jacobides, Knudsen & Augier 2006; Porter 2008). In the qualitative studies, the original idea of Chains, Shops, and Networks utilizing structural characterization (Stabell & Fjeldstad 1998) is developed further. For instance, five structural scenarios have been identified as relevant for the evolution of value network dynamics from 3G to 4G mobile communication (Pagani & Fine 2008). In this research, modelling is applied to specific cases of mobile communication, internet, and mobility as a service -value systems.

Notation methodology builds on the earlier work on value network configurations used in communications (Casey, Smura & Sorri 2010), including different scenarios (centralized /decentralized and vertical/horizontal) of value creation (Heikkinen, Casey & Hecht 2010). This research combines the notations for detailed and dynamic analysis. Value system structure is shown for both technical and operational interfaces. Technical interfaces that support interoperability between technical elements of the value system define the technical architecture of the value system, while the business architecture is defined through operational business interfaces, often based on contracts between the parties. Furthermore, operational interfaces define the flow of value, products, and money in the value system. The final complex value system structure used in the analyses is defined by considering both technical and operational business interfaces.

Dynamics related to each identified complex value system actor are shown in two ways: A) as the number of actors in the same role and B) as a type of interconnections between the actors. There are four types of possible interconnection: 1) Embedded, 2) Tight, 3) Loose, or 4) no connection. Technically, the interconnection types follow the four different ways to create interoperability through standards as shown in Table 2.

Tight and loose interconnections are shown in the notation as arrows of solid and dotted lines, respectively. The bold solid line indicates embedded interconnection in the case of a monopoly relationship. The notation includes technical (based on, e.g., standards) interfaces and operational (collaborative) interfaces as well as product (value) delivery interfaces between the actors within the same group of actors (curved arrows) and between the different groups (straight arrows). Specifically, it is important to note the difference between two extreme cases: 1) only one actor, no externally visible interconnections, all the connections are internal, embedded and 4) unorganized, random or no interconnections, multiple decentralized actors. Figure 11 shows the legend with different color codes (shades of grey) for different system states as discussed in the next section.

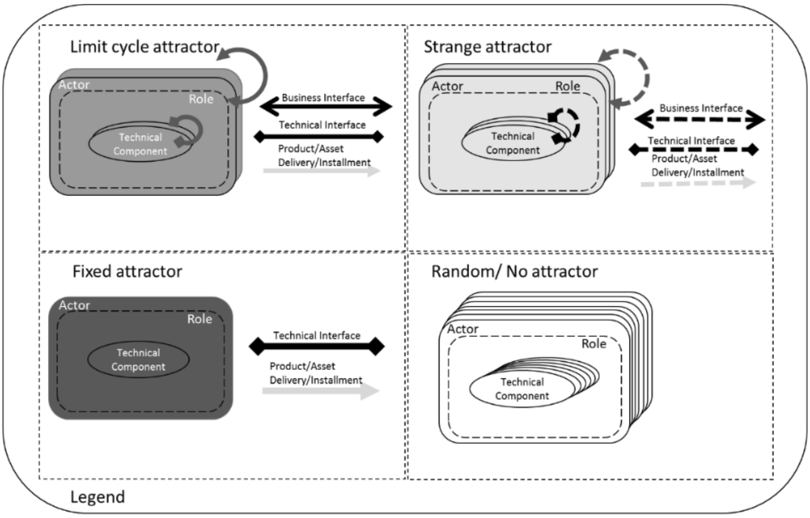

Figure 11. Legend of the actor roles in the system states[61]
Adopted from Publication II. Copyright 2012 SAGE Publishing. Reprinted with Permission

4.2.2 System state model

Qualitative analysis examines complex value system structure, its technical and business-driven architectures and their evolution with a specific focus to identify complex value system states and transitions between the system states. The relationship between technology and business architecture in mobile communication is tight (Tee & Gawer 2009), and the competition to gain the leadership position in the value system is hard, connecting technology and platform leadership (coring), while standardization is one of the options to gain a dominant design position (tipping) for the value system (Gawer & Cusumano 2008).

System state modelling complements the structural analysis. The system state model is an adaptation from the high-level state model of complex adaptive systems (Fowler 2003). Existing literature on complex system behaviors uses the set of conceptual attractor archetypes to characterize the system state, whereas in the case of value systems, openness and centralization of control define the key dimensions spanning the space of system states as discussed in section 2. For instance, openness as a dimension defines how the system interacts internally and externally, and centralization defines the decision-making process and how well the interactions are coordinated and managed (Levä, Hämmäinen & Kilkki 2009). The case studies develop the modelling further to address the dynamic behaviors of the complex value systems in more details and within dynamic boundaries. The alignment of complex system behaviors, such as system synchronization (Strogatz 2001), and complex value system behaviors like system interactions follow the lines of considerations utilized, e.g., in regulations (Cherry 2007) and business

[61] Fixed attractor is used parallel to the Monopoly model; Limit cycle attractor is used parallel to the Licensed model; Strange attractor is used parallel to the License-exempted model; No attractor is used to refer to the Fragmented model.

strategies (Fowler 2003) for situations containing non-linearities, inertia, delay, and feedback loops. For simplicity, the adapted state model is shown in Figure 12 below, noting that the drawing achieved its final stage only in the Publication VI[62].

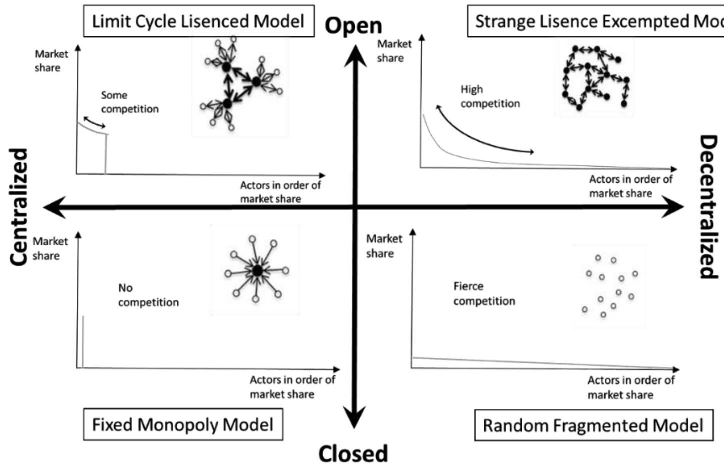

Figure 12. Model for the system states

(Publication VI). Copyright 2017 SAGE Publishing. Reprinted with permission.

Table 7 below lists a set of considered key dimensions with some related other factors and shows their different characteristics in each system state characterized by a conceptual attractor type. The system feedback loops of mobile communication and wireless access are discussed in detail in Publication IV.

Table 7. Selected characteristics of the four system states

ATTRACTORS/ SELECTED CHARACTERISTICS	System state 1: Fixed attractor	System state 2: Limit cycle attractor	System state 3: Strange attractor	System state 4: No attractor
Degree of centralization	Fully centralized	Semi centralized	Decentralized, self-centralized	Decentralized
Degree of openness	Closed system interfaces	Partially open system interfaces	Open system interfaces	No defined interfaces
Related Actor interaction	One actor directs the system permanently	Few key actors co-operate and compete in a harmonized tight system	Many actors co-operate and compete in a heterogeneous system	Many (isolated) actors competing and collaborating randomly
Related Degree of planning	Fully designed and optimized	Moderate joint planning	Mainly emergence, limited planning	No coordinated planning
Related Rules	Many rules, all centrally defined	Medium set of global rules	Few simple local implementable rules	No rules

62 Note: During the research, terminology developed, and unlicensed and license-exempted models started to converge in business. In the publications, the terminology is still partly ambiguous. A new term "License-free" is introduced to denote the situation where there is no consideration in place for any kind of license. For the purpose of this thesis, the system attractor names are used as a general reference with the system state numbers corresponding to the states as follows: 1: Fixed, 2: Limit cycle, 3: Strange, 4: No attractor.

Related Speed of adaptation	Slow or no adaptation	Medium, cyclical	Fast	Random
Related Switching costs	High (lock-in)	Moderate	Low	None
Related Scalability	Limited	Somewhat limited	Unlimited	None (local, isolated)
Related Availability of tools for service production / distribution	Controlled by a single entity	Controlled by (or licensed to) a few	Democratized and used by all for all	Proprietary sets of tools used without coordination
Related Complexity of the network	Low	Some	High	Random
Related Feedback structure	Only negative feedback	More negative feedback than positive	More positive feedback than negative	Only positive feedback

Adapted and simplified from Publication II

Value systems of the ICT-driven businesses are structured in section 3 into four different clusters (Fransman 2010). The system state addresses the dynamics which may be relevant for one cluster or may span over multiple clusters. The systemic synchronization of the cluster dynamics over the key interfaces is an important factor in assessing the total end-to-end service interoperability the value system aims to provide to the end users. Synchronization in this context refers to the alignment of system states referenced by the complex value system archetypes within and between the clusters.

The value system modelling maps the empirical value systems using their technical and operative interfaces and competition models to identify the value system states in each cluster and to examine the state of the overall complex value system. Using the notation described above in Figure 11 and the concept of four archetype system states yields a template to construct four fully aligned complex value system scenarios, as illustrated in Figure 13.

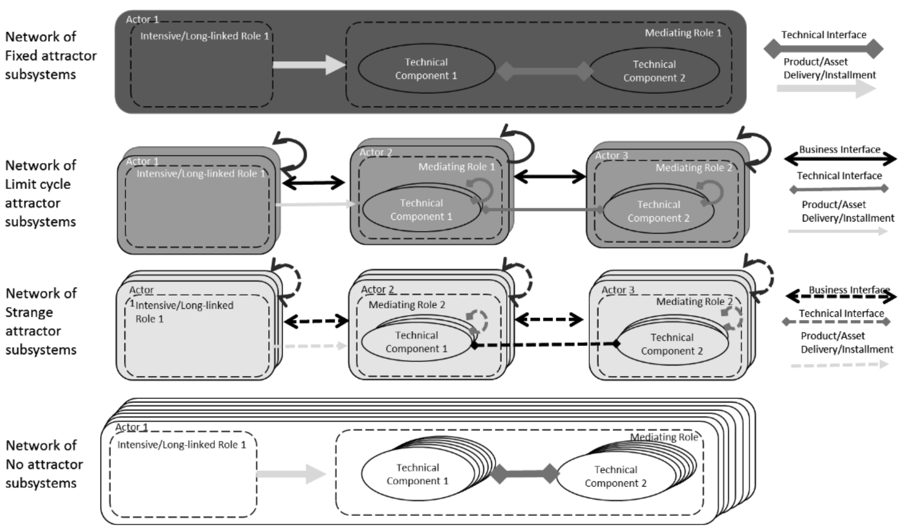

Figure 13. The four system archetypes in full alignment (Publication II) Copyright 2012 SAGE. Reprinted with permission.

The four value system scenarios are idealistic models showing full alignment between system states and the interconnection types, following the characterization of Table 7. In practical systems, however, full alignment is seldom archived.

4.3 Wireless access evolution

Over the last two decades, mobile communications and internet systems have developed through two separate paths (Lehr & McKnight 2003). Initially, mobile communications services were provided by government-controlled national monopolies with no direct interaction except with the national fixed network, which took care of all interoperability needs. The first-generation mobile communications systems were solid monopolies on a national level. However, internationally they were fragmented, each country had their own system and their local dynamics. As it relates to boundaries defining systems, 1G systems are considered monopoly systems within their own boundaries (Manninen 2002).

Parallel to this, the Internet service was available only in a limited fashion, used for file transfer and primitive email applications in a small number of universities mainly in the United States. Internet wireless access capabilities have been developed as an extension to wired local area networking (Lemstra & Hayes 2009). Beyond the direct comparison of the technical or commercial merits of these two wireless access systems, this research studies the development to identify the systemic elements driving the evolution and disruptions in the complex value systems.

As discussed in section 3, the value systems include many different types of actors and stakeholders. The structural analysis of the value system considers structural actors which play a direct and core role in providing the customer value (Bouwman et al. 2008), while the role of the other stakeholders is indirect. As this study relates to 1G and 2G mobile networks and the internet access network, the value-added services and applications, i.e. the content cluster, are seen in this study only through the core network functionalities. Services and applications of the cluster are either integrated into walled gardens of the network operators or provided fully separately in the case of the internet value system. To examine the wireless access network, the roles of all **relevant actors** were identified as follows:

The **Spectrum owner** is ultimately a government that licenses the spectrum to network operators or otherwise allows use of the spectrum. For the network cluster, the **Core network operator**[63] operates the physical core network elements such as routing, switching, and internetwork transmission. The **Access network operator** operates the physical access network and the immediate wireless network functionalities, such as a network of base stations or a network of locally connected access points. The access network operator logically controls the radio spectrum through the license or through other mechanisms like physical control of the space where the network is used. The **Network**

[63] As it relates to 1G and 2G mobile networks, the core network includes also all of the value-added services. The role of the content cluster in this analysis is low.

equipment manufacturer produces and provides network infrastructure elements, hardware and software products, such as switching and transmission equipment, including base stations and WLAN access points. The **Service provider** operates Authentication, Billing, and Charging (ABC) functionalities. The service provider manages end user accounts and may provide other services related to provisioning such as personalization of end user devices. Network cluster actors are often consolidated into two main entities, network operations and equipment manufacturing.

For the device cluster, the **Device manufacturer** produces wireless end user devices, such as mobile phones and personal computers. **Device distribution** distributes the wireless end user devices to the end customers. Device distributors include wholesale and retail outlets and the necessary logistics to bring the products to the hands of the end users.

For the Personal data cluster, the **End user** controls his identity and data through his devices. There may be several end users operating the same device, and one end user may have multiple devices. Furthermore, the roles of end user and device owner are combined in this study for simplicity.

Additionally, a generic role of **Technology creator** is noted. In practice, this role is often separate for network and device clusters. The technology creator, for instance, provides technical content to standardization and software and hardware components and modules for the network and device cluster product companies.

Value system actors and the technical components and modules they manage form the nodes of the complex value system modelling in this section. Interfaces between the nodes define the type of interoperability through operational (including contractual) and technical connections. The analyses for wireless access follow the notation in Figure 11 and the system state models in Figure 13 to examine the structures and dynamics created by the actors explained above.

4.3.1 Modelling transitions in mobile communication

Publication II considers the transition from 1G to 2G and the related system states and state changes in Europe. The transition is well known as a technology disruption from analog to digital communication technologies, but the state transition of the overall complex value system requires further analysis. The system state model presented in section 4.2 is used in this analysis.

The mobile communication value systems in the 1G era were dominated by government-controlled actors with some national variations as discussed in section 3.2. For this research, the NMT system is used as the reference for the 1G system, and the GSM system is used as a reference for the 2G system.

Utilizing the notation explained in section 4.2, the NMT system model implemented in the Nordic countries is shown in Figure 14. The single government-owned operator controls all the value system clusters and interfaces between them. The government controls also the radio spectrum, which is assigned only to the government-owned network operator by the governmental spectrum management organized as a department of the network operator. The monopoly network operator developed the specifications, using technology companies as subcontractors only (in collaboration with other national monopoly operators in other Nordic countries). For instance, in Finland, the government even owned and controlled part of the manufacturing industry[64]. Naturally, all the network functionalities were operated by the network operator. Similarly, the mobile devices for the network were produced and type-approved based on the specifications developed by the operators. The network supported all the services without any interface for other potentially value adding actors. The state-owned operator owned and operated both the fixed and mobile networks, and the mobile network was connected to other networks only through the fixed telephone network.

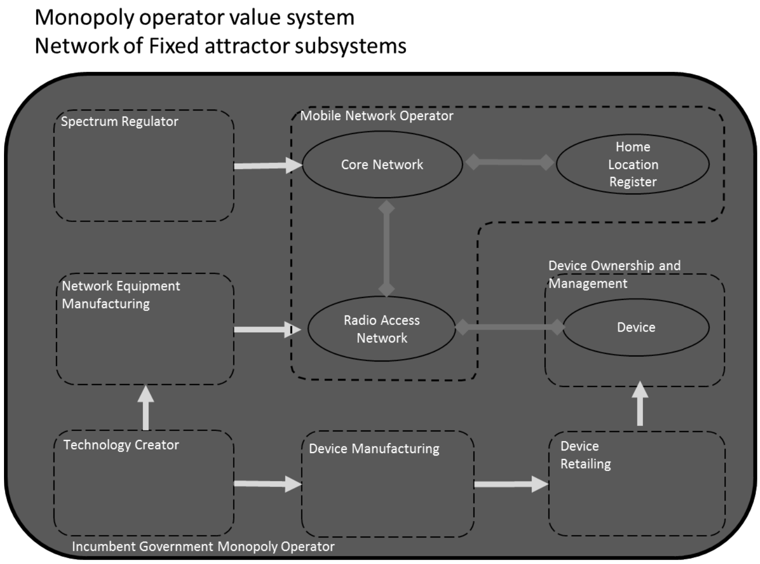

Figure 14. Mobile communication system model in case of National monopoly (Publication II) Copyright 2012 SAGE Publishing. Reprinted with permission.

Figure 14 is a generalization, showing all interfaces in a fixed relationship under full governmental control. Real-life networks, however, implemented some exceptions which deviate from Figure 14. For instance, in the United Kingdom, there were two competing 1G operators, Cellnet[65] and Vodafone[66]. Also, a small operator Comvik[67] provided mobile communications services during the 1G era in Sweden. In the Nordic countries, some further small steps were taken toward a more open and liberal market model. The NMT system supported limited open

[64] Televa developed switching systems for NMT. The Finnish government sold its majority ownership to Nokia OY in 1981 and divested the remaining minority in 1987.
[65] Cellnet plc. Originally a British Telecom subsidiary finally acquired by Telefonica under brand of O2.
[66] Vodafone plc. Originally a local mobile network operator in the United Kingdom. Today, one of the leaders in the telecom market globally. http://www.vodafone.com/content/index/investors/about_us.html. Accessed January 2, 2018.
[67] Comvik AB. Originally a local mobile network operator in Sweden, finally acquired by TELE2.

interoperability between consumer devices and network elements, allowing several mobile phone manufactures to provide products to the market. In Finland, distribution of mobile phones took place also through an operator-independent sales channel (Lehenkari & Miettinen 2002). Similar deviations can also be found in other countries.

The NMT market was formally a national monopoly. However, the network operators had agreed to support roaming of voice services between the networks. It is an open question whether this can be considered as a regulatory requirement, or simply a business decision of the operators, since those two roles were under the same leadership anyway during the NMT era. National regulatory authorities have paid rather little attention to roaming customers even later (Sutherland 2001), and therefore, in the case of NMT, international roaming can be considered a business issue driven by customer needs.

Needs for better performance, new services, and especially for better mobility drove the development forward. Liberalization of telecommunication regulation initiated a state transition in mobile communication, while the international regional collaboration expanded the limits of the value system beyond national borders, leading to partial decentralization. The regional regulators defined new roles for the operators, encouraged them to use new technologies on the liberalized radio spectrum, and set new rules for interoperability and roaming. The developments were slightly different in different regions of the world, where European administrations took the most holistic approach. The business rules for 2G in Europe created a single-market opportunity for European companies and consumers.

Specifically, as it relates to the strong role and involvement of the regulators in the development of the GSM system, the initial 2G mobile communication setup in Europe was semi-centralized and multinational. The Collaboration body of the national Post and Telecommunications operators (CEPT), responsible for the development of GSM, is even today responsible for coordinating national decisions on spectrum allocations for the European market. Over the years, the European Union has gained a more important role in regulating the mobile communication markets, but radio spectrum matters still fall under national decision-making in all countries. This specific multiparty decision-making was adopted in the second-generation system structure also, and it is visible even today, when the fifth-generation system is in the prototyping phase. The value system characteristics, such as the roles of key actors, is an outcome of the development that started when several ground rules of the GSM system were inherited from NMT and agreed upon during the 1980s (Haug 2002). The oligopolistic nature of the radio spectrum licenses constrained the number of networks with an upper and lower limit. In most markets, the number of mobile operators was defined to be between three and five, which increased competition between operators significantly. Consolidation of MNOs beyond national borders has been slow, while chosen policies of 2G have facilitated collaboration and coordination within the mobile-operator community for all later technology generations.

The GSM value system is presented in Figure 15 below using the notation explained in section 4.2. It shows the relevant actors of the 2G mobile communication value system, including regulators, operators, equipment and device vendors, as well as technology providers, SIM card companies, and device distributors.

The state transition from fixed to limit cycle system dynamics in Europe was driven by deeply collaborating national administrations[68]. National network operators were involved in the dialogue as in the 1G era, but the separation of regulatory authorities from operators was accepted, and especially the new roles of emerging privately-owned network operators required balancing and pushed the separation forward.

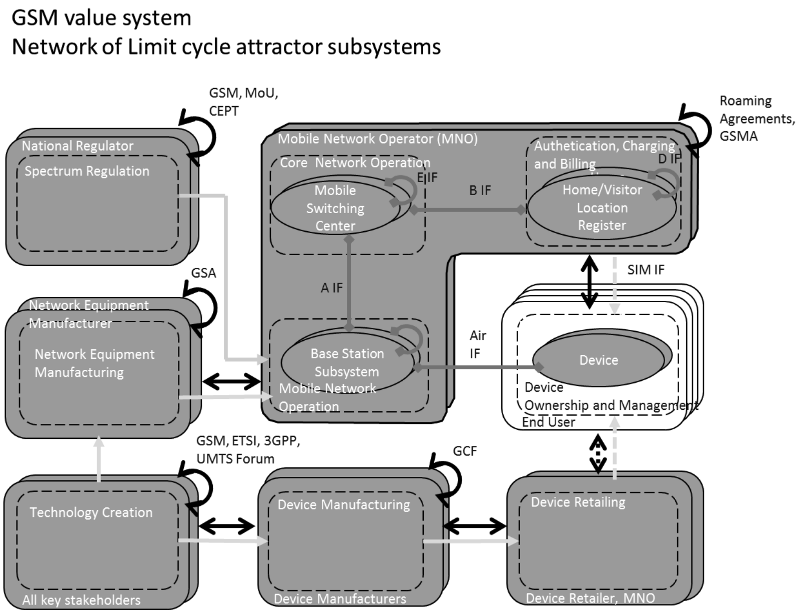

Figure 15. GSM functional structure with system dynamics
(Publication II) Copyright 2012 SAGE Publishing. Reprinted with permission.

The first two major differences relate to the interface between national regulators, enabling rather tight collaboration in CEPT under the pressure of the emerging European Union. Consequently, the leading operator candidates agreed on a Memorandum of Understanding[69], which introduced competition between the operators in each national market, confirmed the commitment to a single interoperable standard, and secured the access to the harmonized radio spectrum. These changes where difficult for established national PTT operators to adapt (Peppard & Rylander 2006). At the same time, the new rules offered a window of opportunity to new actors without a similar legacy.

Privileges and obligations give a special role to the MNOs. Consequently, they also force the MNOs to collaborate and coordinate their services nationally

[68] http://www.gsmhistory.com/who_created-gsm/. Accessed March 11, 2017.
[69] Memorandum of Understanding. http://www.gsm-history.org/fileadmin/user_upload/GSM_MoU/GSM_MOU_1987.pdf. Accessed October 11, 2017.

and internationally. For this specific reason, MNOs have set up their regional and global organizations, such as the GSM Association (GSMA[70]). Other value system actors have followed the model and formed their own coordination organizations, such as the Global mobile Suppliers Association (GSA[71]) and Global Certification Forum (GCF[72]) to build cohesion in the value system. The role of the upstream (technology innovators, network infrastructure suppliers) and downstream (value adding service providers and virtual mobile operators) actors is limited due to the limited number of the MNOs in each market. Consumer device suppliers, specifically the mobile device companies, have possibilities to offer their products and services also independently from the MNOs, especially in those makers, which efficiently limit the ME/SIM bundling. The overall set of value system actors is even broader, including multiple types of subcontractors (site owners of radio network base stations, test houses, maintenance and support functions, financing, etc.) and component vendors (chip sets, software, mechanics, etc.).

The firm requirement for a fully open-air interface between the radio network entity and mobile devices created a fracture in the industry, pushing the network infrastructure and mobile device manufacturing into two different entities in business, in standardization, and even within the companies. Earlier vertical technology bundling between infrastructure and mobile devices was broken into two rather independent entities, where the critical infrastructure entities, like switching centers, radio network, and registers to manage the subscribers, were still operated as one closed system by each MNO. The standardized technical interfaces between the entities enabled utilization of multivendor equipment. No regulation required the manufacturing and technology companies to implement the interfaces in their internal operations, but in practice, the business dynamics made the companies implement their internal system interfaces accordingly to be more competitive externally[73].

National regulatory administrations noted the need to organize the technology development in 2G in a way that is more liberal than the approach during the 1G era. The obvious concerns of the manufacturing and technology industry were noted, and the earlier monopoly position of the network operators was moderated to a nominally equal level with any other stakeholder when the European Telecommunication Standard Institute (ETSI) was established. In practice, the unique position of the network operators as the solid license owners to utilize the radio spectrum, maintained part of their earlier power. Further collaboration entities such as the UMTS Forum, Open Mobile Alliance, and later the Third Generation Partnership Project (3GPP) followed the model built initially for ETSI.

When compared to the NMT system, liberalization proceeded further in mobile devices ownership. Regulation specifically enforced the separation between mobile devices and network operators by requiring the Subscriber

[70] GSM Association, GSMA. https://www.gsma.com/. Accessed October 17, 2017.
[71] Global mobile Suppliers Association. https://gsacom.com/. Accessed October17, 2017.
[72] Global Certification Forum GCF. http://www.globalcertificationforum.org/. Accessed October 17, 2017.
[73] During the later generations, this separation has materialized almost completely.

Identity Module (SIM) to be detachable from the device[74]. This maintained the oligopolistic nature related to subscriptions but enabled an almost fully free market to emerge for mobile phones.

The 2G operative model is different from 1G systematically, including a different structure, a different interoperability model, control of scarce resource, as well as different models of competition and collaboration. Furthermore, value capturing and sharing models were changed when the expected value to be collected by the network operators was shared in advance to the rest of the society in very competitive radio spectrum actions. The state transition from a monopoly to licensed competition was a dramatic change and disruption to all 1G stakeholders, and it opened new opportunities to actors who wanted to substitute the way of working in 1G.

The state transition was only partially systemic. At least two deviations can be observed:

1) The retail market of mobile phones was liberalized further. Initial formal type approvals were substituted by a combination of mandatory and voluntary certifications and market surveillance. This decision enabled operator-independent mobile devices to enter the market. This opened the initially closed walled gardens to many new entrants which created a local system disorder (Kurtz & Snowden 2003) and eventually lead to numerous disputes. To balance the situation, regulators allowed network operators to implement SIM/ME bundling[75] but only as a limited option in selected markets. As a side effect, some operators and service providers attempted to create bundles by using the International Mobile Equipment Identity (IMEI) as a substitute identity of the end user. This created multiple security issues because it misused the standard against its original intention.

2) Bundling of value-adding services in mobile networks was allowed, which disabled a separate content cluster from evolving in mobile communication. As it relates to net neutrality, the regulation limits the bundling of existing content and network clusters but allows embedded "content cluster and services" within the network cluster[76]. In other words, the walled garden model extended to value-adding services without balanced strategies of competition, collaboration, and interoperability.

As the industry was growing older, needs to collaborate were decreasing (Fjeldstad, Becerra & Narayanan 2004), which lead to slow introduction, poor interoperability, and eventually to market failure in case of content cluster emergence inside the network cluster. As an example, the Short Message Service (SMS) and its enhancement Multimedia Messaging Service (MMS) were developed as any other functional standardized network features. Without any clear service obligation, the internetwork operation of SMS and MMS took rather

[74] SIM personalization.
https://docbox.etsi.org/zarchive/smg/SMG/plenary/18_9604_Bonn/tdocs/96-345.pdf.
[75] Service bundle where mobile equipment (mobile device, a.k.a. mobile phone) could be locked in to the subscriber identity (in subscriber identity module, a.k.a. SIM card) provided by a specific mobile network operator.
[76] Figure 14 ignores the value-adding services as a separate entity due to the focus of Publication II on the access-related value system. Value-adding services can and should be included into the entity parallel to, e.g., billing services.

long to emerge. To improve the situation, the key 2G stakeholders decided to enhance their collaboration related to value added services which resulted in the setup of the Open Mobile Alliance (OMA). The OMA develop service enablers[77] but prioritize the walled garden operative model, build service enablers with technical bundling to network, which in practice limited broader expansion of the related services.

Consumers and small- and medium-size enterprises needed support to utilize e-applications efficiently (Brown & Lockett 2004). Little was achieved, and the situation became critical in 3G and finally led to the collapse of garden walls and consequently to the emergence of the Internet oriented service model (OTT) growing on top of the network bit pipe. The cognitive burden on the consumers (Bouwman et al. 2007) was experienced by the SMEs as well. The mobile communication value system self-limited the scope to grow beyond the initial one-to-one mental model of voice service provision. Section 4.4 returns to the confusing hybrid value system in case of Push over Cellular (PoC).

Timewise, this study spans the period from the first-generation cellular systems to the second-generation technologies, GSM and GPRS, and toward the early implementations of third-generation technologies, WCDMA and EDGE. Figure 15 shows the stable 2G walled garden value system structure with related possibilities to compete and collaborate.

As a hindsight, the NMT era paved the road toward second-generation systems by taking limited early steps toward a holistically different value system model, defined by core network capabilities such as intra- and internetwork signaling, registers, and identities. The transition from a fully closed monopoly system to liberalized second-generation mobile communication in the Nordic countries took place in two phases. A small step from manual pre-1G systems to NMT preceded the separate larger change from NMT to GSM, while the state transition directly to GSM was quite radical in some other countries. The less radical early steps in the right direction made it easier for companies providing equipment to the NMT system to adapt to the drastic change of the system state from state 1 to state 2.

The critical and unique innovation related to 2G regulations in Europe was the requirement to provide pan-European roaming of voice services. This decision created a balance between the oligopolistic spectrum licenses by forcing the operators to provide regional interoperable services between the national dedicated spectrum gardens. Regulation-driven introduction of the SIM card and later number portability forced the interoperable competition and collaboration further utilizing the two other symbiotic interfaces beyond net neutrality and open air interface (Fransman 2010).

Developments in other ITU regions were different and are discussed here only for contextual reference. Needs for coordination between the regions during the transition from 1G to 2G was low. Global coordination became essentially important in the transition from 2G to 3G which ignited a standards war or, more accurately, a value system competition between the different regional 2G value

[77] Service enabler as defined in OMA is a functional specification intended to make the actual end user services interoperable.

system stakeholders (Glimstedt 2001). The arm's-length competition between GSM and the region 2 value systems based on the 1G core network and related 2G radio access technologies IS-95 and IS-136 [78] evolved gradually into deep collaboration in 3GPP toward the end of 3G and specifically during the development of 4G. In general, the recognized positions of different mobile communication standards are based often on their radio network functionalities (Funk & Methe 2001; Gandal, Salant & Waverman 2003), while the role of the core network and its path dependencies are often overlooked. Adoption of the air interface technology without network effects created by core network functions such as roaming hindered in practice the unleashing of global economies of scale and competition between service providers. Even today, international roaming may require further public policies and regulation to become a reality (Infante & Vallejo 2012).

4.3.2 Modelling transitions in WLAN access

Section 3.2 discusses the overall internet value system developments, while this section examines the Wireless Local Area Networking (WLAN) as an access to the internet value system. In the early days, internet developers and users recognized no need for either mobility or wireless, which motivated only few fragmented attempts to develop necessary technologies for WLAN. Later, however, the need to make the Internet available worldwide and the competition with mobile communications systems pushed the internet actors to seek solutions through less-fragmented, collaborative ways. The pressure was especially high for interoperability in wireless access, but later similar needs requiring more coordinated decision-making emerged on the web layer also. Competition in the global scope influenced the development also organizationally. The decision to establish the Internet Society (ISOC) to host the technical work of the IETF opened the access to Internet standardization to all contributors worldwide.

As a generalization from the end user perspective, the 1G mobile communication service was closed and centralized, while the early wireless access to the Internet was closed and decentralized (fragmented). The early access network-focused value system model is shown in Figure 16 below, using the notation explained in section 4.2.

[78] Telecom Industry Association (TIA) Interim Standards (IS) IS-136 and IS-95 specify radio access technologies developed in the United States for 2G.

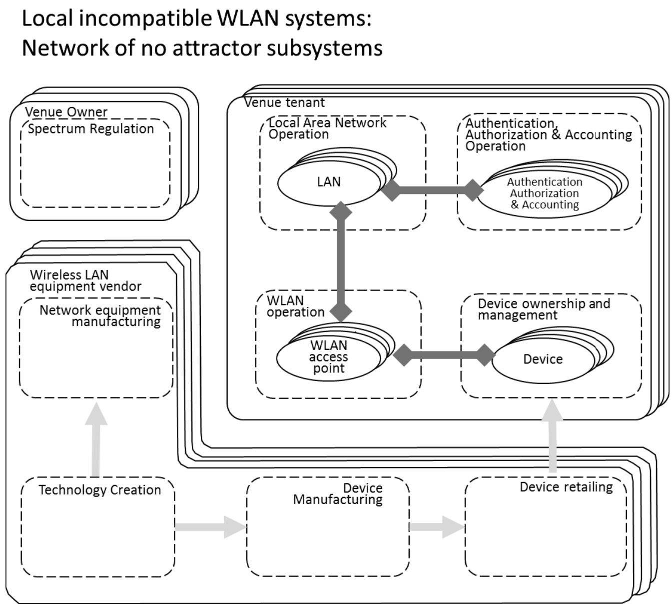

Figure 16. Initial model of the wireless access value system for the (Publication II) Copyright 2012 SAGE Publishing. Reprinted with permission.

As it relates to the internet value system, WLAN access consists of three actor types, venue owners (property owners), venue tenants and wireless LAN equipment providers, bundling roles over the cluster interfaces. As loose regulations governing the IMS frequency band allow internet wireless access network provisioning without any specific licenses, the decision power related to the use of the radio systems on the premises is in practice with the venue owners. The venue owner can lease the asset, physical real estate and buildings, to the party who finally builds the wireless network. De facto, such a leasing contract transfers the spectrum rights as well and disconnects the venue owner from other actors, including other venue owners.

The second group of actors creates a bundle including companies providing the wireless access devices utilizing relatively simple technologies available as specifications, software, and hardware components. Creating technical solutions to solve isolated problems and supporting the limited and focused needs of few customers was easy, and therefore, a myriad of such products and solutions, like connecting cash registers to a back-office computer, proprietary healthcare devices connected to a central unit, and even cordless phones entered the market (Negus & Petrick 2009). These early installations of wireless access systems were typically focused and business-oriented, and actors building the wireless access networks had the power and responsibility to decide on the network components they used. This connected the distribution channels rather tightly together with the technology, device, and network infrastructure providers. Due to the proprietary nature of the devices and technologies, interoperability between different networks or their components was only randomly available, if at all. This bundle is debatable but separating these actors in the modelling would naturally only show even more fragmentation.

Third group consists of the companies and actors who operated the wireless LAN networks, typically for their internal purposes, referred here as venue tenants. They often picked and chose technologies and equipment based on their immediate business needs. Furthermore, they assumed full responsibility related to network access aspects such as authentication and billing, if any. Their connections to technology vendors or device retailing were weak.

In summary, these three bundled actors made their decisions locally and independently. The value system was fragmented both vertically and horizontally, and interoperability between different actors was random. Significant value creation in such a system is difficult due to low network effects.

Gradually, multiple activities emerged to reduce the fragmentation. After a period of fermentation, the IEEE 802 community adopted the leading role. The regulative framework for the critical scarce resource, i.e. radio spectrum, was less limiting and less demanding than in the case of Mobile Communications, but it was still strong enough for sustainable use of the spectrum with suitable etiquette. For this purpose, the IEEE 802.11 standardization group developed technologies, such as Carrier Sense Multiple Access (CSMA)[79], optimized for locally operated low-power radios utilizing the same scarce resource. The WLAN access to Internet, known also as Wi-Fi, was able to emerge in a decentralized, bottom-up fashion (Lehr & McKnight 2003). The structure of evolved internet access value system is shown below in Figure 17 using the notation explained in section 4.2.

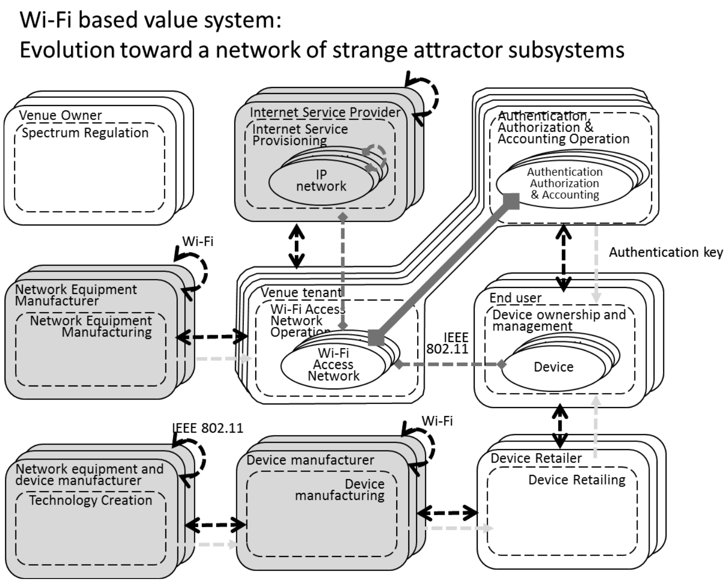

Figure 17. Value system Evolution of the Wireless access in the Internet (Publication II) Copyright 2012 SAGE Publishing. Reprinted with permission.

[79] Based on the original "AlohaNET" listen-before-talk concept developed at the University of Hawaii.

A fundamental difference related to bundling, competition, and strength of the interfaces between the actors can be seen by comparing Figures 16 and 17. The wireless access to the Internet value system has a structure where all logical entities are independently controlled and operated. Typically, the only implemented bundle connects the authentication and possible charging and billing functionalities to the access network, i.e. the access point owner controls and configures the access rights, indicated by a strong solid arrow between the actors in Figure 17. The majority of other business and technical interfaces are based on voluntary collaboration with open interface specifications or, more accurately, preferential attachment. For wireless access, this requirement is fulfilled when using products complying with IEEE 802.11 specifications. The Wi-Fi Alliance (WFA) provides a certification mechanism to make the compliance easy for any stakeholder to benefit, motivating the characterization of Wi-Fi as a license-exempted value system rather than an unlicensed one.

Distribution and ownership of Wi-Fi access points and devices is partially competitive, and collaboration between different distribution channels and separately between different Wi-Fi owners is often completely uncoordinated. However, regulations, implemented de facto through voluntary technical interoperability and compatibility of the Wi-Fi certified access points and end user devices, limit fierce competition, such as using unlimited transmission power to achieve connection in densely populated areas. The de facto radio spectrum owners (venue owners) typically exclude themselves from any collaborative activities in the value system.

Evolution in the internet value system has been driven primarily by the IETF and W3C communities in deep collaboration, including the local area connectivity developments in the IEEE802. Participation in the value system is open as long as the actors follow the general internet principles, such as each internet sub-network being independent without any global control, providing best effort communication through content-transparent black boxes (Leiner et al. 2009). The power of the fixed Internet, specifically in the USA, and its value system dynamics have influenced the development of wireless access, setting the de facto boundaries.

In summary, while the licensed mobile communication value system experienced a transition from a closed and centralized system model toward semi-open and semi-centralized systems, the developments in the license-exempt market experienced a transition from a fully fragmented random setup toward a loosely connected, global, interoperable Internet, where the Wi-Fi access is becoming fully interoperable. Radio spectrum regulation allowed shared use of the ISM frequencies, which required complementing technical solutions to avoid radio signals disturbing each other. Regulation mandated only co-existence, but no interoperability, and therefore, voluntary standardization emerged based on the needs of the companies developing the technologies.

Furthermore, weak voluntary coordination drives markets slowly. A large number of participants in an open value system slows down the creation of standards (Simcoe 2012) and interoperability in the business. Networking standards, such as the Mobile Internet Protocol, have been developed, but nobody has taken care of the holistic system architecture and interoperability requirements. Therefore, some key features like authentication while roaming have been provided only in a limited way, mainly based on further voluntary initiatives.

The IEEE 802 community has facilitated also other technologies providing connectivity to the Internet and utilizing the same frequency band, such as Bluetooth[80] and Zigbee[81]. These focused value systems have later developed toward full independence while still following the etiquette that enables their coexistence. Therefore, a limited fragmentation still exists. Loosely connected voluntary activities lack the power to drive the consolidation of value systems into one structure and platform. Instead, multiple innovative branches have emerged. Such "forking" and unpredictable services, both good and bad, have made the wireless access to the Internet a dream for innovators and a nightmare for risk-averse users. However, the overall system transition from chaotic fragmentation to a rather well behaving, though still a little bit strange, dynamic state has taken place.

4.3.3 Findings of wireless access evolution study

Different complex value system states create value differently. The monopolistic and fragmented system states provide only limited value. The main interest in value system analysis is therefore to look at the value systems where suitable openness and control enable network effects to multiply the system value beyond the sum of its parts. The analyses in section 4.3 highlight the structural fit of the business and technology architectures as well as the synchronized alignment of the different stages of service production and markets as important factors in the widespread diffusion of GSM and Wi-Fi technologies. The analyses also show how the value system around GSM and Wi-Fi follow distinctly different dynamics and evolution paths and how they are on a colliding course. Therefore, a large-scale value system convergence of mobile communication and internet value systems in wireless access has not taken place as expected (Lehr & McKnight 2003). Instead, consumer products incorporate both technologies while value systems maintain their characteristics in separate sandboxes and merely tunnel[82] through each other.

In both value system transitions, system states changed in alignment related to most of the value system nodes, and the interfaces between the nodes were developed to implement these changes on the system level. Both value systems included exceptions where the system states were either ambiguous or conflicting, showing severe issues related to service adoption (OMA specified service enablers and related services), disputes related to SIM/ME bundling, and difficulties to utilize Internet-originated features and functions in mobile communications (IMS,

[80] Bluetooth is a dedicated low power local connectivity technology developed by the Bluetooth Special Interest Group, a standalone voluntary standardization group

[81] Zigbee is a dedicated low power local connectivity technology developed by Zigbee Alliance, a standalone voluntary standardization group

[82] Sandbox refers to a specific application environment which limits the possibilities of the application to influence the supporting system beyond the limits of the sandbox. Tunneling refers to the use of a communication service with limited or no interaction between the transported signals and the infrastructure.

Alternate Access, SIM authentication in Wi-Fi networks, etc.). The ambiguous or undefined interfaces in the mobile communication value system opened the door to Internet-driven OTT services and later application-driven ecosystems to grow on top of mobile communications.

Key findings related to the system states are summarized in Table 8 below. The table lists the system states conceptually aligned with the four attractors used in complex adaptive system models. Publication II addresses this in detail for the technical and business structures, while complementing knowledge on value system development in standardization is provided in Publication III.

Table 8. Key characteristics of Value system states in wireless access

WIRELESS VALUE SYSTEM STATES/ SELECTED CHARACTERISTICS	System Type 1: Fixed	System Type 2: Limit cycle	System Type 3: Strange	System Type 4: No Attractor
Access model	1G	GSM/GPRS	Wi-Fi	Fragmented
Status	Past value system in several countries	Existing value system globally	Existing value system globally	Existing, past and new Value systems in various regions
Availability of Scarce resource (Radio Spectrum)	Monopoly Spectrum	Licensed Spectrum and regulation-based certified products and services	Unlicensed Spectrum with License-exempted devices	Unlicensed (Laissez-faire) Spectrum for proprietary devices
Regulative requirements	Mandated	Mainly licensed	Limited set	Limited set
Scope	National	Regional	Local but globally acceptable	Local
Interoperability	Mandated for System internal reasons	Required to achieve modular, multivendor, multi-operator service	Actors agree on interoperability to suit their own needs	Random, Low/None
Competition between actors	Monopoly, No Competition. Often government-driven	Limited competition between the license holders, corporations	Limited competition within loose requirements, commercial and co-operative actors	Unlimited competition, private actors
Collaboration approach	Not applicable	Guided Collaboration to achieve essential interoperability functionalities, e.g. licensed de jure standardization	Voluntary, often through voluntary de facto standardization and consortia	Only random collaboration if any
Technology creation and diffusion[83]	Closed, Proprietary, Innovation Mandated, Contracted	Often commercial Innovation, diffusion through licensed de jure standardization	Open, networked innovation, often virally, through voluntary, de-facto standardization	Individual proprietary innovation, with aim to Dominant designs
Typical Scope (mobility)	National	International	Local and voluntary global	Local
Performance	High	High and Flexible	Best Effort	Variable
Costs	High	Competitive	Very competitive, even free of charge	Variable
Network effects	Low	Medium	Unlimited	Random

[83] Technology creation and diffusion scenarios aligned with definitions in Open Innovation Strategy Group, OISPG. https://ec.europa.eu/digital-single-market/en/news/open-innovation-publications. Accessed September 6, 2016.

The limit cycle system state drives the value creation beyond a monopoly system. However, limitations related to competition (e.g., licensed spectrum, high spectrum cost) and emphasis on open interfaces and interoperability inside the systemic clusters drive value capture toward the consumers and society.

A loosely connected system state characterized by a strange attractor can create significant value, often in unpredictable ways. A high value creation capability induces some drawbacks. Fast adoption of technical and business innovations due to positive feedback loops can make systems potentially unstable. The “winner takes all” growth pattern is characteristic to the strange attractor systems, whereas the controlled service adoption in limit cycle systems provides higher stability.

4.4 Failing transition of Push over Cellular

After a decade of fast growth, the 2G mobile communication system was in broad use in Europe. Market position for GSM technology in the USA was weaker, and a new service, Push to talk Over Cellular (PoC), was planned to improve the situation. The planned use case, to provide a walkie-talkie type half-duplex communication, was considered useful in competing similar emerging internet services. The PoC service was aimed to challenge the earlier successful proprietary iDEN service operated by the Nextel Corporation[84]. The iDEN service utilized a closed single-company technology and a specific radio spectrum allocation available only for Nextel, which enabled a monopoly access to scarce resources which made the value system operate mainly in system state 1.

The Push to Talk over Cellular service was developed as a dedicated new feature of a broader interoperable mobile communication value system. The main innovation was the utilization of packet transmission and internet-oriented technologies to provide group communication instead of the circuit-switched approach used in traditional Push to Talk (PTT) systems. This approach allowed utilization of the large installed base of the 3GPP global mobile network as a platform for PoC. No specific regulatory rules limited PoC use cases, indicating high potential for a competitive market. Interested mobile communication value system actors, several MNOs and their suppliers, identified the recently created Open Mobile Alliance (OMA) as the proper standardization environment for creating service and technology specifications. The consolidating standardization took place in OMA, where some technologies originated directly from 3GPP, and others were adaptations from the internet domain (Grøtnes 2008). Several IT application companies had joined OMA with their own preferences of value system dynamics and technologies, which created a hybrid model in many aspects in PoC.

The resulting hybrid technology stack of the PoC service is shown in Figure 18. The dark color indicates a 3GPP origin, white indicates origin of the technologies in internet-oriented SSOs, and grey areas indicate embedded use of internet protocols in 3GPP system components.

[84] A mobile communications company headquartered in Virginia, USA, acquired by the Sprint Corporation.

During the standardization, the PoC initiative driven by MNOs and their suppliers faced a broad competition both from existing business, i.e. IDEN services, as well as from different start-up companies building their service offerings directly Over The Top (OTT) of the mobile communication networks. The internet value system-oriented OTT services assumed the independent role of the content cluster for the first time in mobile communication systems and utilized the mobile network as a bit pipe only.

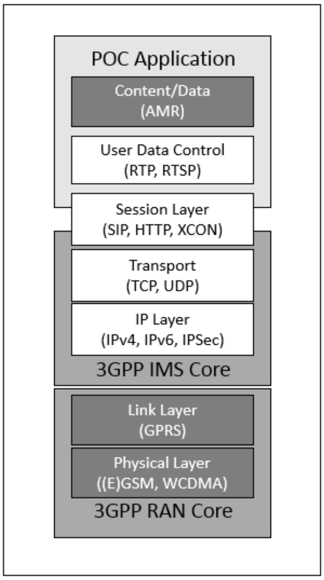

Figure 18. Hybrid technology model of OMA coordinated PoC
(Publication I) Copyright 2006 Springer-Verlag. Reprinted with permission.

The best effort protocols of the Internet created severe technical and performance problems in achieving comparable quality of service for a dedicated group call performance of the iDEN technology, even in case of OMA optimized protocols. Additionally, the OMA PoC service was developed for two separate user groups, consumers and enterprises, each having their own operating points for performance and costs, which created further conflicts in the development.

At the time of writing of Publication I, the outcome was unclear. The fundamental factors of smooth diffusion of an innovation were ignored in PoC development (Rogers 1995), which indicated some difficulties. Afterwards, the situation has become obvious. The planned PoC service failed to offer better performance than the existing iDEN service. The promise of global interoperability for PoC was not achieved either. This failure was due to intense existing (voice and SMS) competition within the MNO group. Further difficulties were created by the hybrid mode of operation, where the PoC service was ambiguous without state alignment, neither to the mobile communication nor internet value system. Without any regulatory pressure, MNOs failed to support the new type of business model fully, which hampered service introduction, created ambiguous marketing messages, cumbersome service, and uncompetitive data tariffs. The need to separate the content cluster from the core network was recognized as a technical requirement but was ignored in operational structures. Table 9 below summarizes the convergence toward a hybrid of mobile communication and information technology development in case of PoC.

Table 9. Key characteristics of a Hybrid value system of PoC

VALUE SYSTEMS/ SELECTED CHARACTERISTICS	System type 1: Fixed	System type 2/3: Hybrid	System type 4: No Attractor
Service model	iDEN	3GPP transmission and PoC protocols	Fastchat, Skype, and other similar
Status	Existing and prevailing value system	Failed value system	Fragmented set of existing, past, and new value systems
Availability of Scarce resource (Radio Spectrum)	Monopoly Spectrum	Licensed Spectrum	Not directly relevant (operates OTT of flat network)
Regulative requirements	Specific (related to mandatory PTT service)	Moderate, No PoC specific	Low/None
Scope	National	International	Global
Interoperability	System internal (Closed)	Horizontally available but limited by walled gardens	Many Multiple closed systems
Competition between actors	Low	Mixed	High, multiple competing actors
Collaboration approach	As defined by the operator, Closed	Through multiple standards organizations	No collaboration
Technology creation and diffusion	Proprietary and mandated	Open, combinations of licensed de jure and de facto standardization	Ambitions to de facto dominant designs
Typical Scope (mobility)	National	Regional, consumer and enterprise	Global
Performance	Very High	High	Low
Costs	High	Ambiguous	Low
Network effects	Low	Medium	Random

The ambiguous equilibrium between a licensed operator business and other business models has been topical since the emergence of unlicensed Internet (Peppard & Rylander 2006). After the launch of multiple group communication applications, platform-driven business models, the issue became a race for survival. While the confusion in the mobile communication value system has prevailed, social network services, such as WhatsApp[85] have been able to cover most of the consumers' needs. The current half-duplex communication services avoid hybrid models and rather focus on the systemic use cases and clear separation of the content and network cluster and in this way avoid the barriers of the early mobile-specific services (Bouwman et al. 2007). Furthermore, bundling of the device and content platforms has created a powerful bypassing channel for

[85] WhatsApp, originally a cross platform instant messaging company and application, acquired by Facebook Inc. https://www.whatsapp.com/about/. Accessed January 2, 2018.

OTT services. However, high-performance Push to Talk technology is under development in the 3GPP for 5G for professional use cases.

The hybrid model of mixed technology architecture and loosely coupled interoperability of the business architecture in a traditionally tightly connected mobile communication value system did not create a random system state without attractor but rather a state of disorder (Kurtz & Snowden 2003), which finally resulted in a clear failure. The early question whether mobile operators seriously were considering to provide internet services or only some dwarfed versions of those (Peppard & Rylander 2006) turned out to be true. Furthermore, if the regulation in Europe had promoted data-oriented broadband mobile communication, the environment would have been significantly more favorable for innovations and system transition, which evidently took place with the 4G (Weber 2014).

Instead of the planned state transition from state 1 to state 2, the proprietary iDEN business model prevailed. Another MNO, the Sprint Corporation [86], acquired Nextel and later replaced the original iDEN technology by another rather centralized technology based on the CDMA 1x technology. Even if the new technology was somewhat more open, standardized in 3GPP2 in the context of CDMA 2000 development, there was still only one network operator providing the service in each country, and therefore, the value system followed the vertical model of first-generation mobile technologies.

4.5 Mobility as a Service

The value system of transportation of people and goods has been stable for decades due to stable regulations and modest and fully evolutionary development of related technologies. Introduction of ICT into the value system has created a major opportunity. This research models the roles of actors including regulators, transportation companies, technology suppliers, and companies in automotive and other relevant industries as well as the roles of end users and examines potential collaboration and competition of the actors shaping the value system.

Publication VI has a specific focus on developments in the Mobility as a Service value system in Finland, while Publication V studies the scenario building as a pan-European challenge, using GSM development as a reference.

4.5.1 Modelling closed value systems in transportation

In Finland, the current transportation services are operated under many different detailed licenses. Consequently, transportation of people and goods is divided into many different, mainly isolated verticals. For instance, bus, taxi, and railroad companies under a strong coordination through a license regime by public authority provide long-distance mobility and transportation services for people. The Finnish Transport Authority (FTA [87]) together with regional ELY

[86] Sprint Corporation, a communications company headquartered in Kansas, USA.
[87] FTA Finnish Transport Authority. https://www.liikennevirasto.fi/web/en. Accessed January 2, 2018.

centers (Centers for Economic Development, Transport, and Environment) are responsible for developing and maintaining the national public transportation plan. This plan, however, includes only some limited static information on public transportation services related licenses and information on the committed bus routes and timetables. Bus companies, on the other hand, have organized their coordination operations through an association (Linja-autoliitto[88]), which owns a service and marketing company, Matkahuolto[89], to manage ticket sales, cargo, and other customer service functions. Traditionally, there has been little competition between the bus companies beyond the competition to get the license to operate a bus route. On the other hand, competition between the monopoly railroad operator, Valtion Rautatiet[90], and the long-distance bus companies is fierce and without any coordination. Additionally, for local public transportation in large cities, the bus and railroad services are coordinated by a monopoly municipal public transportation authority, separately in each city. Taxis operate under regional taxi dispatching centers, which are owned by the owners of the regional taxi licenses. Taxi owners have their national association (Taksiliitto[91]) to promote their views and act as the negotiation party agreeing on the rules and tariffs on behalf of its members.

As it relates to a closed and fragmented value system model, privately provided services in the transportation value system without any license are in principle forbidden in Finland. Each party who prefers not to use licensed, i.e. public transportation, must own (or lease) and operate their own vehicles without sharing possibilities. This is valid for private persons, enterprises, and public actors. In practice, some ride sharing models are allowed and even encouraged, but the situation is currently rather ambiguous. Furthermore, the interoperability between the infrastructure and the other value system clusters is only elementary, such as separate road lanes for public and private transportation. From the complex value system perspective, the system state is fragmented.

When compared to the wireless access value system, the infrastructure and device suppliers (transportation technology and vehicle providers) have a low independent role in the current transportation value system. Transportation operating companies utilize proprietary technologies and products in their closed monopoly value systems. On the other hand, fragmented individual transportation actors like private people and companies operating their own vehicles have only few compatible technologies provided by the car companies as a common standard.

4.5.2 Modelling possible value systems transitions in transportation

Today many ICT-driven trends are reshaping the current structures around the transport and mobility market as discussed in section 3.4. New legislation

[88] Linja-autolitto. http://www.linja-autoliitto.fi/fi/. Accessed January 2, 2018.
[89] Matkahuolto. https://matkahuolto.fi/en/good-know/company-information/#.Wkt2mXmYOCo. Accessed January 2, 2018.
[90] VR, a state-owned railway system including the railways, trains, and service for public transportation. Accessed January 2, 2018.
[91] Taksiliitto. http://www.taksiliitto.fi/en/. Accessed January 2, 2018.

called Liikennekaari[92] has been approved in Finland to enable more flexibility in transportation and mobility services. When this legislation enters into force in July 1, 2018, it will enable the Mobility as a Service value system to emerge. The intention of the new legislation, including its forthcoming steps, is to enable a larger variety of value systems to emerge for transportation. Even if the goal is rather clear, the mechanisms how to achieve the goal are currently actively debated in Finland. Creating sustainable and agile rules for a dynamic market is a typical challenge in regulating complex systems (Longstaff 2003). Therefore, multiple options need to be considered.

Following the model of four complex attractors characterizing four separate system states, the closed centralized and fragmented states represent the starting points, while the transitions to new open states become the focus of the modelling. New system states and related structures and dynamics challenge the roles and behaviors of the current value system actors by opening many new business opportunities and behaviors.

Some opportunities have already been identified and implemented in Finland. For high capacity routes, a new entrant, Onnibus[93], challenges the fixed monopoly value system with new ideas. First, they broke the traditional monopoly setup in long-distance bus transportation by gaining a competitive license without coordination with the existing bus companies. Additionally, they offer a new service concept utilizing digital e-services, including ticket sales through the Internet, highly dynamic tariffs, optimized routes, and efficient technologies, like double deck busses with Wi-Fi connectivity for passengers. The new entrant has been able to gain market access and some market share, and furthermore, it has been able to shape the complex value system dynamics, introducing competition and challenging service offerings of both existing bus companies and the monopoly railroad company. The new service elements have even substituted some private cars for long-distance commuting. Therefore, Onnibus has changed many established rules and practices in long-distance bus service, and hence, it is not implementing a basic new entrant but rather substitute strategies (Porter 1985), which are difficult to existing value system actors to follow. Another approach was tested in taxi service by Uber[94], but strong conflicts with local regulations in Finland forced the service to wait for the new legislation before service expansion. These small fractures in existing closed value system states are too weak to sponsor full openness and collaboration but are examples of new ways of working, and their influence on future systemic change is important.

Utilizing the ICT clustering and systemic scenarios brings in new ideas to address the conflicts between emerging new value systems and traditional ways to operate the services in a strongly regulated environment. As an example, a conceptual model to build open, interoperable, license-oriented value system for local public transportation is shown in Figure 19 using the notation explained in section 4.2. Publication VI utilizes slightly modified notation. The notation used in Figure 19 is adapted and harmonized for this thesis.

[92] A broad renewal of transportation legislation in Finland started in 2014.
[93] Onnibus. http://www.onnibus.com/en/index.htm. Accessed November 11, 2017.
[94] Uber Technologies Incorporated is a privately held company, and there is limited information available. https://en.wikipedia.org/wiki/Uber_(company). Accessed November 11, 2017.

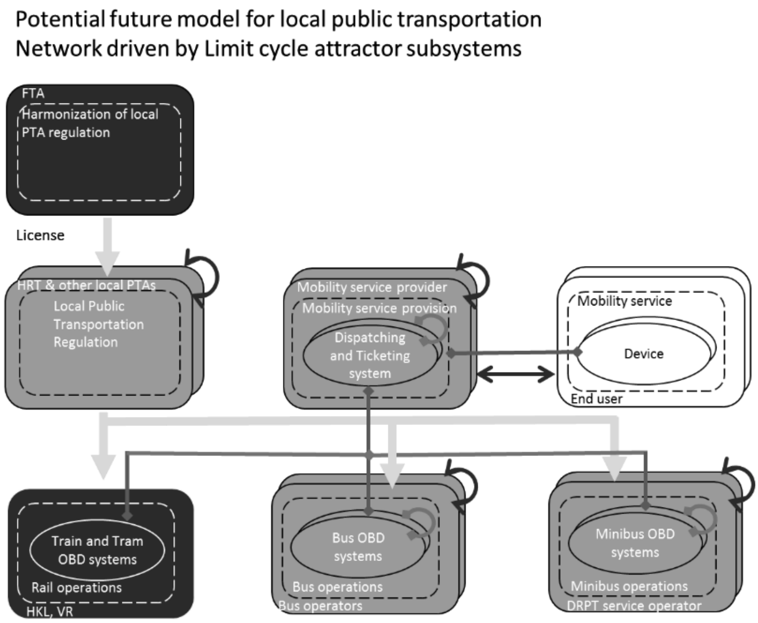

Figure 19. Possible value system model for public transportation in the Helsinki region (Adapted from Publication VI)

The value system in Figure 19 introduces a model of multiple licensed MaaS Service Providers enabling their customers to access services from all transportation network operators. The role of the previous monopolistic regional public transport authority (PTA), such as Helsingin seudun liikenne[95] (HSL/HRT), is reduced to managing the local transportation business environment under national regulations, including coordination with other regions. The MaaS service integrates traditionally separate bus, limo/taxi, and train services into one bundle available to end users. There can be several MaaS operators with different bundles competing locally and nationwide. The independent role of the national regulator (FTA) is important. It will enforce interoperability between the PTAs, enabling the consumers of one region to gain roaming access to public local transportation services in other regions and, in the long term, also internationally.

Competition between MaaS service providers optimizes services to respond to demand, including price flexibility in case of congestion. MaaS operators would use different physical transportation networks and vehicles according to their needs, including infrastructure sharing where applicable. On the other hand, one physical bus would service multiple MaaS service providers as one airplane is shared by several air carrier companies. Transportation as a standalone one-size-fits-all system will gain multiple new additional service offerings and new quality-of-services models. The value system requires a very clear license system, which addresses the potential issues of hybrid operations when monopolistic rail system operators and rival bus and minibus operators compete to serve the customers of multiple MaaS operators.

[95] HSL, a local transportation authority in the Helsinki metropolitan area.

Separately, the success of actors, such as Onnibus and Uber in challenging the monopoly-oriented value systems of long-distance bus transportation and regional taxi companies has encouraged, e.g., the local taxi dispatch centers to develop competing, partially collaborative applications, such as Valopilkku[96]. These applications have not yet developed two-sided market strategies, and competition for platform leadership is taking its first steps (Eisenmann, Parker & Van Alstyne 2006). It is also possible that the collaborative initiatives find a way to share the market in a similar way as the licensed mobile communication services network operators and virtual service providers have developed their positions in the transition from fully protected monopoly positions toward limited licensed competition. In this scenario, the relevant end-user interface to the services is a mobile device with one or more mobile applications for consumers to pick and choose the MaaS service provider they prefer. As it relates to the ICT clusters, the role of consumers' personal data is an emerging open issue, since no data portability between the MaaS service providers has been considered so far.

The other development, emerging from the fragmented system state without any attractor, also needs attention. A loosely connected value system model for transportation is possible, as shown in the Figure 20 using the notation explained in section 4.2. Publication VI utilizes slightly modified notation. The notation used in Figure 20 is harmonized for this thesis.

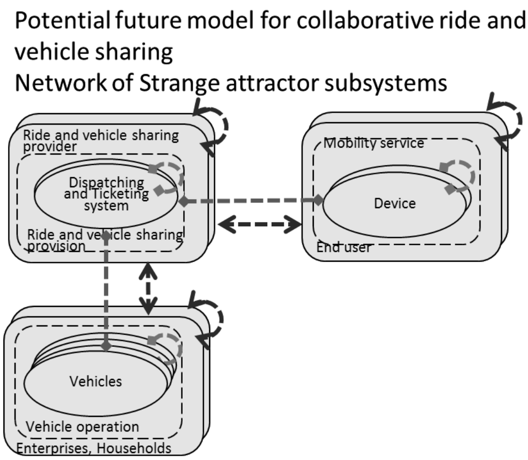

Figure 20. Possible future transition from a fragmented market to a voluntarily collaborating ride- and vehicle-sharing system

(Adapted from Publication VI)

In this loosely connected value system, the key players are the owners of private cars and other vehicles, including private consumers and companies. They generate the majority of the road traffic currently in Finland. The fragmented approach where each user controls and utilizes his own vehicle is inefficient, requiring more investments and imposing high operating costs. Currently, it is rather difficult for any third party to provide any meaningful additional services

[96] Valopilkku, an application to order a Taxi cab in Finland. https://valopilkkutaksi.fi/briefly-in-english/. Accessed December 1, 2017.

due to low interoperability between the users and their vehicles and systems. For instance, each car manufacturer has their own proprietary technologies to access the capabilities in the vehicles.

New concepts using ICT have emerged to reduce fragmentation, for instance, for ride-sharing, but no obvious platform leader has yet surfaced. As the transition is gaining strength, some actors[97] have even introduced new service concepts where they provide car sharing as a commercial offering. All the ride-sharing solutions use applications and databases of their own, which hinders service adoption. However, the underlying ICT clusters support all the applications, and therefore, significant switching costs and lock-in problems have been avoided so far. Multi-homing is possible; i.e. there are no observed restrictions that limit the vehicle owners from providing services through multiple ride-sharing platforms, providing benefits to consumers (Choi 2010). Furthermore, a strong local bias in especially local transportation may limit the power of global platforms (Lee, Lee & Lee 2006). Promotion of openness related to interfaces or resources is an important but challenging issue, similar to promoting innovation and fair evolutionary competition in any privately owned environment, whether a telephone network, operating system, or even a retail store (Wu 2003).

Furthermore, the global internet-driven taxi companies such as Uber are relevant also in consolidating the fragmentation, especially when the new legislation enters into force in July 2018. The complexities related to the hybrid value system setups require special attention. Mixing the licensed and other value systems into one service leads easily to a state of disorder.

This scenario assumes no detailed sector-specific regulation, but rather high-level rules will facilitate the emergence of the structure. Rules, however, are needed to enable easy access to the scarce resources, such as consumers' data. At the same time, rules must protect the misuse of the resource. Finding an equilibrium between the tragedy of the commons (Hardin 1968) and tragedy of the anti-commons (Heller 1998) requires a new type of agility from the regulators (Buchanan & Yoon 2000).

4.5.3 Findings of Mobility as a Service study

The current state of development in the MaaS value system shows alignment with the wireless value system state before their system state transitions three decades ago. The current system states of the transportation value system and their potential transformation is depicted in Figure 21 on the next page. The arrows indicate the two potential system state transitions.

[97] OP Ryhmä. https://op-kausiauto.fi/. Accessed November 30, 2017.

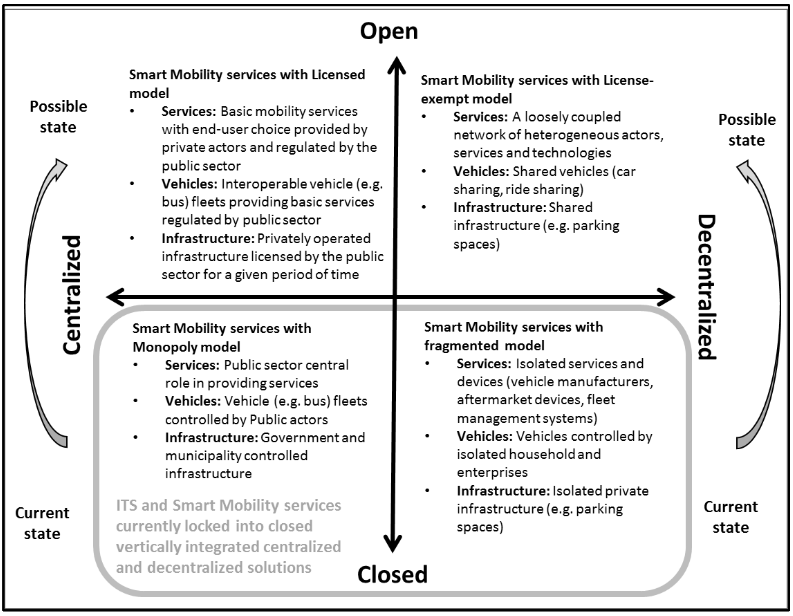

Figure 21. Transition from closed to open value system models in transportation (Adapted from Publications V and VI) Copyright 2016 IEEE, Copyright 2017 SAGE Publishing, Reprinted with permission.

It is tempting to build the future path of MaaS on the empirical developments. However, developments of complex systems are inherently unpredictable. Therefore, only the current value system states can be examined, while the future states must be considered as possible scenarios only. Table 10 follows the format used in section 4.3.

Table 10. Scenarios for Value systems of Transportation

VALUE SYSTEM SCENARIOS/ CHARACTERISTICS	System Type 1: Fixed	System Type 2: Limit cycle	System Type 3: Strange	System Type 4: No Attractor
Mobility model	Local and long-distance public transportation	Expected Licensed MaaS	Expected License exempted MaaS	Applications for car sharing, Uber, Taxify, Valopilkku
Status	Existing value system in Finland	Scenario, under definition	Scenario, under definition, emerging	Existing value system in Finland
Availability of scarce resource	Licenses limit businesses directly, not through critical resources	Road capacity reserved for public transportation. Access to consumers' data debated	Road capacity and access to consumers' data debated	Road capacity, Access to consumers' data
Regulative requirements	Mandatory set	Under definition	Under definition	Unclear
Scope	National	National (also international)	Regional, national, also global	Various

Interoperability	Value system internal as defined by authority	To be required within the scope	Voluntary interoperability expected	Multiple closed systems
Technology creation	Proprietary	Possibly Coordinated	Not visible yet	Multiple proprietary
Competition between actors	Monopoly authorities	Competition between licensed actors expected	Not visible yet	High, uncoordinated
Collaboration approach	Shared routes	Not defined yet	Not defined yet	No collaboration
Technology creation and diffusion	Proprietary, Mandated	Not defined yet	Not defined yet	Proprietary technologies and platforms
Typical scope	National, Local	National	At least national expected	Variable
Performance	As specified	No available yet	Not defined yet	Good
Costs	High, Subsidized	Not defined yet	Not defined yet	Very competitive
Network effects	Low	Medium	Potentially high	Fragmented

The transitions are still in their early stage, and therefore, several potential disorder situations can be observed, such as the entry, withdrawal, and possible re-entry of the Uber ride-sharing service in Finland. In case of loose regulation of key resources and cluster interfaces, network effects can drive the value system from a regulative monopoly to dominant design (Anderson & Tushman 1990), if the bandwagon effect (Cusumano, Mylonadis & Rosenbloom 1992) and the full power of the multi-sided platform is used (Gawer & Cusumano 2014).

As the system states with open interfaces are only emerging, there is no evidence on the possible further convergence between the states. It is expected, however, that the regulative reform will define the licensed and license-exempted models in a somewhat exclusive way, which will delay and potentially disable the full convergence. Furthermore, some transportation services might suffer from enforced openness, for instance, bundling emergency and commercial services into one service bundle is not recommended. Such bundles have been difficult to manage in mobile communication and internet value systems. Clearly, transparency is needed also for service obligations like legal intercept. The lack of transparency has caused delays in legislative renewal in Finland.

The key role of personal data of consumers in open value systems will need further regulative decisions beyond the current General Data Protection Regulation (GDPR) in the European Union. The current regulation is quite prohibitive and requires sophisticated processes in companies, especially in the case of value systems with many participants. On the other hand, such a rigid regulation builds trust among the consumers, which is a mandatory pre-condition in this type of value system. As a metaphor, regulations related to "MyData[98]" keep the consumers in the driver's seat even in the case of self-driving cars (Poikola, Kuikkaniemi & Honko 2015).

[98] MyData is a voluntary initiative to drive the proper use of personal data. https://mydata.org/. Accessed December 1, 2017.

Road capacity is another critical resource in the transport sector, while availability of clean CO_2-free energy is becoming important also. The use of ICT in optimizing the mobility of people and goods will naturally reduce the needs for road capacity and energy.

4.6 Resources, structures, and dynamics

The common line of thought in qualitative studies consists of three specific perspectives. Boundaries including the resources they provide set the limits where structures based on the technical and operational interfaces influence the dynamic behaviors of competition and collaboration.

Four different regulative approaches were observed: closed monopoly model, licensed model, license-excepted model, and fully unregulated model, which in its full extreme does not exist in modern society. The license-exempted model observed in Wi-Fi-based internet access results as a combination of unlicensed radio spectrum regulation with license-exempted devices. Terminology between fully unlicensed and license-exempted is vague and needs specific attention[99]. System states of the examined complex value systems align often with conceptual attractors, but in areas with poor alignment, like in the hybrid approach of PoC, value systems face severe challenges. System modelling utilizing the ICT clusters and conceptual attractors of the complex adaptive system has similarities to models such as "Ecosystem-as-a-Structure" (Adner 2017) and Cynefin framework (Kurtz & Snowden 2003).

Clusters of actors (Fransman 2010) have emerged quite differently in these value systems. Clusters and lower level structures are mature in mobile communications and internet value systems, while in transportation the development is far behind. Synchronization of complex systems (Strogatz 2001) drives the alignment of the structures when the ICT drive value systems further toward convergence.

The examined complex value systems utilize resources, build interoperability and related structures, and compete and collaborate in different ways. As a summary, Table 11 compares the main findings of the qualitative studies related to these key factors.

Table 11. Summary of Complex Value System states

VALUE SYSTEM STATES/ KEY CHARACTERISTICS	Mobile Communication	PoC	Internet Access	Transportation
Characteristic attractor of the System type and state	Initially Fixed, transition to Limit cycle	Hybrid	Evolution to Strange	Currently Fixed and no attractor states. Evolution to system states with open interfaces expected

[99] Example: Status of Wi-Fi regulation globally in 2007. https://www.itu.int/osg/spu/stn/spectrum/workshop_proceedings/Background_Papers_Final/ITU-Horvitz-FINAL.pdf. Accessed November 8, 2017.

Clustering focus	Network, Devices, Personal Data (Identity)	Network, Content (Application)	Network	Network
Maturity	Mature	Failing	Mature	Evolving
Critical Resources	Licensed radio spectrum	Access of data bit piped, derived from scarcity of licensed radio spectrum	Unlicensed spectrum limited by growing congestion due to growing traffic	Licensed and unlicensed rail road and road capacity limited by congestion due to growing traffic
Competition and Collaboration	Limited competition, Collaboration allowed	Limited competition, Collaboration allowed	Unlimited competition, Collaboration allowed	Limited competition, Collaboration limited
Interoperability	Mandated openness, with regional variations	No firm requirements, only voluntary stakeholder actions drive some openness	Set of open protocols, voluntary deployment by the stakeholders	Strong internal control of interoperability in licensed businesses, no external interoperability requirements in unlicensed services, mainly closed interfaces

Summarized from Publications I, II, V, and VI

As a general observation on all value systems studied, sustainable energy production is a growing concern and may significantly influence the value systems in the future. As an analogy, the conflicts that full fragmentation caused in early wireless access systems in case of a virtually unlimited unlicensed radio spectrum regime were evidently tackled by voluntary collaboration of the value system actors. Similar collaboration could be a promising mental model to solve other similar capacity limitations, such as scarcity of energy.

4.7 Exploring complex value systems transitions

Characterization of complex value systems categorize them into four different groups as discussed above. Sometimes, however, the system states align only partially and develop different states for different parts of the value system, which creates tensions between actors in different clusters and may hamper the performance of the value system services. Cluster dynamics based on subjective preferences of some actors may be perceived as dominant characteristics for the whole value system, or the system state in the cluster that creates the largest proportion of the value may be considered to characterize the other clusters also. Furthermore, when some clusters are in the middle of a transition between different system states it is difficult to define any overall state for the complex value system.

The concept of four distinctively different system states encourages us to explore the concept further, to take a step forward, and to discusses the possible transitions between the four states. The four system states yield $N \times (N-1) = 4 \times 3 = 12$ state transitions and 4 other cases where the state transition fails and the system state prevails. Such a situation is potentially still a transition in the business. For instance, when a fixed monopoly system replaces another fixed monopoly, there is a major, easy to observe change in business.

However, system-level behavior prevails, and from the end users' perspective, the change may be meaningless[100]. Similarly, in a cluster without attractor, with random changes due to randomly behaving actors, the system state is random without any emerging attractor. Therefore, it is important to see the actors and the system they jointly form, separately. Table 12 shows the possible transitions between the system states, including those where the dynamics stay the same.

Table 12. Analyzed complex value system transitions

New system states

Old system states — Real World examples discussed in Publications [and other examples in parenthesis]

	New System state is Fixed	New System state is Limit cycle	New System state is Strange	New System State without attractor
Old System state is Fixed Analysis in Publications I and II and V/VI	**IDEN network replaced by CDMA 1x as a consequence of Sprint overtaking NEXTEL**	**1G cellular systems replaced by 2G GSM system in Europe;** ***Possible Licensed MaaS in Finland***	**Arpanet transition to University domain Internet**	Regulation model change from monopoly to laizzes faire (e.g. Broadcast radio liberalization in Finland)
Old System state is Limit cycle Publication II	Full consolidation of actors (e.g. 2G to 3G transition in China using TD SCMA)	**2G system evolution (GSM) to 3G (UMTS)**	Regulation change from licensed to license-exmpted (e.g. Data roaming enabling OTT Internet value system in EU)	Regulation model change from licensed to laissez faire (no good example)
Old System state is Strange Publications V/VI, Publication II	***Possible Global platform leader gaining "Winner take all" in MaaS***	Multiple platforms build federated interoperability (e.g. Facebook identity used in social networks)	**Open Internet and Web and wireless access collaboration**	Loss of common interest (e.g. Forking in open source sofware)
Old System state without attractor Analysis in Publication II and V/VI	External intervention (no good example)	External intervention (no good example)	**WLAN networking based on IEEE 802.11;** ***Possible License-excepted MaaS in Finland***	State transition from a random state to another random state is a meaningless case

Only two clear transitions shown in Table 12 are discussed in depth in this section, the transition from 1G to 2G in mobile communication and transition from fragmentation to voluntary collaboration in wireless access of the internet value system using WLAN. Furthermore, the failed transition in case of PoC is discussed, providing insights to the iDEN/CDMA technology upgrade without any state change. Possible scenarios of system state transitions in MaaS are briefly addressed, while Publications I, II, V, and VI explore these also in more detail as well as the transitions of 2G to 3G, the transition of early internet from a closed research initiative to a collaboration between universities, and finally the developments related to the collaboration of internet, internet access, and web related standardization. In summary, this research has explored seven of the

[100] If one dictator overthrows the previous one, it may feel like a change, but from the perspective of system dynamics, there is no change.

possible sixteen value system transitions (white boxes), while the other transitions (grey boxes) are shown merely as illustrations[101]. However, the illustrative cases provide useful perspective for the model evaluation phase in section 5.

The observed value system transitions align with the ideas of architectural innovation, where the reconfiguration of an established system re-links existing components together in a new way (Henderson & Clark 1990). Strategic signals from the market may be confusing and contradictory during the transition. Therefore, the value system transitions are challenging for the established firms since speed and flexibility without a solid strategy lead nowhere (Porter 2001). For instance, the technology transition from analog to digital transmission and voice coding in mobile communication was only a modular innovation, but when the new architectural elements, such as new network interfaces, roaming, and SIM cards, were introduced, a period of architectural innovations made the system state change. The opportunities in such a transition were exploited differently in different regions and countries. Similarly, the observation that for some industries the Internet is only a tool for better productivity (Porter 2001) is valid only for a minority, when the digitalization of value creation mechanisms enables new architectural and systemic transitions to challenge the traditional thinking in the society.

4.7.1 The qualitative model

When considering the qualitative analyses of clustering, boundaries, system structures, and the resulting dynamic behaviors, a conceptual model becomes visible. The model consists of four phases and the modelling flow. In more detail, the modelling includes a phase to study and define the roles for the four ICT clusters and to examine the status of six critical interfaces (Fransman 2010). The detailed module level analysis in each cluster reveals technical and operative structure, including information related to the control of the resources, level of openness of interfaces facilitating interoperability, and rules and practices of competition and collaboration. These factors drive the module and cluster level structures and dynamics and can finally reveal the system state for each subsystem. The overall (system of systems) dynamics of the complex value system depends on the possible system state alignments on the level of clusters, actors, and actor groups. The final step explores the stability of the complex value system state,

[101] For instance, the transition related to the privatization of the broadcasting services in Finland is an example where the state-controlled monopoly broadcasting company Yleisradio lost its position as a vertical monopoly system to a large group of strongly competing content providers. The transition related to the transition in China, where China Mobile, the state-owned leading mobile operator was licensed as a monopoly to operate the intermediate 3G/4G TD-SCDMA technology-based mobile network. The transition related to data roaming in the European Union liberalized the use of the mobile communication platform to Over The Top data services, primarily following the internet paradigm, which can be considered in this case to drive the end-user experience of the mobile network beyond the initial 2G limit cycle approach. The transition where platforms federate is visible, for instance, when Facebook identities are used to access other smaller platforms. Finally, as it relates to forking in an open-source environment, this can be observed in multiple deviations from the original Linux software base and further to multiple partially interoperable Android mobile devices, with related applications stores, such as Jolla, a Finnish device and operating system provider.

identifies the long-term attractor or attractors in the complex value system, and considers the likelihood of system state transitions.

In summary, the model depicted in Figure 22 shows the modelling as a flow (indicated by the curved arrow). The figure shows also the structural and dynamic elements of the model. The ideal model includes the following structural elements:

- Four clusters of ICT-driven value systems (Content, Network, Devices, Personal Data)
- Four interaction types defining competition and collaboration models (Closed Centralized, Open Centralized, Open Decentralized, Closed decentralized)
- Four different boundary conditions types (Mandated, Licensed, License-excepted, Laissez-faire)

The ideal model also yields the following possible dynamic options.

- Four system types/states (characterized by Fixed, Limit cycle, Strange, Random/no attractor)
- Sixteen transitions between the system states, with potential misalignment of the overall system of systems (state of disorder)

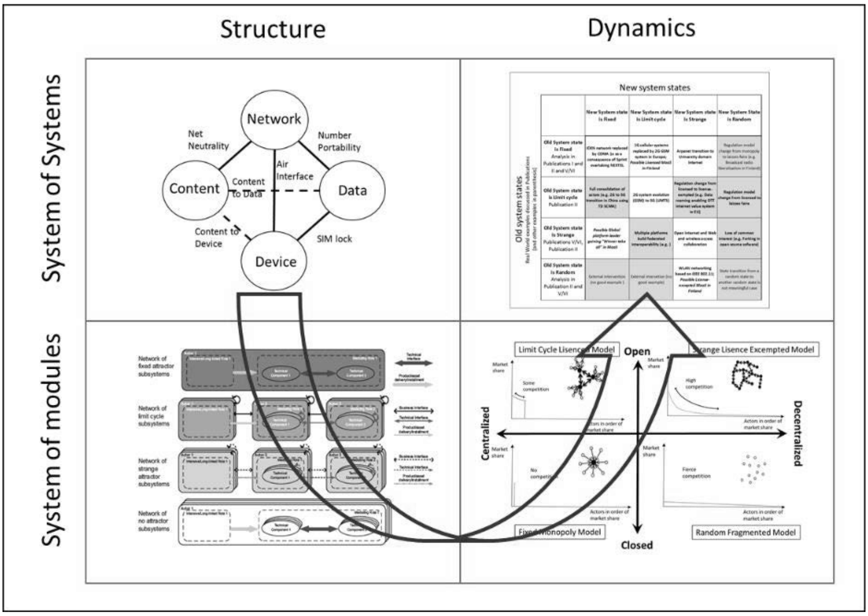

Figure 22. The model

The flow of the analysis begins at the conceptual level to examine the characteristics of the system of system, progresses with the details, and returns to the conceptual level as indicated by the arrow in Figure 22. Such a V-shape path is often used in various system design methodologies.

As a general observation, if the sixteen transitions between the system states in each of the four clusters take place independently, even more scenarios need to be considered. A set of sixty-four different shades of grey are needed in theory to analyze ICT-driven value systems on the cluster level only. Furthermore, succeeding in business planning by accident is unlikely, especially in case of architectural innovations aiming to influence system structures and dynamics.

4.8 Modelling conclusions

Qualitative studies address the key characteristics of the value systems, such as boundaries and structural elements, and build a model to examine developments and behaviors in complex value systems utilizing ICT. These studies form a conceptual process for model development. Beyond the modelling, several business-relevant issues are observed and discussed. Three propositions based on the earlier theories were developed in section 2.6 to provide the challenge for the modelling. The following section discusses the propositions in the light of the qualitative studies. For better visualization, a subjective scoring is used to summarize the discussion points at the end of the section using a scale of [---, +++].

4.8.1 Assessing qualitative propositions

The studied wireless access systems show quite different characteristics. The initial mobile communication value system of the 1G era is an almost fully closed and centralized system, which through regulative decisions and new technologies experiences a transition to a new system state with licensed openness and related semi-centralized and well-coordinated decision making of the 2G mobile communication. The boundaries, regulation and standardization, as well as technical and operational structures that facilitate competition and collaboration, are in line with characteristics of the system types defined in section 2.6: in 1G with fixed system type 1 and in 2G with limit cycle system type 2. As an observation, periodic, generation-oriented value creation cycles from 2G to 5G are characteristic to limit attractor-oriented systems. However, the 1G and 2G value systems show some deviations from the theoretical ideal model. As an example, the content cluster in 2G is embedded in the network cluster without the desired interface to separate the clusters. Furthermore, the device distribution is less centrally coordinated both in 1G and 2G mobile value systems than idealistically expected. The deviations are often identified as pain points in the business. Therefore, in the case of mobile communication, the model using the conceptual fixed and limit cycle attractors characterizes the real-world business system states quite well. (P2 ~ [++])

As it relates to wireless access to the Internet, the value system was initially fragmented without any attractor. Over time, the value system developed a voluntary, loosely coordinated collaboration, with aligned technical and operative structures and behaviors typical to strange attractor systems. The developed system models characterize the wireless access of internet value system states with a low number of deviations. (P2 ~ [++])

Furthermore, the mobile communication and internet value systems show clearly two different starting points and transition paths to two different end states, demonstrating the existence of a total of four different systems states. (P2 ~ [+++])

The influence of the boundaries, especially the regulation for wireless access, is strong. For the mobile communication value system, it even defines part of the structures explicitly, like enforcing the openness of the interfaces as part of the system transition from 1G to 2G, and in the GSM system, regulations enforce the four options to lock and unlock the SIM card with the mobile device. For wireless access to internet, the voluntary collaboration requires the combined influence of an unlicensed radio spectrum, real-life congestion, and license-exempted certification for device sales, which jointly create the necessary but moderate force to induce a strange attractor in the value system. The influence of boundaries is strong for all four system states and their structures and extends to the way the innovations are created and diffused in the market through the mechanisms of different types of standardization. (P1 ~ [+++])

Value system development for the Push to talk over Cellular business failed. This, however, is no surprise due to the confusing combination of end user segments, set of technologies, and mixture of actors and actor groups. Furthermore, ambiguous regulative guidance (obligation to provide interoperable service) delayed the service deployment beyond the point of failure. Instead of defining a well aligned value system, the ambiguous set of factors created systemic misalignment. The failure in the value system relates to the mixture of different levels of complexity in different parts of the value system, including expectations of the different value system actors. The failure of the value system transitions is, however, a success for the modelling, as the findings support the applicability of the model in examining ICT-driven value system issues. More detailed analysis on each specific network deployment case of the PoC service is likely to reveal further case-specific factors which have not been studied in this research. (P1 ~ [++], P2 ~ [++])

As it relates to proposition P3, only two clear empirical system state transitions were studied in this section, the transition from 1G to 2G (characterized by transition from fixed to limit cycle attractor) and the transition from full fragmentation to voluntary collaboration in wireless access to internet (characterized by transition from no attractor state to strange attractor). The transitions required significant changes to all technical structures and operative structures and behaviors in both value systems. The linkage between regulation and standardization influenced the evolution of the value systems both during the technology development and deployment phases. (P3 ~ [+++])

The PoC case provides an interesting message that the fixed attractor-oriented iDEN value system maintained its structures and value creation model even when the technology base was updated from analog to digital, providing support to the model through negation. Similarly, the failing transition with ambiguous hybrid structures can be considered as an indirect support to P3. (P3 ~ [++])

As it relates to transportation, similar system states become visible. Closed and fragmented transportation value systems show evidence of system states only with fixed and no attractor. In case of public transportation, strong regulation drives monopolistic value system behavior. Needs for enhanced services require a new balance of openness and centralization, and consequently, the emergence of new system states is foreseen, if the regulative decisions related to data portability and liberalization of public transportation, for instance, make progress. Differently from mobile communication and internet value systems, the immature roles of ICT clusters fail to facilitate collaboration between actors and actor groups in transportation. Existing regulation dominates the dynamics, and only two system states are observed, which provides limited evidence for the characterization. The situation is expected to change when the transportation value system adopts ICT based concepts like MaaS and when the regulative guidance and needs for better operative efficiency drive horizontalization and the emergence of actor clusters, more liberal rules for innovation, and enhanced use of critical resources such as the personal data of the consumers. However, evidence of such transitions is so far limited. (P1 ~ [++]), P2 ~ [+]), (P3 ~ [+-])

In summary, the propositions gain support through the results of qualitative studies, especially in case of mobile communication and internet value systems. Similar developments are expected to emerge also in case of the transportation and MaaS value systems, but today, the process is still in its early stage. The PoC study supports the propositions, partially via negation. A summary of these conclusions is visualized in Table 13.

Table 13. Propositions in the light of qualitative studies

PROPOSITIONS/ CASE STUDIES	P1	P2	P3
Wireless access	+++	+++	+++
Push over Cellular	++	++	+ +
Mobility as a Service	++	+	+-

(see definition of the Propositions in section 2.6 for details)

4.8.2 Toward evaluation of the model

Qualitative studies provide a reasonable indication that the modelling and the model based on system states characterized by complex attractors is a relevant approach for examining developments in ICT-driven value systems. To gain a deeper insight and specifically to answer the main research question R2, further analyses are needed. The model evaluation as a deductive part of the research focuses on two key boundaries of the ICT-driven value systems, regulations and standardization, and evaluates the model in these two specific cases.

The qualitative model was built using theories and empirical data. The evaluation of the model completes the iterative process cycle by utilizing the model to gain insights related to relevant business issues as well as for theories as shown in Figure 5 in section 2.5 (Manson 2007).

The evaluation criteria consist of three types of considerations:

C1: Model calibration,
C2: Model functions,
C3: Independence of the modelling and the evaluation.

As it relates to the model calibration, the model consists of structural and dynamical elements, which are derived from the openness of technical and operational structures and the level of coordination in decision-making used in the value systems. Calibration of the openness refers to the openness of technical interfaces setting the upper limits, which operational decisions can limit, like in the case of mobile, where operators sometimes limit the use of the full openness of the technical standards in their walled gardens (e.g., bundling of mobile phone and subscription). However, openness of the technical interfaces sets the baseline, and therefore, it is a useful reference point in model calibration. Openness of the standardized technical interfaces is a derivative of the participation rules of the related standardization organizations and extends to rules related to consensus building and voting, document availability, ownership of standards and related technologies. Openness of other technical interfaces without an open standardization process is typically defined by the owner of the interface specification, and this approach may have many variations, which are beyond the scope of this research.

Calibration of the centralization of decision making can be done qualitatively and partially also quantitatively. It is possible to explore the level of coordination needed in standardization and utilize standardization as a proxy to the decision making in the value systems (Hawkins & Ballon 2007). Naturally, this proxy is useful only in those cases where an open standardization approach is used. On the other hand, closed technologies are results of hierarchical decision-making by default, and coordination of such technologies is based on commercial contracts where decision-making is typically centralized by default.

Similarly, the boundaries are important factors in the model. The ICT-driven value systems are exogenously controlled by regulation. Therefore, calibrating the dynamic behaviors of the model through a regulatory perspective is relevant. Availability of the critical resource is directly influencing the value systems, and therefore, calibrating the model by examining this influence is straightforward. However, separating the impact of one factor from many other factors is challenging, and thus, indirect calibration through system simulation is used as a proxy.

Three criteria are used to consider model calibration.

EC11: Level of openness of the standardization
EC12: Level of centralized coordination in decision making in standardization
EC13: Alignment of simulated and empirical market dynamics

As it relates to model functions, the evaluation must consider whether the model provides results that make sense and whether those results are consistent. These are naturally demanding requirements, especially in the case of complex system modelling, where the model is building an iterative bridge between the real world and theories. Furthermore, any closed-form proof is unlikely due to the nature of complexity. Therefore, rather simple but practical questions become relevant. The model is useful in examining the complex value systems if, for instance, the following criteria show positive results at least on the qualitative level.

EC21: Visibility of the complex value system states in the actions of the stakeholders
EC22: Measurability of the complex value system states transitions
EC23: Measurability of the internal alignments in complex value systems
EC24: Consistency of the quantitative studies

Finally, independence of the model and its evaluation requires one criterium of its own right.

EC31: Independence of modelling and evaluation

When considering Tables 5 and 11, it becomes obvious that the value system modelling related to transportation has a limited focus in Finland, and the ICT-driven MaaS is taking only its early steps with limited quantitative data available. Therefore, for the detailed evaluation of a complex value system model, it is a natural choice to focus on mature and global mobile communication and internet value systems, and therefore, the detailed evaluation criteria developed in this section are studied in relation to those systems only. Requirements to meet the evaluation criteria are also considered as part of the analyses.

5 Quantitative and qualitative evaluation

The model developed in the section 4 is broad and holistic. This section explores specific evaluation criteria defined in the previous section to gain knowledge on applicability of the model presented in section 4.7.1. The evaluation criteria are applied specifically to two relevant boundaries of the ICT-driven value systems, regulation and standardization.

Section 5.1 discusses the used methods and data and briefly introduces Publications III and IV. Section 5.2 examines the complex value system structures and dynamics during the intangible phase of the business, in standardization, where the technical and part of the business structures are developed. Section 5.2 is divided into two sets of studies. The first set, including sections 5.2.1 – 5.2.3, focuses on the structures in standardization collaboration. The second set, consisting of sections 5.2.4 and 5.2.5, examines time-variant developments. Social network analysis is used as a tool to analyze the collaboration in standardization. Section 5.3 examines the dynamics of the mobile communication value system further by looking at the possible scenarios and market dynamics related to the future radio resources management, especially to the role of spectrum regulation models of the wireless access to the Internet. Dynamic simulations are used to model the scenarios and to provide quantitative estimates. Section 5.3 is divided into two parts, where the staring points for each part are the initial licensed and license-exempted wireless access market situations. Section 5.4 summarizes the model evaluation results.

5.1 Research methods, data, and role of the publications

Section 5 complements the qualitative modelling by focusing on dynamic system simulations to examine the behaviors of the model under different rules set by the system boundaries to verify that all possible real systems follow one of the modelled behaviors. Furthermore, social network analysis is used to verify that the observed composite behaviors and operational structures in value systems and specifically in related standardization are aligned (Bobrow 2012). The qualitative modelling and case studies in section 4 provide insights as well as a framework to process the data whereas section 5 complements the modelling by numerical data and partially quantitative results through simulations and social network analysis (Yin 2006). The combination of qualitative and quantitative research methods with numerical, written, and mental data is able to give multifaceted perspectives on the research of complex value systems (Forrester 1980), such as in mobile communication (Leiponen 2008; Di Minin & Bianchi 2011).

The first evaluation study focuses on the collaboration in five critical standardization organizations (SSO) of mobile communications and internet value systems. The benefit of this specific angle of view is to gain both quantitative and qualitative information on the behaviors of the actors in the complex value systems. Complex value system developments are often difficult to study quantitatively due to the lack of suitable data sets (Baron & Spulber 2018), and therefore, such studies are rather rare. Large standardization data over a long period provides a unique opportunity to examine the life of these systems in detail. Strong linkage of tangible and intangible parts of the ICT-driven value systems makes these observations relevant in general beyond standardization covering all clusters. The research focus period (years 2003–2008) covers the critical time when the evolution of the mobile communications and internet value systems started to converge towards the communication platform of the ICT ecosystems of today. The developments in the value systems have influenced the way of working in the related standardization groups.

The numerical data are derived from the databases of relevant standardization forums, such as OMA, 3GPP (hosted by ETSI), IETF, and IEEE and W3C (Sultan & Mulligan 2013). The analyses of the standardization documents and specifically the header information of those documents are used to discover the network structures and characteristics of the collaboration in those forums. The document header information includes the contributors' names and the date when the document was presented in a standardization meeting. This information is used to build a collaboration adjacency matrix for Social Network Analysis (SNA). Contributions of coordinators, chairpersons, editors, ad hoc groups, etc. are ignored since they are supposed to provide contributions on behalf of the whole SSO membership, and in the SNA, it is impossible to associate these contributions with any individual members of the SSO.

The SNA is using methods and concepts of complex network theory (Newman 2003; Boccaletti et al. 2006), which are discussed in further details in Appendix I of Publication III. Quantitative SNA methods provide visualization and insights that are complemented by qualitative observations. All SNAs and statistical calculations have been executed using Microsoft Excel and the open-source software R[102] with SNA-specific "igraph" library.

The second model evaluation examines the impacts of regulation of the critical resource on the market dynamics of wireless access value systems in Finland. A specific system dynamic model complemented by an agent-based model is developed to explore the system behavior under different set of constraints set by the system boundaries. This research is relevant to examine the historical market development of the wireless access, and it becomes critical when considering the future scenarios in the 5G era, when new concepts of Cognitive Radio and Dynamical Spectrum Allocation become accepted for mainstream

[102] The R project for statistical computing. https://www.r-project.org/. Accessed December 7, 2017.

business use. New licensing models will open opportunities for further system state transitions.

As it relates to the Cognitive radio system dynamics, the numerical data consist of statistical and time-series data on the business systems. For instance, the statistical market data include historical growth patterns of the existing radio systems within known boundaries. The reference market data are from Finland, including data about 1G, 2G, and 3G mobile communication systems as well as Wi-Fi local area connectivity. The agent-based simulation model implements two types of agents, representing service providers and end users, which in some scenarios could also operate as service providers (e.g., in case of light or loose spectrum regulations). In simulation, each agent follows its own logic for internal decision making as well as for its relationships with the other agents. All the agent attributes and logic are calculated endogenously and updated for each agent regularly to build a bottom-up dynamic model (Macal & North 2010). Quantitative empirical data are used to calibrate the simulation models. The dynamic system simulations build on the earlier conceptual studies on radio spectrum regulation impacting the system dynamics (Basaure, Casey & Hämmäinen 2012). Advanced ABM simulations are recently applied also to related areas such as influence of ICT standards on other interrelated industry sectors (Heinrich 2014) and as a crossover study to explore the influences of network structures on the adoption of de facto standards (Techatassanasoontorn & Suo 2011).

The formal knowledge related to each SSO, including regulations, governance rules, memberships, internal organizations and processes, gives the frame for the quantitative evaluations as well as provides data to assess some criteria requirements directly. Similarly, technical and commercial knowledge on cognitive radio systems and their practical implementations is used to build the simulation models.

Semi-structured interviews related to mobile communication and internet value systems of section 4 are re-utilized in this section to frame the research. Additionally, another field study, consisting of thirteen semi-structured expert interviews, was conducted to provide contextual insight to complement the quantitative studies on competition and collaboration in the five key SSOs. The research questions focused on gaining insights from each SSO and from the interrelations between the SSOs. The interviews were structured to address the value of standardization in general and to explore the successful and less successful standardization initiatives in those selected SSOs. The interviewed experts represented the regulator, leaders of the SSOs, standardization delegates, and elected chairpersons with a technical, commercial, or legal background. The data initially in the form of audio recordings were analyzed to examine the structures and dynamics in each SSO. Table 14 summarizes the research methods and theories and the research data used in the Publications.

Table 14. Evaluation Studies. Scope, methods, theories, and data

EVALUATION STUDIES/ PUBLICATIONS	Scope	Methods	Theories	Data
Publication III	Collaboration structures and dynamics in standardization	Social Network analyses complemented by semi-structural interviews	Social Network theory, Complexity and systems theories. Standardization theory	Quantitative: Standardization contributions in the SSOs. Qualitative: Interviews of standardization professionals.
Publication IV	Market dynamics of wireless access value systems	Simulations using System Dynamic and Agent Based models	Complexity theory, Dynamical systems theory, Regulation theory	Quantitative: Market data on 1G, 2G, and 3G and Wi-Fi users in Finland. Qualitative: Expert interviews.

The challenge in all business strategies is to understand the intentions of the other stakeholders. The problem becomes even more difficult in the case of business systems including elements of complexity. Methods that focus on the present time only have limited value, as they have little information on the history of the business and about systemic path dependences in it. Visibility to the developments over time can reveal information on the business system dynamics and hence provide causally meaningful perspectives.

5.2 Structures and dynamics of compatibility pursuit

Network effects enabled by compatibility are influencing both mobile communications and internet value systems and beyond (Heinrich 2014). Therefore, standardization as a mechanism to achieve compatibility and interoperability can give further insights for the future. The earlier platform studies typically emphasize the role of the platform leader, a single company (Gawer & Cusumano 2014), while this research explores structures created though more distributed (decentralized) collaboration in standardization. Multiple factors influencing the success of standardization have been analyzed, while more attention is needed to study the diversity of the network of stakeholders (van de Kaa & de Vries 2015). Stakeholders and especially contributors influence the standardization directly and indirectly through the interactions in and between the standardization activities under the governance rules of the relevant standardization organizations (Brunsson, Rasche & Seidl 2012). Rules defining openness of the standardization activity may be related to membership and ownership rules (Baron & Spulber 2018) as well as to open access to the document databases of the SSOs. Furthermore, all stakeholders in standardization beyond the structural actors can influence the outcome, and their role is directly visible in the SNA results through the contributions they have provided.

Collaboration networks in standardization have developed over the years from their quite different initial starting points. For instance, OMA is a voluntary organization, which resulted as a merger of several smaller focused groups that were developing services with service enablers for mobile communication. A large part of OMA standards is applicable to the network cluster, but the intention of OMA is to address any necessary service enabler functionality to make the end-to-end services work. OMA membership is open to organizational members, while databases are available only to the members. 3GPP is a joint project of the formal regional and national de jure telecommunications standardization bodies that are responsible for the network clusters, with extensions to other clusters. The membership rules of the 3GPP are inherited from the liberalized de jure organizations and membership is aligned with them. However, 3GPP provides a fully open access to all the documents, which makes it easy for anybody to monitor the development work.

Similarly, the internet value system relies strongly on the work in IETF and W3C, which both have a governmental organization as a fermentation platform followed by a collaboration network of universities. The current governance for IETF and W3C is open to anybody, whereas W3C aims to limit the membership to organizations rather than individual people. Access to data is fully open. For internet radio access, the role of the IEEE 802.11 group is unique. The governance organization is the IEEE, a voluntary association of individual professional electrical engineers. Membership in IEEE is open to anybody, but affiliation information is needed. Access to IEEE 802.11 data is open, including even the email reflectors. These five mobile communications and internet-oriented SSOs produce commercially highly important standards for mobile devices for the convergence of mobile communications and internet value systems.

For mobile communications, the research period (2003–2008) covers the time from the commercial launch of the first third-generation UMTS Release 4 to the first formal fourth-generation Release 8. The third-generation effort had been ongoing in ETSI/SMG5 for years before Release 4. Therefore, 3GPP inherited most of its processes and practices from this earlier effort. The critical decision to use Wideband CDMA radio technology with the GSM core network and smart-card-based identity (SIM/USIM) as a holistic system concept for third-generation mobile communications was achieved in ETSI in January 1998[103]. 3GPP was formally set up in December 1998. Most of the standardization work for GSM was transferred with the UMTS effort from ETSI to 3GPP. The SIM/USIM work continued in the ETSI Smart Card group (ETSI/SCP). The momentum in 3GPP moved quickly to the new 3G radio technology, the WCDMA (Hillebrand 2013). During the research period, 3GPP decided to launch the work to develop the new System Architecture Evolution (SAE) parallel with the 4G radio technology, originally called Long Term Evolution (LTE). By the end of the research period, the emphasis of the work in 3GPP was in SAE and LTE, while the WCDMA evolution, High Speed Packet Access (HSPA) radio network development was maturing. Quantitative 3GPP data utilized in this research include documents from all 3GPP subgroups but exclude the data on the ETSI groups such as ETSI/SCP.

OMA was established in 2002 to develop service enablers for applications intended to work on top of the network functionalities. The research period covers

[103] SMG meeting 24bis on January 28th, 1998, in Paris. http://www.qtc.jp/3GPP/GSM/SMG_24BI/Report/RP_S_24b.pdf. Accessed January 28, 2018.

the timespan from almost the beginning of OMA to the introduction of competing, network-independent Over The Top (OTT) applications and related business models in 2007 by, e.g., Apple Inc[104]. The proprietary-oriented business models used in OTT applications were disruptive to the collaboration-oriented approach in OMA, but this was to a large extent ignored by the main stakeholders of the mobile communication value system. Additionally, OMA was aiming to serve also the competing 3GPP2 value system (Grøtnes 2008), which falls outside of the scope of this research.

As it relates to the internet-focused standardization organizations, the lifespan of the IETF is substantially longer than that of the other studied SSOs, extending far back to the time before the research period 2003–2008 (Leiner et al. 2009). In 1993, a major change took place in the IETF governance. The Internet Society (ISOC) was established, and it took over the hosting responsibility from the U.S. government. The international nature of ISOC opened IETF for any contributor to participate, globally. The IETF work plan consists of multiple separate protocol developments rather than complete architectural releases. During the research period, the IETF was working, for instance, on important protocols to enable real-time communication over the Internet. The set of protocols for Conference calls included, e.g., the RFC 4353 Framework for Conferencing with Session Initiation Protocol (SIP) as well as RFC 4575 and RFC 4579 for more-detailed use of SIP. In case of IETF, there are data available since 1989 providing a time-series continuum of almost twenty years. These data are comparable to data sets from other SSO for the period between 2003 and 2008.

The Session Initiation Protocol (SIP) development is important for the mobile communication value system because SIP is the core of the set of IETF protocols reused in 3GPP for the Internet Multimedia Subsystem (IMS). The IMS is the first ambitious attempt to make mobile communications and the Internet converge. The IMS work in 3GPP was started as part of Release 5 in 2002, parallel to the development of the Conference call functionalities in the IETF, and it was further enhanced in consecutive 3GPP releases 6 and 7. The IMS feature set has evolved continuously, reflecting the developments in the 3GPP system, including LTE support and regulatory real-time communication features, such as emergency calls. The project has taken substantially longer than initially anticipated. For the IETF, the IMS development in 3GPP has been only one of many projects, and the reuse of any mobile communications technologies in the IETF has been minimal.

World Wide Web (WWW) standardization started formally when the WWW Consortium (W3C) was established in 1994. The setup of the advisory board in 1998 and the technical architecture group in 2001 shows the gradual evolution of the W3C toward a more-structured organization (Berners-Lee et al. 2006). The W3C has a similar work plan to the IETF, without any major architectural steps but with a continuous flow of specifications aligned with the evolving functionalities of web browsers. The initial competition between proprietary web browsers has settled, and the development of web technologies using W3C

[104] Apple Incorporated, a computer and information technology company, headquartered in California, USA.

standards on top of the Open Web platform enables application developers to create rich end-user experiences using the latest versions of the HTML (Hypertext Markup Language) protocol. Other key protocols of the W3C include, for instance, the Hypertext Transport Protocol (HTTP) and Unified Resource Locators (URL). Full independence of the underlying hardware is one of the main design principles in the W3C. The work in the W3C falls into three main tracks: Markup languages, Stylesheets, and Scripts and Document object models. W3C standards are closely related to areas like the Scripts from ECMA and the Identifier and transport protocols from the IETF.

IEEE is an association facilitating a large network of voluntary collaboration in electrical engineering, including scientific research, with standardization being only a part of the overall community activities. Specifically, the IEEE 802.11 standardization was set up to consolidate technology fragmentation in local-area wireless networking on the ISM frequency band at 2.4 GHz (Lemstra, Hayes & Groenewegen 2011). This frequency resource had become available for shared use without any specific license in 1985. The IEEE 802.11 group started to build the system on top of the Ethernet local-area networking knowledge base, which had been developed by the IEEE 802.3 group. The first Wireless Local Area Network (WLAN) access standard was published in 1997. Its third release, IEEE 802.11g, was published in 2003, and the next release, IEEE 802.11n, was technically ready by 2007, but its formal approval took place only in 2009. The Wi-Fi Alliance was later established to promote IEEE 802.11 technologies for commercial use and to provide additional services such as interoperability test certificates.

Publication III provides deeper analysis of the historical evolution of the SSOs and discusses the rules of participation and contribution. There are some challenges in assessing the openness of the standardization due to its multifaceted nature, which is full of interpretations (Baron & Spulber 2018). Table 15 provides a simple qualitative assessment of the openness of the SSOs in this study. All the SSOs are open, but the mobile communication-oriented SSOs emphasize organizational membership, including higher costs which limit individual personal participation.

Table 15. Openness of the SSOs

SSO OPENNESS/ SSO	Membership	Access to data	Dominance	Decision making	Qualitative assessment
OMA	Companies	Open to members	Not specified	50% majority	Somewhat open
3GPP	Companies, in relationship to de jure SSOs	Open to read, members to write	Not specified	71% majority	Open
IETF	Open	Open for all to read, participants to write	Not specified	Rough Consensus	Very open
W3C	Organizational preference	Open for all to read, members+ to write	Not specified	Consensus	Very open
IEEE802.11	IEEE membership, Individual or company	Open to read, members to write	Specified	75% majority	Very open

Adopted and simplified from (Baron & Spulber 2018)

As a reference, there are still some national standardization organizations that limit significantly access to their processes and data. Those forums are often related to topics like cyber security. On the opposite side, numerous proprietary technologies have been developed in a closed environment, and only final documents have been provided to the potential users. Some of these initiatives have been opened later in the process to include external innovation and to promote such technologies in broader use, for instance, the case of Sun Microsystem and Java (Garud, Jain & Kumaraswamy 2002).

5.2.1 Working together and standing alone

The standardization groups examined in Publication III follow the typical "Small World" paradigm with high transitivity (clustering) and low average path length (Watts & Strogatz 1998). In such communities, innovation output is greater than in other types of networks (Schilling 2000; Schilling & Phelps 2007). This observation has limitations since social network analysis ignores the actors that are disconnected. Standardization contributions with only one contributor add no links to the network, and companies contributing alone show up in SNA as disconnected nodes, and their role is excluded in commonly used SNA metrics. Furthermore, written documents form only one medium through which standardization works, and therefore, the quantitatively observed differences between the SSOs must be studied with care.

When contributors systematically contribute alone, their way of working is often considered competitive. Many contributors choose sometimes to contribute alone and sometimes jointly with others, being coopetitive contributors (Majchrzak, Jarvenpaa & Bagherzadeh 2015). There are also contributors who never contribute anything alone, but whose written contributions are all joint documents. These contributors are quite firmly collaborative. Finally, there are also standardization participants that never contribute anything in writing. The role of this last group is small, and it is ignored in this research.

Figure 23 below shows statistical distributions of the contributors. Ranking is based on their collaboration style, i.e. the ratio between standalone and joint contributions. This analysis ignores the number of contributions that each contributor has provided; therefore, the "share of voice" in standardization is differently distributed. The calculated distributions yield the overall collaboration style profile for each SSO. The horizontal axis scales from 0 to 100%.

The collaboration style profiles for 3GPP and OMA look almost identical. The style profiles of IETF and W3C are also somewhat similar, with the W3C showing the highest relative number of contributors collaborating only. The profile of the IEEE 802.11 group is quite different, having the majority (59%) of the companies working as stand-alone contributors.

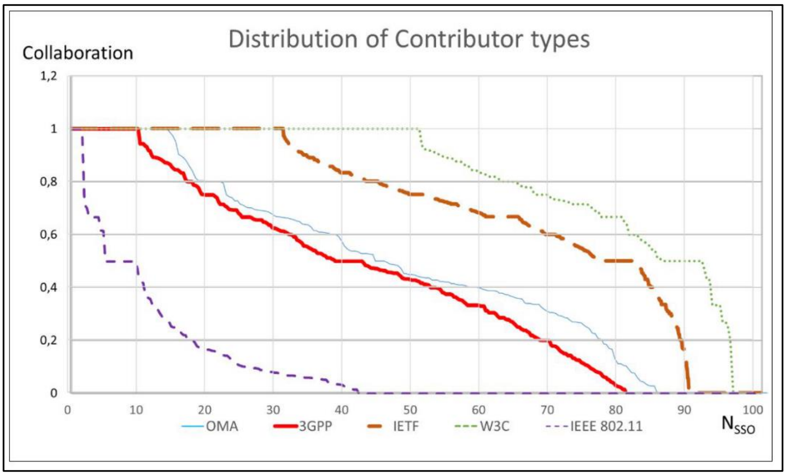

Figure 23. Collaboration style profiles of SSOs

Collaboration style profiles of five different SSOs. Ratio of collaboration-only (Collaboration = 1), competitive-only (Collaboration = 0), and coopetitive (0 < Collaboration < 1) companies is shown separately for each SSO. Data consolidated over the research period 2003–2008. (Publication III) Copyright 2016 IGI Global. Reprinted with permission.

5.2.2 Maximum spanning tree analysis

Maximum spanning tree analysis provides multiple insights on the competition and collaboration in standardization. The maximum spanning tree simplifies the busy standardization collaboration network to the minimum hierarchy showing only the strongest links. The spanning trees of this research give visual indication of contributors' activity as the circle size of a node and the intensity of collaboration as the width of the critical links. Standalone contributors are shown also as disconnected circles. However, their activity is in most cases so low that the circles show up as dots only. The relatively small cumulative size of the disconnected nodes indicates that their role is typically less important than the role of the more active connected contributors. Therefore, the SNA results are considered meaningful also for the SSOs where the share of the disconnected nodes is high.

The independent role of the MNOs is visible in the maximum spanning tree of the 3GPP standardization shown in Figure 24, where the operators form a branch of their own. The other specific subnetworks include the nationally organized networks of Chinese, Japanese, and Korean contributors, which indicates that the later liberalization of mobile communication in those countries has caused national collaboration to continue in the 3GPP environment.

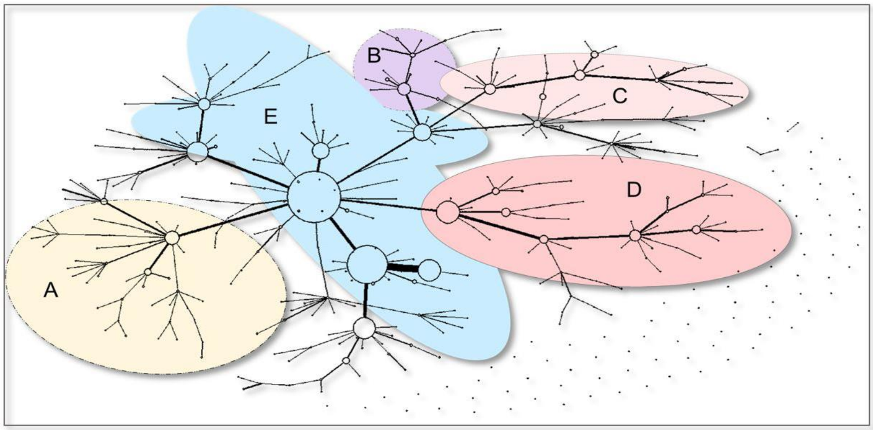

Figure 24. Spanning tree of the 3GPP contributor network
A: Mainly network operators, B: Mainly Korean companies, C: Mainly Japanese companies, D: Mainly Chinese companies, E: Mainly technology and product companies from other countries. Consolidated over the years 2003-2008. (Publication III) Copyright 2016 IGI Global. Reprinted with permission.

The key role of global technology and product companies as the most active and most central contributors is clear. The computed 3GPP spanning tree shows that most of the contributors are also collaborating, i.e. are connected to the main body (giant component) of the network. A relatively low number of not-connected contributors — visible as a cloud of dots — indicates the limited role of standalone contributors outside of the strongly connected network. The cumulative spanning three shows only the average. More detailed analyses show that the overall network topology has been stable during the research period 2003–2008. This is natural, since there have been no major changes in the standardization environment either.

OMA was set up to expand the mobile communication value system to form a more versatile ecosystem of actors with less stringent rules and regulations. However, in Publication III, the collaboration network structures in OMA and 3GPP are similar except that the IT companies form a separate branch of their own. The failure of the PoC as discussed in section 4 is better understood through the social network analysis. Even if OMA aimed to build collaboration between mobile communication and information technology companies, the way of working in OMA maintained the 3GPP dynamics. Similar observations can be made also in the later analyses of this section.

The collaboration structure and dynamics in standardization in the internet value system are different. The maximum spanning tree of the IEEE 802.11 group deviates from the 3GPP tree in many ways. The collaboration network structure of IEEE 802.11 presented in Figure 25 reflects the boundary conditions set by regulation and evolutional history of the IEEE. As discussed in Publication III, these environmental factors have influenced the limited network size and large number of independent, formally disconnected contributors as well as the missing visible logic in the spanning tree branches. As a specific characteristic of the group, there are many disconnected nodes visible in the spanning tree analysis presented in Figure 25. This is in line with the previous analysis of the collaboration styles in the SSOs.

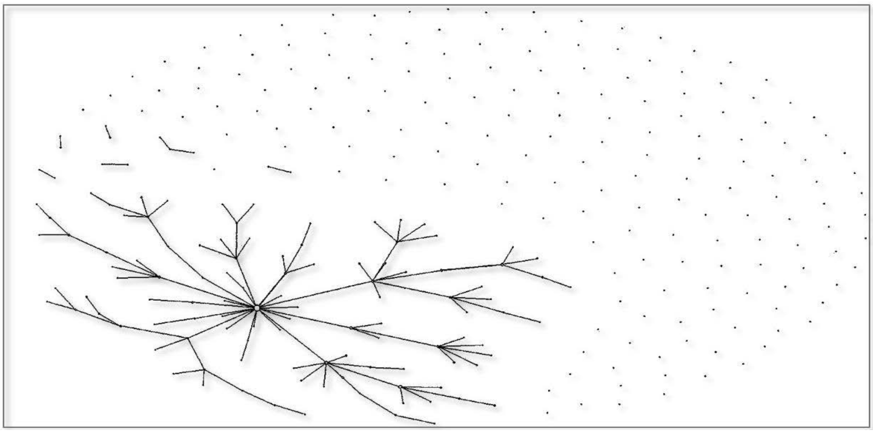

Figure 25. Spanning tree of the IEEE 802.11 contributors
Consolidated over the years 2003–2008. (Publication III) Copyright 2016 IGI Global. Reprinted with permission.

Wireless local area business started as a competition of fragmented sporadic initiatives of different contenders. The regulative decisions on radio spectrum spurred the development forward, but using a different set of rules than in the mobile communication value system. The IEEE 802.11 group has gained a leading position in standardization, reflecting the commercial success of Wi-Fi products, as discussed in Publication III. Rather liberal and modest regulative requirements, including no need to acquire any specific license, have encouraged similar liberal behavior between contributors in standardization. Holistic interoperability is less important due to the related commercial deployment scenarios, which is reflected in the loosely connected structure of standardization collaboration.

Furthermore, the IEEE 802.11 group specifically developed a different process than typically used in formal standardization activities, such as the ETSI-driven HIPERLAN[105]. This more liberal approach helped the IEEE 802.11 group gain leadership over the mobile communication-oriented group (Lemstra & Hayes 2009; Negus & Petrick 2009). Flexibility to allow different technology details in standardization made IEEE 802.11 more competitive also against HomeRF (van den Ende et al. 2012). No mandatory minimum performance requirements and no formal needs to coordinate the development with service providers existed in this setup. This very liberal approach turned out to be too loose. A specific additional organization, the Wi-Fi Alliance (WFA), was established to complement the work of IEEE 802.11. The role of the WFA is, however, outside the scope of this study.

[105] HIPERLAN High Performance Radio Local Area Network, a wireless technology and a set of standards for local area networking, developed by ETSI

The IEEE 802.11 group is working on the air interface layer only. Therefore, comparisons to 3GPP are only partially meaningful. Structural evolution of the overall internet value chain requires a broader perspective, including also the work done in IEFT and potentially W3C.

5.2.3 Eigenvector centrality distribution analysis

Standardization paves the way for communications systems and technologies as well as for business systems, which utilize the standards. Decision-making in standardization is therefore a critical phase of the overall innovation process. In this research, the eigenvector centrality distribution is used to examine the strength of the internal coordination between standardization contributors in the selected SSOs. In the eigenvectors, the ranking of the vector elements represents the nodes, i.e. the standardization contributors. Often node distributions reflect the histograms of the data. The direct use of ranking allows for better comparison of the statistical data and the qualitative observations, for instance, of the interviews. This analysis finds that the collaboration network decision-making structures have a visible alignment into two groups, as shown in Figure 26.

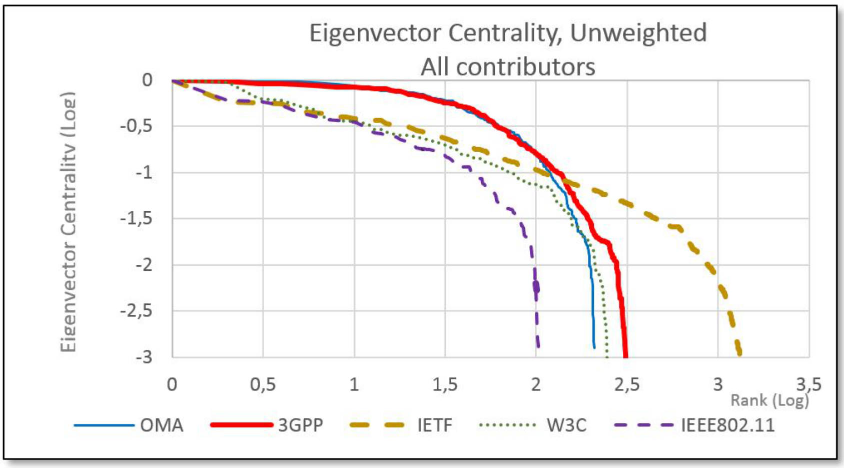

Figure 26. Eigenvector centrality distributions of the mobile communications and internet-related standardization contributor networks

(Publication III) Copyright 2016 IGI Global. Reprinted with permission.

The mobile communication standardizations in 3GPP and OMA show almost identical collaboration structure. Separately, the internet-related SSOs also show alignment with each other, but at the same time, they show a clear non-alignment with the mobile communications group. Eigenvector centrality consolidates the collaboration ties over the entire connected network, including all connected contributors. A flat distribution of eigenvector centrality indicates a broad negotiation process, characteristic to both 3GPP and OMA. The cutoff[106] at

[106] The cutoff point is estimated approximately as the point where the eigenvector component value drops 3dB below the trend or trajectory set by the top 20 contributors. There is no better rationale known to estimate the cutoff in the case of eigenvector centrality ranking. The 3dB

around 38 gives a rough estimate for the number of contributors forming the core for the decision making in those forums.

The internet-oriented SSOs show power law characteristics for a large part of the network. The tail starts curving out after the first 109, 78, and 48 contributors for IETF, W3C, and IEEE 802.11, respectively. The power law distributions indicate a voluntary nature of the collaboration which gradually fades off. It is important to note that the absolute number of contributors in these networks is quite different, and therefore, the cutoff points are not directly comparable. Only the shape of the curve until the cutoff point is meaningful in this discussion.

Earlier complex network studies have found that networks follow typically either power law or exponential distributions (Barabási & Albert 1999; Newman 2003). Earlier research has also found that empirical networks follow the theoretical networks only in a limited way. Empirical networks with physical constrains, such as power grid and railway networks, show exponential distributions, while some other networks such as the hyperlink network of the World Wide Web show power law distributions, and networks of scientific collaboration (citations) show power law distributions with a cutoff (Newman 2003; Hyötyniemi 2006). Similar correlation of social network characteristics of articles and authors has been found in the Wikipedia project (Kane 2009). As it relates especially to IETF and W3C, these results follow the similar scale-free behavior including cutoffs.

The OMA and the 3GPP collaboration distributions show exponential behavior. There are some earlier studies (Riccaboni & Pammolli 2002; Powell et al. 2005) showing a somewhat similar shape for the distributions of research and development collaboration in life sciences. The stronger control and more explicit boundaries, both in mobile communications and in life sciences, will limit the growth of the span of the collaboration network and encourage deeper and broader internal collaboration instead.

The connection between the system states discussed in section 4 and the eigenvector centrality distributions is through the level of coordination in the decision-making. The exponential distribution reflects semi-centralized, broadly coordinated decision-making, while the power law reflects loose voluntary preferential attachment in the consensus building. 3GPP and OMA show an exponential distribution, and the internet-oriented groups, including IEEE 802.11, show a power law distribution, reflecting the behaviors of system states 2 and 3 respectively. The short tails of the OMA and 3GPP distributions reflect the limited number of influential contributors, which is characteristic to a system with limit cycle attractor. The cutoff points are visible also in internet-oriented SSOs, which is rather an exception to the ideal strange attractor-oriented system.

As it relates to OMA, the results indicate a deviation from expected behaviors typical for voluntary collaboration. Since OMA has worked in close co-operation with 3GPP, the strong interworking requirements evidently forced OMA

cutoff point corresponds rather well to the points where only 10% of the value is left for IETF, W3C, and IEEE 802.11 However, for OMA and 3GPP, the cutoff based on 10% signal strength extends to the level of 120 and 130 contributors, respectively.

to develop a similar operating model regardless of the less restrictive regulations. OMA developed evolutionally compatible services with 3GPP limiting the deployment of these functionalities to the mobile communications value system only. These results are in line with the qualitative insights of the maximum spanning tree analysis.

Quantitative analyses in Publication III based on the interviews of standardization align with the observations through the SNA lens. Controlling the access to the radio spectrum sets the limits on competition and rules for collaboration through interoperability standards (Courcobetis & Weber 2003). The characteristics of the collaboration network structures and observed system behaviors of the wireless access value systems come together through the three principles of liberty to utilize resources, a model of competition and collaboration driven by requirements for interoperability.

To assess these observations and especially the differences between the eigenvector ranking scores in different SSOs, we can use, for instance, the Kolmogorov-Smirnov test (KS test) to compare two sets of data to see if they follow the same (null hypothesis) or different distributions. The two-sided KS test is a simple statistical test which can be applied to two unknown distributions (Young 1977). The tests are executed using the open-source software R Studio.

The two-sample KS test provides an estimated distance D between the two samples, which is larger than the critical factor c(α) * $F(N)$ if the null hypothesis is invalid. The factor c(α) is defined as

$$c(\alpha) = \sqrt{-\frac{1}{2}\ln\left(\frac{\alpha}{2}\right)}. \quad (1)$$

For statistical probability, α = 0.05, c(α) = 1.36, and the $F(N)$ is calculated using the formula

$$F(N) = \sqrt{\frac{n+m}{m*m}} \quad (2)$$

where n and m are the numbers of observations in the two sample sets. For n = 40 and m = 40, the critical distance D = 0,304. The KS test results where the distance is smaller than D are considered to be representing the same original distribution.

Table 16 below shows the results of the KS test 1 for the eigenvector scores shown in Figure 27. The indicative test focuses on the top 40 contributors and ignores the long tail on purpose. The null hypothesis is indicated in bold * (null hypothesis valid), while in other cases, the null hypothesis must be abandoned.

Table 16. Results of two-sample KS test 1

SSO/ SSO	OMA	3GPP	IETF	W3C	IEEE802.11
OMA	**0**				
3GPP	**0,125***	**0**			
IETF	0,45	0,425	**0**		
W3E	0,525	0,525	**0,15***	**0**	
IEEE802.11	0,475	0,475	**0,2***	**0,125***	**0**

A pairwise comparison of eigenvector centrality distributions for the top 40 contributors (D value for all test cases is D = 0,304). *(Ali-Vehmas 2018)*

In the case of the top 40 contributors, the distributions fall into two groups, where the first group consists of OMA and 3GPP, and the other group includes IETF, W3C, and IEEE 802.11. Another way to estimate similarities between the eigenvector distributions is to use an estimated cutoff point separately for each SSO and compare the distributions accordingly, as discussed in footnote 101. This approach aligns well with visual estimation of cutoff points based on Figure 26. When the KS test 1 is repeated using these separate cutoff points, somewhat different results are achieved. Table 17 shows the results of KS test 2, where the number of included contributors is SSO specific. The different number of the samples yields different $F(N)$ and critical distance for each test. The D values are shown in table 17 also. N shows the number of the most influential contributors in each SSO included into the test.

Table 17. Results of two-sample KS test 2

SSO/ SS0	OMA	3GPP	IETF	W3C	IEEE802.11
N	37	39	109	78	48
OMA	**0**				
3GPP	**0,177* (0,312)**	**0**			
IETF	0,790 (0,258)	0,789 (0,253)	**0**		
W3C	0,766 (0,271)	0,744 (0,266)	**0,140* (0,201)**	**0**	
IEEE802.11	0,571 (0,297)	0,563 (0,297)	0,391 (0,235)	0,268 (0249)	**0**

A pairwise comparison of eigenvector centrality distributions, excluding less active contributors beyond cutoff point. (D values in parentheses)

When using the assumed cutoff points, the OMA and 3GPP show similar behavior as IETF and W3C, respectively, but separately from OMA and 3GPP. Furthermore, the eigenvector distribution for IEEE 802.11 starts showing deviating results from all the other SSOs.

The KS tests support the visual observation of Figure 26 by showing the close relationship between the eigenvalue rank distributions for OMA and 3GPP, while the other SSOs form another loose group with similar eigenvalue distributions. Separately, these tests show also the rather high sensitivity to the number of contributors included into the testing. Statistical studies on empirical networks are challenging, as found in several other similar studies.

5.2.4 Standardization collaboration development over time

Complex value systems develop over time, and sometimes, they experience changes in their behavior. Structural and behavioral analyses can provide valuable insights, especially when connected to independent qualitative observations. This section builds on the previous static eigenvector analyses and focuses on developments over time in two SSOs, one from each group of mobile communications and internet-oriented SSOs.

The eigenvector centrality distribution of the 3GPP collaboration, presented as an average in the previous analysis, experienced steady development over the years, as shown in this analysis in Figure 27.

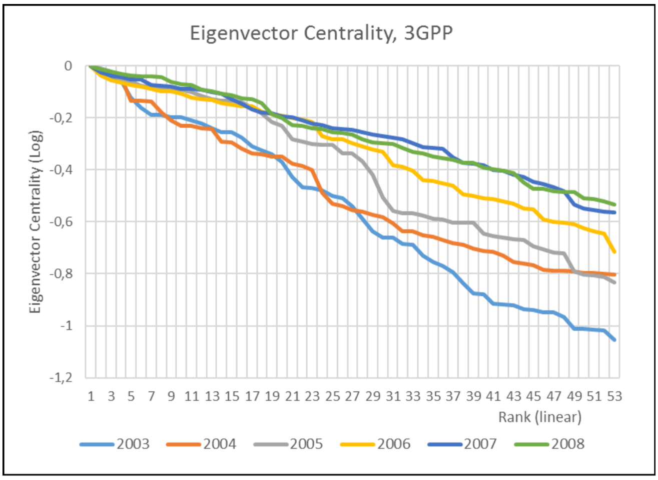

Figure 27. Development of eigenvector centrality in 3GPP (Ali-Vehmas 2018)

Collaboration of the top fifty-three most influential contributors developed toward more and more equal status, which is demonstrated by a more and more flat distribution. The development seems to stop, however, for the last year of the research period. The slope of the distribution at the end of the period is about half of that at the beginning. It is possible to interpret this observation by noting that the depth of collaboration during those years had doubled in 3GPP. The standardization expert interviews indicate two related explanations: Contributors have learned to collaborate broader, and the need for broader collaboration has grown due to broader and more difficult technologies developed in 3GPP.

As a specific example related to the difficulty in assessing the SNA results in the context of qualitative data, the development of the eigenvector centrality has tiny details which complements the discussions during the expert interviews. We can look at a specific weakly visible point in Figure 27: The yearly distribution curves seem to fall into two slightly separate groups, one for the years 2003–2004, and the other group consisting of the years 2006–2008. The curve for the year 2005 falls partially between the groups. For the year 2005, the top thirty contributors show alignment with years 2007 and 2008, while the less-central contributors show alignment with previous years. The expert interviews emphasized the broad challenges in creating the 4G standard, i.e. the LTE/SAE release of 2008. This work required more extensive collaboration than any of the previous generations. The standardization of Release 8 started in 2004. Furthermore, the visible change during 2005 indicates that the change in collaboration took place gradually, led by the most influential contributors in 3GPP. Therefore, it is a tempting idea to use the SNA results as fully statistically significant indications. However, the primary intention of the SNA in this research is to help in making the connection with the real-life business and theories and to facilitate a broad holistic thinking process, and therefore, the quantitative SNA results are used merely to evaluate the usability of the qualitative model and to ascertain that the structure and behavior of the model are aligned (Bobrow 2012). The same metric, the eigenvector centrality distribution over time, when applied to the data from IEEE 802.11, shows rather different qualitative characteristics, as can be seen in Figure 28.

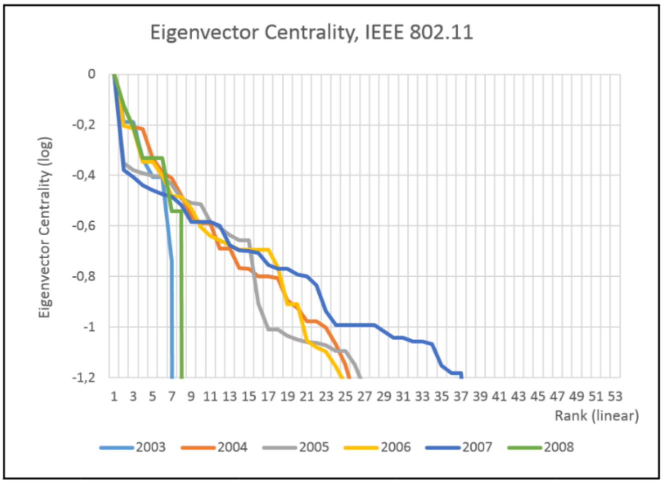

Figure 28. Development of eigenvector centrality in IEEE 802.11
(Ali-Vehmas 2018)

As was already discussed, the overall eigenvector centrality distributions are different in average for 3GPP and IEEE 802.11 over the years 2003–2008. When the distributions are examined separately for each year, further differences become visible. The IEEE 802.11 eigenvector centrality distributions are quite short for two specific years (2003 and 2008), indicating that the collaborative networking was weak and unequally distributed in those years, with only about ten contributors collaborating through written documents. Furthermore, there seems to be no specific trend in collaboration development, and expert interviews raised no concern for needs to develop the collaboration behaviors either. The interviews took place before the SNA analysis results were available.

5.2.5 Collaborating with different peers

The assortativity coefficient of the collaboration networks is another powerful indicator to study collaborative networks. The assortativity coefficient has been observed to fluctuate with changes in the priorities and constraints of the network actors in theory (König, Tessone & Zenou 2010), and in real collaboration networks (Tomasello et al. 2016). The assortativity coefficient shows the correlation of the degree centrality of connected nodes. The assortativity coefficient of a network is positive when highly connected contributors are connected to similar highly connected nodes and less-connected nodes are typically connected to similar less-connected nodes. In the opposite case, when highly connected nodes are mainly connected to less-connected nodes, the network is disassortative; in other words, the assortativity is negative.

The assortativity coefficient is a relative score always in the range of [-1, 1]. Therefore, it can be easily used to characterize collaboration in a single network or between different networks. There is a different amount of data available from each SSO, and the results are shown per data availability. Due to the relative nature of the assortativity coefficient, the results are comparable even if the SSO-specific data are available differently. For the years 2003–2008, the input data sets are comparable. Figure 29 shows the development of assortativity in standardization collaboration over years for each SSO.

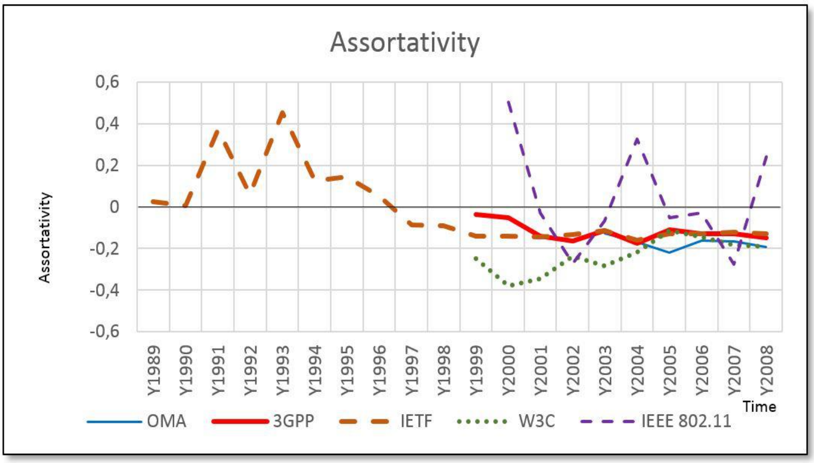

Figure 29. Assortativity development over time of key SSOs (Publication III) Copyright 2016 IGI Global. Reprinted with permission.

As it related to IEFT, there are data available from 1989 onwards. During the years, IETF has developed from a community of professional network experts with positive correlation to a slightly disassortative industrial network with more capabilities similar to simulated networks without capacity constraints (König, Tessone & Zenou 2010). The IETF transition from assortative to disassortative took place at the same time when the governance and scope of the IETF changed from local academic collaboration to global open industry-oriented standardization. The change in the collaboration mode improved the information flow between the core and periphery, which was necessary when many new contributors joined the IEFT. The increased flow of information multiplied by the high number of new contributors may have influenced the observed slowdown of the standardization process in the IETF (Simcoe 2012). In an assortative collaboration network, only few leading contributors make the decisions without sharing the information with the periphery, which naturally facilitates fast progress while possibly jeopardizing the quality of the work, as noted in (Simcoe 2012). Aligning the assortativity coefficient changes with historical events provides new insights which complement well the observations of the earlier studies. Furthermore, this concrete example supports the value of SNA in examining complex value system dynamics.

Slightly negative assortativity coefficients are typical for industrial collaboration (Crespo, Suire & Vicente 2014). After the governance changes in 1993, the IETF has developed towards an industrial organization as far as the assortativity coefficient indicates. Similarly, the mobile communications-oriented SSOs, 3GPP and OMA, have maintained their negative assortativity since the beginning, while the W3C has moved closer to the others from even more negative scores.

The IEEE 802.11 group shows fundamentally different behavior from all the other SSOs. The assortativity coefficient in the case of IEEE 802.11 cycles between positive and negative scores within a period of 3–4 years. There is no governance change taking place in IEEE 802.11 which could explain the assortative cycling. Instead, the cycling of the collaboration style aligns with the standard definition cycles, as can be observed in Figure 30. When a new major standardization undertaking starts in IEEE 802.11, the collaboration between the strongly connected contributors intensifies. Over time, when the standardization process becomes mature, the collaboration network becomes disassortative, like in other SSOs. Observed statistics on different industry alliances show similar fluctuations related to the maturity of the business (Tomasello et al. 2016).

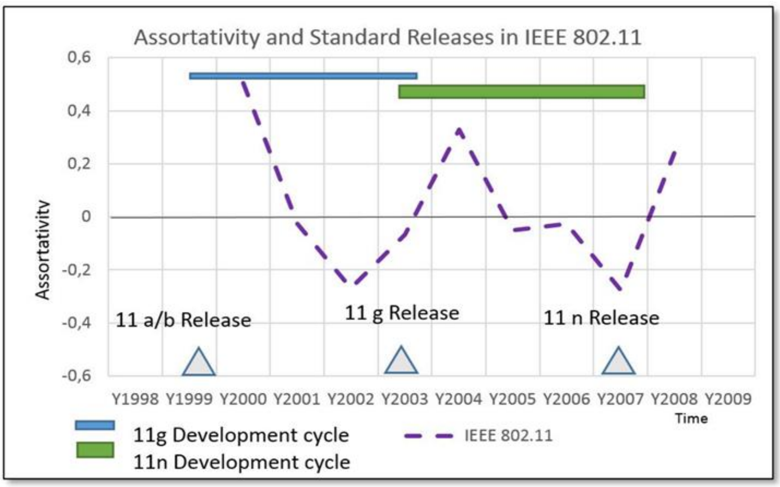

Figure 30. Assortativity of IEEE 802.11 collaboration and key standards releases (Publication III) Copyright 2016 IGI Global. Reprinted with permission.

Earlier research has shown that collaboration networks are resilient, i.e. able to cope with changes in their environment if those networks have at the same time high degree centrality and negative assortativity (Crespo, Suire & Vicente 2014). On the other hand, one of the main goals of standardization is to bring stability and remove market uncertainties (Gaynor & Bradner 2001). This is well in line with the observed resilient behavior of the collaboration observed in all other SSOs except for IEEE 802.11. IEEE 802.11 collaboration cycles between resilient and assortative (core/periphery) behaviors as shown in Figure 31. The arrows indicate the strength of alignment of the system states.

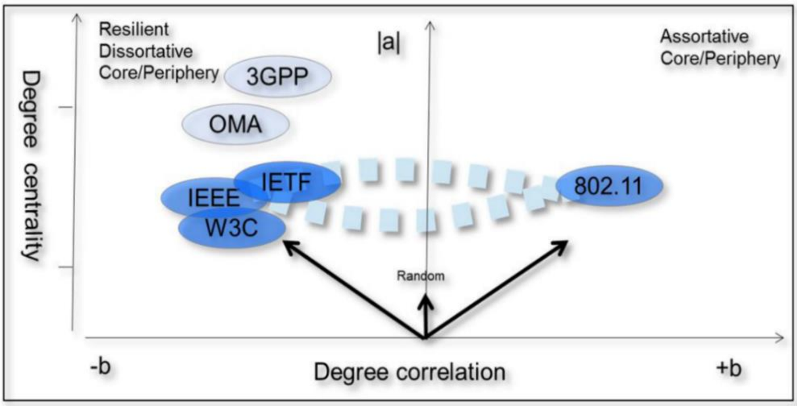

Figure 31. Resilience of the standardization value systems
Adapted from Joan Crespo, Raphael Suire and Jerome Vicente (Crespo, Suire, & Vicente 2014) and Publication III. Copyright 2016 IGI Global. Reprinted with permission.

However, the IEEE 802.11 standards have been adopted broadly in many markets, including several releases of new technologies and features. During periods of resilience, the IEEE 802.11 community experiences the diversity of information flows and adaptive learning that is characteristic to resilient networks. Although it is in the hands of a few contributors, decision-making seems to be efficient even during the assortative periods of behavior. The very short tails of the eigenvector distributions fall partially to the same years, 2003 and 2008, when new standardization projects where started, as can be seen from Figure 30.

5.2.6 SNA conclusions

Collaboration in each SSO has multiple features, which can be used to categorize the SSOs by their specific ways to operate. As a summary, Table 18 on the next page compares the mobile communications and internet-oriented SSOs based on their collaboration styles to assess the centralization of the collaboration and to reference the network structures to the comparable structures of complex systems and networks.

From the standardization perspective, lifestyles in the studied complex value systems fall into three different groups. The first group consists of the mobile communications-oriented SSOs (3GPP and OMA), while the second group consists of the internet-oriented SSOs (IETF, W3C, and IEEE 802.11). However, IEEE 802.11 forms a subgroup of its own, where the relatively high number of standalone contributors and especially the specific behavior of the assortativity coefficient are different from all other SSOs. Collaboration and related decision making in mobile communication SSOs is engaging and involves a nucleus of tens of contributors who lead the work and jointly make the coordinated decisions. The strong coordination, shown, for instance, in the eigenvector distribution makes the decision-making process centralized, which is natural when considering the membership and governance rules and mechanisms of OMA and 3GPP, inherited from de jure standardization.

The voluntary association of the standardization contributors around the strong leader creates less-coordinated decision-making. Communication in the form of standardization documents emphasizes the role of the leading contributor, but the level of coordination is low. The power law -oriented rank distributions indicate development towards a "winner takes all" type of system, which may happen if the role of the leader becomes too strong. Interestingly, the IEEE 802.11 group has set specific governance rules to avoid dominance by any single actor (Baron & Spulber 2018).

The collaboration between the mobile communications-oriented SSOs (3GPP and OMA) and separately between the internet-oriented groups (IETF, W3C, and IEEE 802.11) has been broad and successful, as observed in the expert interviews. The collaboration between the SSOs from different groups has been more ambiguous and less successful. The interviews specifically pointed out the collaboration between IETF and 3GPP related to the Internet Multimedia Subsystem (IMS) for mobile communication to be an example of a one-directional successful case. 3GPP has adopted IETF protocols, while the adoption rate of ideas in the opposite direction is low. There have been multiple similar collaboration projects between the SSOs from different groups, but the successful deployments of the converged services are limited. Therefore, as it relates to collaboration between groups, joint development is more likely to be successful between the groups that share similar SNA results.

Table 18. Key findings of the SNA complemented with qualitative observations

VALUE SYSTEMS/ SNA RESULTS	**Mobile communications OMA, 3GPP**	**Web, Internet IETF, W3C**	**Internet Access IEEE802.11**
Collaboration profile	High	Very high	Low
Transitivity	Very high	High	High
Local activity (weighted degree centrality)	Exponential, Medium tail	Exponential, Long/Medium tail	Exponential, Short tail
Global influence through the structure (unweighted eigenvector centrality)	Exponential, medium tail	Power law, Long/Medium tail	Power law, Short tail
Assortativity	Negative	Negative	Cycling positive and negative

Regulative framework	Licensed (3GPP)	License-Free[107]	License-Exempted
Role of the end customers	High presence	Medium/Low presence	Low presence
Interoperability focus	Very high, Global	High Global	Primarily Local
Scope	System	Network	Access/Component

The research period from 2003 to 2008 is too short to explicitly show a complete state transition in any of the value systems examined in this study. However, the mobile communications and internet standardization systems show two different behaviors. These results align with system state analysis of the related tangible business value systems of section 4. The structures and collaboration dynamics in standardization follow the categorization developed for business value systems. Mobile communications standardization follows the system state model characteristics of the limit cycle system (system state 2). The internet-oriented standardization characteristics follow rather the long-tail strange attractor model (system state 3) with power-law distributions, but with cut-off points (Newman 2003).

The historical roots of the standardization forums qualitatively follow the same logic as discussed in Publication III. However, the monopolistic fixed attractor (system state 1) or the fragmented no attractor system models (system state 4) are irrelevant in open standardization because those system states are closed with little collaboration. All the studied SSOs have open access rules with some different flavors, which is not the case for monopoly and fragmented setups. Voluntary collaboration has reduced fragmentation even if some remaining signs are weakly visible in IEEE 802.11. The ratio of stand-alone contributors is rather high in IEEE 802.11, and the core/periphery type of collaboration for each new standard release temporarily reminds us of the historical fragmentation of wireless local area technologies. Standardizing a component, like Wi-Fi access technology, is different from system level standardization, like in 3GPP for mobile communication. A strong technology focus without strong ex-ante commitments can lead to fast changes in company policies, which can influence standardization, as has been observed earlier, for instance, in the case of Blu-Ray vs. HD-DVD discs (Daidj, Grazia & Hammoudi 2010).

5.3 Explorative system dynamics within recourse boundaries

The model developed in this research is qualitative and explores the characteristics of the complex value system states and evolution scenarios through periods of growth (stable system state) and disruptions (system state transition). Therefore, the evaluation criteria are specific for this purpose. For instance, instead of assessing the sensitivity of the model to the inaccurate calibration, the parameter sensitivity in the model can be used to examine the scenario of complex value system dynamics.

[107] Terminology adjusted and harmonized after the publication of the Journal paper.

Publication IV takes the research forward by examining future market dynamics of the wireless value systems. This study explores quantitatively the impacts of radio spectrum regulations, i.e. different radio spectrum license policies, on the possibilities of the market actors to develop their businesses. The resulting complex value system states are observed as a function of different boundary conditions. System state transitions are difficult to study empirically because it takes years for the transitions to happen, and it is difficult to separate the influences of many simultaneous drivers. While section 4 examines the transitions empirically and qualitatively, this section provides further insights through simulations.

Allocation and management of the global radio spectrum have long traditions, as discussed in section 3.2. The coordinating approach and roles of ITU and national and regional actors have prevailed for many decades. Furthermore, the radio spectrum allocation methods have been maintained since the introduction of 2G mobile communication and use of the ISM band for internet access in the 1980s. Introduction of new concepts, like Cognitive Radio and Dynamic Spectrum Access (Mitola & Maguire 1999) have initiated development, which is finally gaining momentum. This development is still rather slow for many reasons, including multifunctional and broad negotiation mechanisms between the national administrations but also due to vested interests of a large amount of companies and other actors operating radio systems.

Radio spectrum licensing models used in the simulation were adopted from current radio spectrum regulation, where there are four different ways to allocate the radio spectrum. Different radio spectrum allocation methods with some use case examples are listed in Table 19 below.

Table 19. Examples of radio spectrum allocation options

RADIO SPECTRUM ALLOCATIONS	Monopoly allocations	Licensed allocations	License-exempt allocations	License-free use
Examples	Spectrum bands for Mobile communications during 1G, Military, aviation	Spectrum bands for Mobile communications during 2G, 3G, 4G	Spectrum band for Wi-Fi, Bluetooth, and ISM in general	Spectrum band of visible light

Simulation models are built in two phases in Publication IV. A system dynamic model is used to conceptualize the positive and negative feedback loops in the value system. A positive feedback loop connects the number of subscribers and market share to the capability to gain access to more resources, while negative feedback increases competitive efforts in case of losing market share. These simple feedback mechanisms define the basic logic for the actors and interactions between them. These micro-behaviors fail to explain the system-level behavior, even though a researcher must believe that the behavior of the whole system is a consequence of the interactions of its many parts (Forrester 2007).

An Agent Based Model (ABM) is used to examine the detailed dynamics on the system level with many actors, where each actor operates either as an end user or a service provider in the system. A set of parameters is used to model the behaviors of the agents. The model is calibrated using market data from NMT, GSM and 3G systems and separately using market data from public Wi-Fi service providers in Finland. The data cover the period from the launch of the services until the year 2012. The model builds on a parallel research on voice service adoption in Finland (Casey & Töyli 2012). Value system states and their evolution as discussed in section 4.3 set the reference operating points for the simulation, yielding two separate sets of parameters for licensed and license-exempted value systems. The simulation model produces market shares of the mobile operators and public Wi-Fi service providers in alignment with the market data, shown in Figure 32 below.

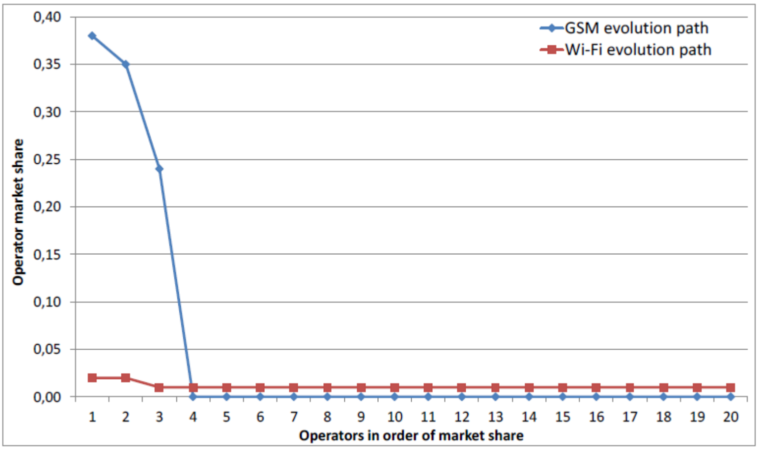

Figure 32. Calibrated simulation of the Top 20 operators in order of their market share (Publication IV) Copyright 2012 IEEE. Reprinted with permission.

Concepts like cognitive radio are finally driving new models to incentivize efficient use of the spectrum beyond the static licensed and unlicensed allocations. The dynamic use of radio spectrum is modelled by modifying the parameters of the calibrated simulations to reflect the new set of constraints. Consequently, the simulations show the impact on the market dynamics, more specifically on the market shares of the mobile operators and other service providers. Using multiple simulation scenarios, the simulations explore the possible transitions toward 5G.

The key variable for the future scenarios is the parameter "Resource accumulation speed" (S_R), which reflects the strength of the positive feedback loop of the dynamic system model. This parameter is considered to reflect also the strength of the network effects of the system. The model uses calibrated values for S_R as follows: $S_R = 0.02$ for unlicensed spectrum, $S_R = 0.12$ for light licensing (e.g., Cognitive radio approach), $S_R = 0.15$ for traditional regulated exclusive spectrum licensing, and $S_R = 0.4$ for unregulated licensing case (i.e. no limitations, even exclusive use is possible).

The two system states of GSM/GPRS and Wi-Fi based wireless access value systems examined in section 4.3 are taken as the base cases for the scenarios. Both base cases are simulated further assuming that by the year 2020 new regulative models are available in Finland. The calibrated base case parameters are maintained, except the resource accumulation speed S_R is used as a variable with four possible values as defined above. This yields two analyses, each including four scenarios.

When exploring the future of GSM system evolution toward 5G, simulations show four different scenarios based on the different parameter of resource accumulation as depicted in Figure 33. The change of the scarce resource-management mechanisms can change the system dynamics drastically.

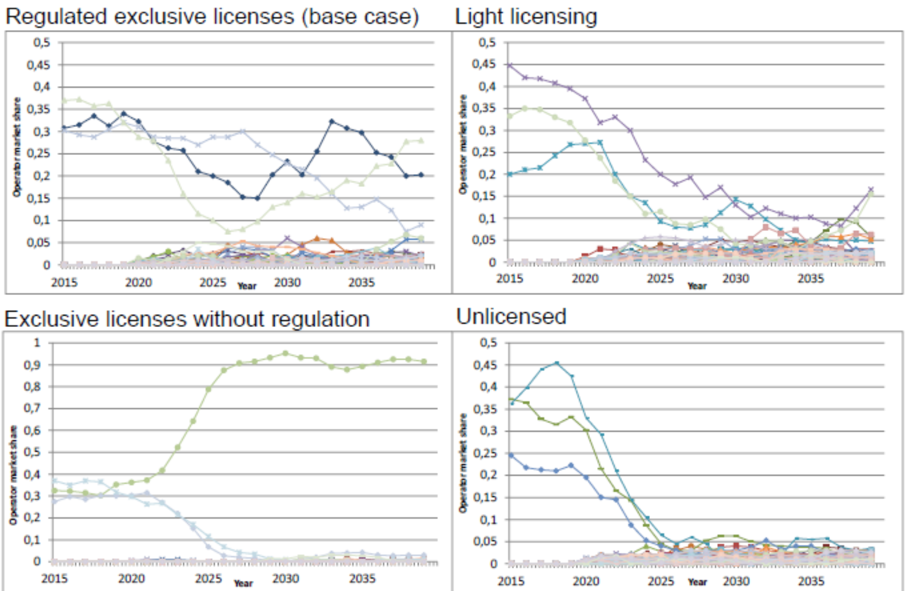

Figure 33. System state transition scenarios, GSM evolution (Publication IV) Copyright 2012 IEEE. Reprinted with permission.

The two scenarios, without any coordination or collaboration between the actors, lead to either a winner-take-all situation with unregulated resource accumulation and high preferential attachment or to fully fragmented cases when there is no reward for collaboration, i.e. the simple unlicensed model with no preferences. The regulated exclusive spectrum licenses maintain the position of the mobile operators. Introduction of the lower switching costs forces them to pay more attention to the competition. This, however, makes their market shares fluctuate, which may negatively impact their interest in investments.

Another simulation takes the light licensing as a starting point, reflecting the future development possibilities of voluntary collaboration under different sets of rules. This analysis re-uses the previous simulation except that the base case parameters are calibrated using the Wi-Fi market data. The base case assumes cognitive radio technologies to be available and used to increase the spectrum utilization and coordination between the spectrum users. Figure 34 depicts the market share changes for different scenarios of the resource accumulation speed.

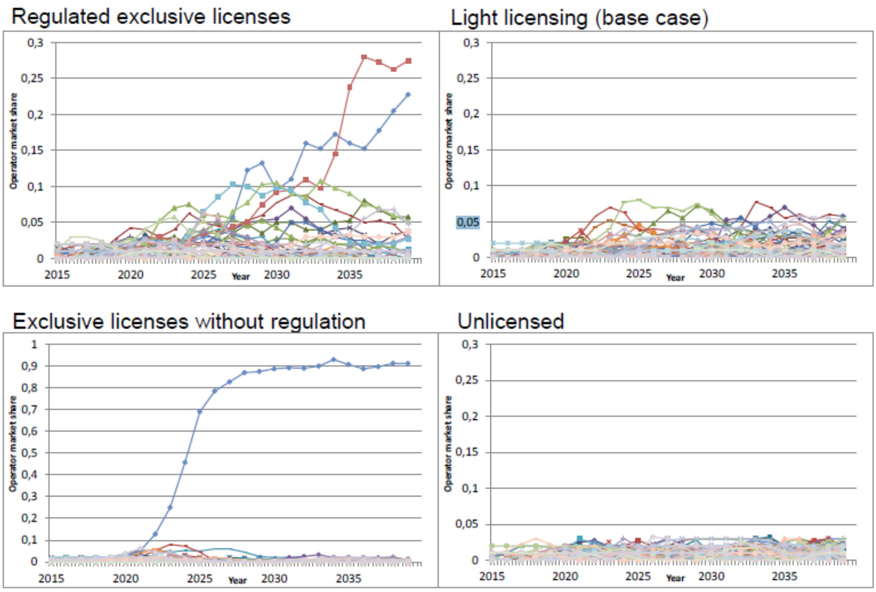

Figure 34. System state transition scenarios, Wi-Fi evolution (Publication IV) Copyright 2012 IEEE. Reprinted with permission.

Independently from the starting point, the simulated market developments show similar dynamics. The regulated exclusive spectrum licenses enable growth of a few stronger service providers, which take similar positions as in the case with the traditional network operators of the previous analysis. In a light licensing scenario, using new technologies helps some service providers to gain market share, but no stable leaders emerge, and market dynamics show unpredictable fluctuations like strange attractor behavior. The fully fragmented, random competition continues in case of a fully license free situation, and one fixed attractor leader emerges in case no limits are set on the network effects.

5.3.1 ABM conclusions

Modelling complex systems, in this case wireless access markets, has many challenges (Sterman 2002; Manson 2007). The simple model developed in Publication IV captures the empirical market developments using a low number of parameters. The simulation models the dynamics of the value systems based on competition and access to resources, while the traditional models often focus on the characteristics of the innovations (Bass 1969; Rogers 1995). The developed dynamic model can be used to explore the market dynamics over time. At the same time, it is important to understand that the simulations are not predictions. Through this quantitative approach, only qualitative observations can be made on the scenarios.

The simulations show that the system under competition experiences changes as a function of the rules on critical resource accumulation. These changes reflect the four different system archetypes observed in complex systems, based on the four different attractor models. Instead of validating the model stability, sensitivity analysis is used to explore instabilities, i.e. state transitions the system can develop.

Data from existing markets and businesses, wireless access in mobile communication and internet value systems, give the reference points for the simulations and provide the calibration possibility for the tunings of the feedback loop mechanics implemented in the dynamic simulator. The simulator was calibrated with two separate data sets, one from licensed and the other from license-exempted value systems. The model shows different calibrated parameter values of resource accumulation for mobile licensed and license-exempted cases, giving an indication of different network effects present in these two value systems. There are many other factors influencing the real value systems; therefore, the absolute values of parameters are not directly comparable between the two base cases. However, the experienced state transitions are similar in both cases. The different rules of resource accumulation lead to different system states, and same rules lead to similar states independently from the starting point. This indicates firmly that smart guidance is needed to avoid low value generating system states in the future 5G, as expected (Lemstra, Anker & Hayes 2011).

Complex systems are difficult to study but computational models have been adopted as a viable approach. Using computational models to explore relative scenarios, e.g., extreme system states, with complementary knowledge on a real-world system can provide useful information to policy makers (Manson 2007).

5.4 Evaluation conclusions

The evaluation of the complex model includes three elements: model calibration, assessment of the model itself, and considerations related to the independence of the data to develop and evaluate the model. The following section discusses the evaluation criteria developed in section 4 and provides a similar subjective scoring, [---, +++] to summarize and visualize the evaluation results.

Calibration of the openness in this context is qualitative only. Openness rules of the relevant SSOs are discussed in section 5.2. The qualitative model includes four different levels of openness, whereas in open standardization only two of them, licensed de jure and voluntary de facto collaboration, are used. Within these two main categories of openness, the OMA is slightly more restricting than 3GPP, while both build their practices from the de jure approach of ETSI. For internet-related SSOs, openness is a general trend but includes many variations. Voluntary collaboration, including no strong preferences related to membership, has produced slightly different shades of grey, for instance, in governance, membership rules, and access to the documents. Therefore, the SSOs implement two different levels of openness which align with the levels of liberties in the use of scarce resources, i.e. the rules and practices related to use of radio spectrum in Table 19.

This study addresses innovation and specification creation processes in open and collaborative environments. As extreme calibration points, there are many national standardization organizations and numerous private companies maintaining full control and allowing very limited or no access to third parties.

Openness of the operative interfaces was discussed during the model development, but its full evaluation through standardization aspects is not possible. Often, however, the operative deployments follow the standards in a straightforward manner. In summary, openness sets good criteria to evaluate the model, and the different shades of grey in openness are relevant in complex value system modelling. (EC11 ~ [++])

The centralization of decision making is rather difficult to assess directly. This research addresses centralization through the level of coordination observed in standardization collaboration. The benefit of this approach is that it provides a quantitative assessment of centralization. Specifically, as standardization is a consensus-building process where voting is used selectively, the level of observed collaboration and coordination provides a solid empirical metric. As an extreme calibration point, a fully distributed system without any attractor would show a fully disconnected spanning tree, and consequently, the collaboration profile would equal zero in the case of standalone contributions only. Most of the social network analysis tools, such as different centrality metrices, work only for connected systems, and their applicability is limited in disconnected configurations. In business, however, strongly distributed configurations exist, and therefore, such a calibration point is relevant. At the opposite end, fully centralized decision making with a strong fixed attractor would show only one contributor delivering all the contributions, which makes the network analyses useless. Therefore, both ends of the scale can be calibrated using a subset of the metrices, for instance, maximum spanning tree and collaboration profile. All the SSOs studied in this research are semi-centralized with partially connected spanning trees and non-zero collaboration profiles. The collaboration in IEEE 802.11 shows several indications of a somewhat distributed approach. Other calibration points refer to earlier literature where specific distributions, such as exponential and power law distributions, are considered to characterize limit cycle and strange attractor-oriented systems, respectively. As in the previous paragraph, the connection between standardization and operative business is an issue. Visible roles of the industry forums, like GSMA, GSA, and WFA indicate that the collaboration between value system actors extends further. In summary, all system states have their specific calibration points, and therefore, collaboration in standardization can be used as evaluation criteria for the model. (EC12 ~ [+++])

The third way to calibrate the model relates to the simulations of the market dynamics under different access to the critical system resource, the radio spectrum. Calibration of the ABM simulations references the real-life market data to gain the initial parameters for the simulations. Simulations with calibrated parameters maintained the expected system behavior independently of the starting point, indicating stability of the model in the case of licensed and license exempted rules reflecting system state 2 with limit cycle attractor and system state 3 with strange attractor, respectively. The system simulations experienced all four system states, depending on the set of parameters tuning the operating range of the simulator, completing the calibration of the model for the system states 2 and 3. As it relates to the model calibration of system states 1 and 4, the simulation calibrations with the market data explicitly provide evidence for these two cases from the model calibration point of view also. (EC13 ~ [+++])

The second set of evaluation criteria relates to the functions of the model and its capability to provide useful information. Evaluation criterium EC21 was set to examine the visible actions of the stakeholders in the value systems. Competition and collaboration in standardization was chosen as the specific test case. More specifically, the level of the coordination in decision making is used to examine the behaviors of the actors in different SSOs.

As it relates to mobile communication, the 3GPP collaboration structure visualized by the eigenvector rankings follows an exponential distribution model up to the level of the rather clear cutoff point as shown in Figure 26. The wide coordination between the contributors becomes visible in the shape of the eigenvector distribution. This discovery is not possible using the basic share of voice, i.e. the number of the documents provided by each contributor, but it requires advanced methods, such as SNA. The result is in line with the expected limit cycle system state, where the licensed privileges of the MNOs influence the structures of collaboration. Without similar regulative limitations, the IETF and the W3C collaboration structures roughly follow the power law distribution as expected.

Furthermore, the collaboration profiles show the limited role of written joint contributions in IEEE 802.11, whereas the document-based collaboration in IETF and W3C is extensive. OMA and 3GPP are similar in the middle ground. Maximum spanning trees show the clustering based on the value system roles and geographies both in OMA and in 3GPP, while no similar behaviors are observed in other forums. Maximum spanning trees show the rather limited role of disconnected contributors in all SSOs, including the IEEE 802.11, where the share of standalone contributors is high. The share of standalone contributions of the disconnected contributors is, however, low. These metrices support other findings that actors' behaviors in 3GPP and OMA are aligned with each other, while in IEFT and W3C, contributors show a lot of voluntary collaboration and the IEEE 802.11 collaboration is still partially fragmented, developing toward the other internet collaboration groups. These observations are in line with tightness of the qualitative constraints as well as with the structures of complex systems with limit cycle, strange, and no attractors. Therefore, standardization is not just "an organization" (Brunsson, Rasche & Seidl 2012), but each standardization activity reflects the system dynamics of the value system it serves, and the model is usable in examining the behaviors of the complex value systems as a function of their stakeholders' actions.

As a specific observation related to the visualization of actors' behaviors, the OMA collaboration distribution shows identical structure with the 3GPP even if there are no formal license requirements for services using OMA service enablers. The leading role of the licensed network operators as key customers both in OMA and in 3GPP influences both collaboration networks in a similar way, both driven by vertical business thinking (Grøtnes 2008). Alignment of the actors' behaviors in the mobile communication value system is stronger than expected based on the related boundary conditions.

As it relates to the visualization of stakeholders' actions, the model provides several useful insights otherwise impossible to assess quantitatively. The findings are well aligned with the views expressed in the interviews.

The ABM simulations provide a different type of visualization of the system behaviors, where the cumulative competitive actions of stakeholders, including simulated users and service providers in the wireless access business, drive the system states to show convergence toward different system states characterized by different types of attractors. Simulations connect the model to real-life situations and to theories of regulation and visualize both the actions of the stakeholders and the cumulative results of their actions.

In conclusion, the model provides several ways to examine the actions of the stakeholders in complex value systems, both during the technology development phase as well as during the tangible business phase. The model shows the fully distributed and fully centralized systems with closed interfaces as extreme operation points, whereas the behaviors between the extreme points align with two points of attractions, the real-life mobile communication and internet value systems. Both value systems are rather open and semi-centralized related to their competition and collaboration behaviors but additionally have distractive differences separating the behaviors into two different groups characterized by two different attractor types. Therefore, the model is considered quite usable to examine different value system scenarios. (EC21 ~ [+++])

The ambition to examine complex value system states and specifically transitions between the states quantitatively is challenging. As it relates to the real world, the measured developments in standardization provide a proxy for the market developments (Hawkins & Ballon 2007). The fluctuations of the assortativity and eigenvector centrality rankings provide a limited possibility to examine the dynamics and related system states and their transitions. The transition in IETF took place when the boundaries were opened to include more voluntary contributors to join the work. This change resulted in a change in collaboration, connecting the core and periphery of the networks together. This is visible in the change of assortativity scores from positive to negative during the years 1993–1996. A similar transition took place in W3C from the opposite starting point. The vertical fragmented nature of W3C collaboration is visible in strong negative assortativity, which melts away at the same time when the "browser wars" started to converge towards open standards, at least partially due to a strong push by the European Commission[108]. This evidence as a causal linkage is weak, but the transition from fragmented collaboration toward openness in W3C is still visible, based on the developments in assortativity scorings.

As it relates to assortativity, the third type of behavior is visible in the IEEE 802.11. The quite strong cycling between negative and positive assortativity scorings provides evidence of frequent transitions between core/periphery structure and horizontal open collaboration in the community. Furthermore, the IEEE 802.11 collaboration shows similar cycling in the eigenvector centrality distribution, indicating that during the times of positive assortativity, the collaboration span is limited. As the cycling aligns with the timings of new standard versions the group has started to define, the observation exposes that

[108] The Microsoft vs. European Commission dispute started in 2004. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007D0053&from=EN. Accessed February 7, 2018.

periods of limited collaboration take place in IEEE 802.11 between more solid collaborative operations. This implies that the IEEE 802.11 group operates at the borderline between the states of strange and no attractors. The external constraints in IEEE 802.11 are so loose that operations have stabilized only partially.

Dynamic simulation provides a tool to estimate impacts of resource accumulation and network effects on the resulting complex value system state. As the model is calibrated with the real-life market data, it provides a tool to study transitions in the value systems and even measure the outcome of the simulations by using different parameter values. The empirical data for Wi-Fi wireless access in Figure 34 shows severe market fragmentation. The base case in Figure 36 shows only modest improvement even if a better collaborative model using new spectrum sharing mechanisms is included. This simulated observation aligns with the empirical observations from the Wi-Fi standardization in IEEE 802.11, where the collaboration is still somewhat weak. These observations raise a concern related to too loose rules, which may hamper the value creation in voluntary collaboration models. Vertical coordination in the internet value system is left open for actors, such as emerging platform leaders, rather than for collaborative communities to manage. However, as pointed out earlier, the simulations of complex systems are useful to explore potential scenarios rather than to provide exact predictions.

In general, the complex value system transitions are measurable. However, the results provide mainly indicative and qualitative information since the precise tipping point between the system states is usually uncertain for any complex system. (EC22 ~ [++])

The overall state of the system of systems is important for the value systems, especially from a performance perspective. When the whole system follows the same attractor, the actors and stakeholders in such a system face less ambiguous issues and conflict. Therefore, the criteria which address the alignment of system states in different parts of the system are important when assessing usability of the model. Alignment between the SSO characteristics is used to assess the alignment in the system of system. The most visible alignment is shown in the eigenvector centrality distributions of the SSOs, indicating the level of coordination for the decision-making in each of the SSOs. The eigenvector centrality distributions categorize the SSOs into two groups, one for mobile communication and another for internet-oriented SSOs. The internal alignment of the distributions in each group indicates the alignment of the sub-system actors within each value system as shown in Figure 26. This visual observation is supported by simple Kolmogorov-Smirnov analyses. OMA aligns with 3GPP, and separately W3C aligns with IETF. The IEEE 802.11 shows partial alignment with IETF and W3C for about 40 of the most influential contributors. However, the alignment disappears when more contributors are included. Similar alignments of the behaviors are visible also in other metrices such as unweighted degree centrality distributions shown in Publication III. As a clarification, the capability to assess the operative alignments in complex value systems is in the focus of the model evaluation, which is only a methodology aspect, while the possible analysis of the business issues in the complex value system is a different question.

The qualitative model was developed using the technical and operative structures in wireless access networks. The evaluation shows similar alignment in the collaborative structures in standardization for these limited test cases. The methodology and evidence related to standardization is relevant for connected networks of collaboration, and therefore, the evaluation criteria for fixed and no attractor cases are omitted. (EC23 ~ [++])

The three previous evaluation criteria utilize two separate sets of data, the empirical data from five standardization organizations and data from the ABM simulations. Additional semi-structured interviews provide further connections to real-life business situations. The different analyses of section 5 provide quite harmonious results, where the system states oriented to either limit cycle or strange attractors become visible in multiple ways. As it relates to standardization, Table 18 summarizes the results, showing that OMA and 3GPP operate similarly. OMA follows 3GPP even if its policy rules would allow other behaviors also. The power of technology and operative dependences in the mobile communication value system keep the standardization activities aligned. For the standardization in the internet value system, the IETF and W3C are well aligned, while collaboration in IEEE 802.11 shows only partial alignment. The other results show further alignments, like between the time-variant assortativity developments, eigenvector centralization development, and empirical evidence from the interviews of standardization experts. The dynamic simulations are mutually consistent independently of the initial state of the simulation. The simulation end states converge to four qualitatively different dynamics as a function of the boundary conditions in alignment with the four conceptual attractors. Therefore, the consistency of the quantitative studies is quite good, and the exceptions can be traced back to real-life situations. (EC24 ~ [+++])

Finally, the last evaluation criterion assesses the interdependence of the modelling and evaluation. The model was developed based on the observations from the technical and operative interfaces, boundary conditions, and dynamic behaviors of mobile communication, internet, and transportation value systems under the influence of ICT. The model evaluations used totally different sets of empirical data from standardization and simulation results derived from the market data. Semi-structured interviews for qualitative modelling provided additional information with partial reuse in building the simulation model. Interviews for the standardization studies were utilized in the evaluation phase only. The interdependence between the modelling and evaluation is therefore quite weak, which provides strong support for fulfilling the requirements of the evaluation criterion. (EC31 ~ [+++])

As a summary of the discussion, the requirements fulfil the evaluation criteria as shown in Table 20 below. The subjective scoring visualizes the detailed discussion above. The applicability of the results is shown separately for each system state. The subjective scale of [---, +++] is used as in section 4.

Table 20. Qualitative summary of the evaluation studies

EVALUATION CRITERIA/ RESULTS	EC11	EC12	EC13	EC21	EC22	EC23	EC24	EC31
Requirements fulfilled	++	+++	+++	+++	++	++	+++	+++
Applicability in system states	1,2,3,4	1,2,3,4	1,2,3,4	2,3 (1,4)	1,2,3,4	2,3	2,3 (1,4)	1,2,3,4

6 Discussion

The discussion of the results is divided into the following sections. Section 6.1 summarizes the modelling process, the model, and its evaluation. Section 6.2 focuses on contributions to theory, methodologies, and terminology and proposes some implications to policy makers and business leaders. Section 6.3 discusses limitations of the research, and section 6.4 explores the needs and possibilities for further work.

6.1 Complex Value System modelling

The developed qualitative model consists of technical and operative structures, boundary conditions, and dynamic behaviors of the complex value systems. The model recognizes value systems according to their dynamic state with an additional focus on transitions between the states. Three initially different real-life value systems – mobile communication, internet, and transportation – provide empirical data for the modelling.

The modelling process of complex systems is challenging due to the nature of complexity. Therefore, an iterative process where the granularity of the modelling is increased gradually is necessary (Manson 2007). This research examines the complex value systems from the top down by focusing on actor types and groups rather than individual actors.

The model defines a qualitative framework and provides a tool for decision makers to examine and explore the characteristics of the complex value systems. The model uses four conceptual attractors as references for the four dynamic system states, which leads to sixteen possible system state transitions. The complex value system model connects the real-life business systems with different levels of observed complexity to the theoretical models of value chains and networks and to the models of complex systems as defined in section 2.

Section 4 provides a broad and positive response to research question RQ1 on how to develop a model to examine complex value systems driven by ICT. Table 13 in section 4.8 visualizes the outcome of the qualitative modelling.

Section 5 evaluates the developed model using two boundaries, regulation and standardization, as lenses to quantitatively connect the theoretical model to real-life business issues. Three types of evaluation criteria are used. The model is calibrated at its boundaries, using regulation and standardization as calibration environments. Empirical statistical market data are used to calibrate the dynamic

ABM system simulator. Statistical data from interoperability standardization provides the basis for calibration of the social network analysis toolset with known theoretical reference points of fully centralized and fully distributed systems.

Finally, the quantitative analyses confirm the applicability of the model in a consistent manner, where expert interviews provide important insights, especially in the cases of observed inconsistences. Section 5 gives a broad and positive answer to research question RQ2 and provides a consistent and to some extent robust evaluation of the model. Table 20 in section 5.4 summarizes the discussion on evaluation results.

6.2 Summary of the contributions and implications

In the context of the principal research questions, this research provides several contributions to theories and methodologies related to value systems and system modelling with complexity.

6.2.1 Theoretical contributions

The findings support the idea of using theories of complexity and concepts of complex adaptive systems to model the structures and dynamics in ICT-driven value systems. The examined value systems experience the four different dynamics under four different boundary conditions. The value systems develop four different types of technical and business structures enabled by the four possible interaction types between the subsystems. Table 8 in section 4.3 summarizes the value system characteristics for wireless access systems, while tables 9 and 10 in sections 4.4 and 4.5, respectively, provide comparable results for the other value systems studied in this research. As a summary, Table 11 in section 4.6 provides a comparison of the value systems using the key dimensions of the model.

Specifically, the wireless value systems experience four different states, which align with the four conceptual complex attractors. The monopolistic value systems of 1G mobile communication systems as well as the current regional public transportation systems align with the fixed attractor model with centralized and closed decision making. The licensed mobile communication value system after the transitions from 1G to 2G systems follows the characteristics of a limit cycle attractor. Furthermore, the internet value system follows the strange attractor model typical to scale-free systems, while fully fragmented value system states were identified during the early stage of development both in unlicensed wireless access and in transportation systems at the time when incentives to collaborate were yet undefined and hence no attractor was available.

The concept of four system states and their transition scenarios provide a comprehensive way to examine value systems with complexity beyond the broad earlier literature of value chains, networks, and ecosystems discussed in section 2.2. Complexity theory recognizes only four different attractor archetypes, for instance, in (Strogatz 2001; Grösser 2017). Applying these models to value systems with complexity simplifies the business analyses and clarifies the applicability of different behaviors to different business scenarios by providing additional shades of grey to generalized studies related, for instance, to innovation and standardization (Shapiro & Varian 1999; Swann 2010; Weber 2014) or adoption of new services (Aldhaban 2012).

The four-state system model provides possibilities to examine state transitions. As the system states are defined based on different structures, this implies that for a successful state transition, the internal structures must change in the transition. This observation aligns with the earlier research related to difficulties to manage architectural innovations (Henderson & Clark 1990) and complements the earlier literature on company strategy planning, for instance, in choosing between a substitutor and new entrant approach, which often align with entering the market with or without a state transition pursuit, respectively (Porter 2008; Dobbs 2014).

Modelling reveals the deep systemic difference between the value systems that follow different types of attractors, like the mobile communication and internet value systems. Convergence of the two value systems has been difficult as expected due to the competition between the geographies and different types of competing companies (Steinbock 2003), but the additional difficulties based on the undiscovered or ignored misalignments in systemic factors have not been broadly recognized earlier in the value systems studied in this research. Instead of convergence, the internet services have found a tunnel through the mobile communication value system, and they operate in a separated sandbox. However, the benefits related, for instance, to network effects become real only within the connected section of the system. The hybrid approach utilized in PoC failed completely to provide any solid outcome, and no alignment of the system states for ICT clusters was achieved. These different cases indicate that the system state misalignment may either be only temporary, as in the transition from 1G to 2G, may result in a stable separation of two or more value system states, as in the case of converging mobile communication and internet value systems, or result in a failure, permanent state of “disorder” (Kurtz & Snowden 2003), as in the case of PoC.

Furthermore, the transition matrix in Table 12 in section 4.7 lists all possible transitions the four-state system model imposes. From a theoretical perspective, such a simple framework provides new possibilities to examine and categorize complex value systems and extends the scope of earlier similar models, such as Cynefin (Kurtz & Snowden 2003).

As a specific example, this research provides a potential framework to address challenges of Public-Private partnership programs when governments, private companies, scientific communities, and individual people try to find common ways to collaborate in the Quadruple Helix with up to four different ideas of openness and decision-making (Arnkil et al. 2010). To minimize the systemic conflicts, the systems states in the value system, including the subsystems, benefit from the alignment of the configurations of technical and operative interfaces. For instance, openness of a technical interface is an illusion if the operative actions of the value system actors close the opportunities to interoperate[109].

[109] In other words, using the ecosystem metaphor: “Garden walls become easily walls of prison or similarly, plants able to flourish in the garden die in the open field”.

The ICT cluster model is a useful reference when considering the alignments of all relevant interfaces, for instance, in the complex value systems in transition driven by ICT, such as Mobility as a Service in transportation. Especially systemic thinking related to all six interfaces between the clusters is critical (Fransman 2010) because opportunistic bundling between the clusters can have a drastic influence on the overall value system structures and related dynamics, like has been observed in the case of bundling of end-user applications with device operating system or in the case of bundling of subscriber identity and mobile phones. Connecting complex value system states and their embedded complexity with the value system structures, including all the clusters and all the related interfaces is often overlooked in earlier regulation literature. This research highlights the need for a holistic model.

As a specific case, earlier literature has observed the internet value system as a scale-free complex system with some reservations (Park 2005). This research provides further support to the strange nature of the internet value system and additionally extends the scope of such considerations to less strange, limit-cycle - oriented value systems with an exponential, not scale-free nature of networking. The observed distributions deviate from idealistic scale-free and exponential distributions with individual cutoff points. Therefore, the results are considered to be qualitative only. The qualitative logic is extended further to monopolistic and fully fragmented systems, where the statistical analyses are not usable. Earlier literature typically focuses on one or maximum two different types of complex value systems, while this research consolidates all four types into one model.

The role of boundaries is not straightforward. On the one hand, the observed rules and regulations, ranging from fully controlled, to licensed, to more liberal license-exempted, and to almost fully unregulated, are well aligned in most of the cases with the observed complex value system dynamics following the conceptual attractors from fixed, to limit cycle, to strange, and finally to no attractor state, respectively. These results therefore complement the earlier studies related to regulation with complexity, such as (Cherry 2007). Similar earlier research related to standardization is scarce, and therefore, this research opens new theoretical issues related to standardization research, especially related to collaboration between multiple different SSOs.

On the other hand, in some cases, significant misalignment was observed. For instance, the loose systemic rules imposed by regulations in the case of PoC were well aligned for business and for standardization, both implying strange attractor dynamics. However, when the real-life standardization drove alignment with the limit cycle oriented 3GPP approach, the misalignment of the initially assumed system state in regulation and the actual system state of standardization created confusion and finally contributed to the business failure.

Co-existence of two and even three different types of attractors in one system setup is known in complex systems, whereas most systems have only one single type of attractor (Sprott, Wang & Chen 2013). Achieving a single attractor situation and a less confusing business system is therefore a reasonable goal. In the case of PoC, this would have required either stronger regulative guidance, aligned with traditional voice service regulation, which would have resulted in a harmonized limit cycle environment, or clear separation of the PoC service from the network cluster structures, including the standardization approach, which would have enabled OTT-oriented tunneling and the co-existence of two different system states to emerge earlier. The latter option was realized after years of confusion.

The disorder observed in PoC is visible also quantitatively in broader SNA results in two ways. First, the collaboration characteristics of OMA and 3GPP are fully aligned, while the regulative requirements are different. Secondly, the IT companies participating in OMA form a separate branch of their own in the OMA maximum spanning tree, while in the 3GPP spanning tree there is no such ICT cluster-oriented branch at all. This indicates that actors in the OMA innovation process had partially different motivations, leading to specific camps. Afterwards, it became evident that the cumbersome work division arrangement between the related standardization organizations (3GPP, IETF, and OMA) caused further delays. These findings provide additional insights and align with the other related studies such as the recent strategy considerations related to ecosystems (Adner 2017) and complement the earlier studies on service adoption in mobile communication (Bouwman et al. 2007) and in related standardization (Grøtnes 2008).

The different collaboration structures in mobile communication and internet-related SSOs were found quantitatively for the first time. Such findings on the collaboration networks of standardization are novel in many aspects. First, the differently distributed node degree and eigenvector rankings indicate different preferential logic between standardization contributors when seeking partnerships in different SSOs. These findings align well with similar studies related to research and business collaboration in life sciences (Powell et al. 2005), where dedicated biotech firms, comparable to dedicated technology firms in ICT, seek broader and more diverse collaboration possibilities over time under strong sector-specific requirements. For instance, limitations by the boundary conditions drive collaboration networks to follow an exponential distribution in 3GPP and OMA. Initially, collaboration networks were considered to be scale-free, but recently, complex systems with different sets of limitations have been found to divert from power law characteristics (Barabási 2002; Broido & Clauset 2018). The discoveries of this research contribute substantially to this debate.

Secondly, the dynamic changes in the collaboration between contributors in IEEE 802.11 as a function of the development phase of each standard revision, visible in the correlation between node degrees of the connected nodes, provides exceptional insight into the dynamics in social networks in standardization, similar to those that have been recently observed in R&D collaboration (Tomasello et al. 2016). The comparison of eigenvector centrality development over time in 3GPP and IEEE 802.11 provides a complementing view to the initial discovery and connects the structural and dynamic characteristics of the collaboration processes. Applying SNA as a function of time is an emerging area of research benefiting from these findings.

Thirdly, collaboration profiles, maximum spanning tree analyses, and information on transitivity and path length provide information on standardization structures and dynamics in the value systems and provide insights into the strategies of the contributors, whether they are universities, network operators, technology and equipment companies, or other types of contributors.

By focusing on the multiple views of collaboration in different SSOs, this research provides a new perspective on standardization research and on categorization of standardization beyond the earlier studies (Schilling & Phelps 2007; Shin, Kim & Hwang 2015). Especially understanding the different approaches in different compatibility pursuits is an important issue, as the role of standardization in various business and innovation ecosystems has not yet been addressed broadly (Aarikka-Stenroos et al. 2016). For instance, the juxtapositions in standardization (Fomin 2012) are different in case the standardization collaboration and technology convergence initiatives follow the same attractor model like in the case of IEFT and W3C or different, like in the case of IETF and 3GPP.

6.2.2 Methods

The qualitative modelling in this research utilizes earlier structural models (Heikkinen, Casey & Hecht 2010) and related notation (Casey, Smura & Sorri 2010). The developed modelling complements the static approach by using dynamics in the structures, like changes in the level of openness of technical and operative interfaces, to introduce possibilities to address state transitions in the value system modelling. Introduction of conceptual system attractors provides the framework to the modelling as well as mechanisms to characterize the complex value systems in a specific way. During the research, the alignment with other similar concepts became visible (Kurtz & Snowden 2003), even if the original starting point for the modelling was quite different. The multistep modelling, consisting of structural analysis, consideration of boundaries and boundary conditions, as well as scenarios of different system clustering and alignment of system states is a broad and holistic approach which supports a top-down system understanding needed when examining business systems with complexity.

Closed-form evaluation possibilities of complex models are limited (Manson 2007). Therefore, Table 20 provides a summary of limited but rather clear evaluation results showing that the model is useful and applicable in examining wireless value systems. Furthermore, the concept used in complex system modelling in geography is applicable to ICT oriented value systems, including when the concept is applied to each and all ICT clusters (Fransman 2010).

Social Network Analysis used in Publication III provides new insights into the important and challenging area of coevolution and co-creation. The SNA methodology revealed differences in collaboration in five SSOs while building on similar research methodologies applied, for instance, in life sciences (Powell et al. 2005). The solid empirical quantitative data on standardization contributions rigorously connects the research to real-world issues. Applicability of different SNA metrices and the details of building the collaboration network structures and showing their evolution over time provides significant additional information on how to assess different standardization initiatives and their collaboration. Application of SNA methods to evolving collaboration in innovative communities is an emerging approach (Gençer 2012; Crespo, Suire & Vicente 2016). Initial time-variant analyses of eigenvector centrality provide exceptional insights to the collaboration in standardization. Additionally, simple new concepts, such as the collaboration profile, provide more ways to address networks with large sections of disconnected nodes while most of the traditional SNA tools ignore these nodes.

Finally, technical and operational structural studies on industry and, more specifically, ICT-driven value systems and their architectures of section 4 provide an important complement to traditional business-oriented research of platforms and multi-sided markets (Tee & Gawer 2009), which often focus on the role of a single company rather than a system of a large number of different stakeholders. Analyses of value creation from the perspective of any single actor or even actor group, for instance, mobile network operators (Peppard & Rylander 2006), benefit from these broader systemic views on opportunities and constraints related to boundaries, structures, and differences in dynamic behaviors. When the business develops toward more and more versatile network models, the considerations related to all actors in complex value systems, especially in case of long-term strategic analysis, become essential. Furthermore, by observing developments over time in different complex value systems, this research intends to raise the importance of path dependency in system designs and modelling.

6.2.3 Policy and business implications

The initial goal for this research emerged from the need to understand significant changes in the market and potentially avoid their negative impacts on the existing businesses. Gradually, the opportunities to build new businesses broadened the scope to the system of systems and their developments.

The first obvious recommendation to both policy makers and business leaders is to look at the clustering and specifically at the six key interfaces between the clusters (Fransman 2010) in all ICT-driven value systems. As identified in this research, only four of the interfaces have a solid regulation in place related to mobile communication today, while the two remaining interfaces are typically ignored. In other value systems, the situation is even worse. Such undefined situations leave value systems open for undefined vertical bundling (Bauer 2010).

Using the relative speed of change as a factor to separate the ICT-driven value system from its environment is a gentle way to simplify and limit the scope of research. The many important ties connecting the ICT-driven value systems to the "static" laws of physics, to slow-moving actions of the governments, and to very fast-moving technologies are managed in this research through two interfacing elements, regulation toward the much slower and standardization toward the much faster environments.

Understanding the importance of alignment of all the boundaries and the requirements they define is important for the smooth evolution of the value system, even if some individual actors might take proprietary advantages in case of misalignment. The risks related to hybrid value systems provide important implications to policy makers to consider the possibility of market failure and mechanisms to avoid it.

Furthermore, the possible “winner takes all” growth model, observed in strange attractor dynamics, when regulative requirements are less tight, requires adaptive, agile regulation (Clark & Claffy 2015). Liberal, loose regulation facilitates growth during the fermentation period (Vogelsang 2017), but there must be mechanisms to limit the power of the positive feedback loops once a platform leader becomes strong and dominant. In other type of value systems, such risks are smaller, and therefore, similar competition policies may not be necessary. Policies of full deregulation include significant risks as foreseen also before (Cherry 2007). Holistic value system level considerations are crucial in assessing the influence of any single regulative decision related to the interfaces, boundary conditions, and desired dynamics.

As it relates to standardization, it is rather difficult to decide when collaboration between different types of SSOs is useful and when it is not (Blind & Gauch 2008), since the alignment of the elements, such as coordination for decision making, is difficult to observe. Only the deeper, data-based methods like SNA can reveal such information. As an implication to standardization and business managers, the social collaborative platform must be seen as a single integrated environment rather than a portfolio of independent collaborative efforts (Kane 2009). As an example, a possible misalignment was identified in the case of IEEE 802.11, where the strange attractor -oriented system state characteristic of the internet value system is only partially followed in creating standards for Wi-Fi.

These discoveries facilitate open, fair, and reasonable pre-competitive and pro-competition leadership of the future standardization initiatives also in the case of multiple collaborating SSOs and complement the earlier literature related to strategies of successful standardization, for instance, (Leiponen 2008; Blind & Gauch 2008; Farrell & Simcoe 2012).

The SNA methodologies can provide a powerful tool to analyze the developments in standardization even in real time, when standardization documents become available for automatic tools to explore and analyze. Similarly, utilization of system simulations provides deeper insights into the future scenarios, such as cognitive radio, and in this way contributes to the current discussion on the role of radio spectrum licensing in 5G. The deductive studies of this research support directly high-level business needs by applying the model to derive managerial implications, which help in optimizing the business portfolio for multiple, partly interdependent value systems, where the traditional profit and risk balancing typically ignores the impacts of complexity.

In general, this research emphasizes the need to make conscious choices in favor of desired system states by aligning factors that drive the structures and dynamics accordingly. Vertical integration toward new technology helps companies survive during transitions (Afuah 2001); however, once the system state stabilizes, open collaboration and competition with some level of interoperability will enable broader possibilities for value creation and capture, making the respective open and collaborative system states necessary (Chesbrough & Appleyard 2007). Sustainable changes in system dynamics require systematic implementations in each ICT cluster. The challenge of architectural change (Henderson & Clark 1990) becomes critical when the borders of the clusters and system state preferences are unclear. For instance, earlier research has found that even a clear segmentation in one part of the value system does not automatically align the rest of the value system (Bouwman et al. 2014).

This research recommends no specific system state as the universal optimum but rather points out the different advantages and disadvantages of each system state. However, the system transitions in mobile communications and internet to limit-cycle and strange attractor -oriented system states, respectively, are considered significant success stories. The open and collaborative approach seems to be beneficial to all stakeholders. Similar opportunities of growth and prosperity are likely to emerge in other sectors of the society, like transportation, when adoption of the ICT and respective value systems evolve.

A specific concern is raised related to the ambiguities of any hybrid state between the four systemic states and disorder situations during their transitions. Finally, when cycle times in business tend to accelerate, agility in defining boundary conditions such as regulation and standardization becomes mandatory.

6.2.4 Terminology

Recognizing the four complex value system states yields rather strong guidance also to consider related terminology. For almost three decades, the importance of positive and negative feedback loops, for instance, in economy (Arthur 1990) has inspired researchers (Moore 1993) and, more recently, business leaders to use the word “ecosystem” as a modern way to explore the value creation, capture, and sharing in society and in business. However, the broad use of the work parallel with traditional value system thinking causes continuous ambiguities. Aligning with the recent considerations, where structural characteristics (Adner 2017), roles of the members, and processes define the ecosystems, this research offers a clarification by recommending to limit the application of the word “ecosystem” only to the cases where the complex value system state is characterized by a strange attractor. Consequently, as it relates to all other system states with lower levels of complexity, it is preferable to recognize them traditionally, for instance, as value systems. This way, also the value system evolution toward ecosystems and the difference between traditional theory of the firm and the reality of network-based value creation becomes a bit more clear (Prahalad & Ramaswamy 2004). Evidently, there is no such smooth evolution but rather a disruptive system transition, which leads to a new state dominated by a strange attractor, scale-free structures, and ever-fluctuating behaviors, which characterize the value system as an ecosystem.

For policy makers and business leaders, it is important that the terminology is clear. With ambiguous terminology it is difficult to avoid ambiguous strategies. As an example, as business strategies that often struggle with *ambidexterity* problems between two different ways to operate, these results align with the opposite observation that any two ways to operate do not necessarily require ambidexterity (Markides 2013). However, the differences between two system states defined by two different complex attractors are so fundamental that such a real-life situation will require ambidexterity of the business leadership. This implication can even be extended by observing all four possible system states (and consequently recognizing a kind of mental *tetrapodigity*). As business managers are typically dealing with two different system states at the same time, for instance, in transforming the company business model optimized for one system state to another state, ambidexterity is clearly a relevant challenge. Policymakers, however, must have an even broader perspective and include all four complex value system states in their scenario building, since all the different system states have different advantages and disadvantages, and in a modern society, all those states may be useful. The system level considerations are important in the evolving ICT-driven value systems since rather seldom any single company or even government, regardless of how hard it competes, can significantly influence global ecosystems; therefore, the single company-oriented strategies and business considerations without broader, often complex value system aspects are in many cases an obsolete approach (Pellikka & Ali-Vehmas 2018). One of the learnings of this research is the need to highlight the art of dynamic balancing between competition and collaboration, for instance, the liquid equilibrium of war and peace in standardization.

The qualitative and quantitative studies of this thesis provide valuable new insights into the empirical developments in mobile communication and internet value systems. Policy makers and business leaders can consider these results in developing regulation and business models for future ICT-driven value systems, such as Mobility as a Service. These issues are currently topical for countries investing in a data-driven economy, like Finland. Business-oriented ambitions do not devaluate the scientific discoveries but are rather meaningful evidence of the value of academic work to the practitioners. Table 21 provides a summary of the key results of this research.

Table 21. Summary of results and contributions

SUMMARY OF RESULTS	Contributions to concepts, methods and theory	Substance-specific findings	Policy or business implications
Boundaries of Complex Value Systems	Regulation and standardization form systemic boundaries for ICT-driven value systems and have a systemic impact on value system structures and dynamics.	Speed of development separates the complex value systems from their environment. Four sets of boundary conditions yield four different system states, where self-regulation can further set limitations to system states.	Cycle times of regulation and standardization influence the cycle time of the value system and vice a versa. Agility needs in regulation and standardization processes are increasing.
Complex Value System structures	Value systems: High-level clustering of ICT-driven value systems with six key interfaces identified in all studied value systems.	Detailed technical and operative structures and clusters identified for mobile communications and wireless internet access. Model applied to examine MaaS.	All six key interfaces need explicit policies and regulation. Value systems in transportation require significant new boundary rules for new paradigms like MaaS to emerge.
	Complexity in Standardization: Applicability of eigenvector and degree centrality to standardization.	Collaboration structures in standardization have SSO-specific characteristics that follow attractor models of complex systems.	Each SSO has unique characteristics, and therefore, collaboration between SSOs is an issue of complexity.
Complex Value System dynamics	Value System Complexity: Applicability of system models with complexity to ICT-driven value systems.	All four system dynamics are real. Full alignment of all clusters is rare.	Awareness of the possible system states and some tools to influence the desired state.
	Standardization: Set of methods to analyze collaboration and competition for connected and disconnected networks.	Analyses of key ICT SSOs based on their internal social networks. Quantitative SNA results provide new visibility to dynamics in the SSOs.	Detailed system level insight is needed for successful regulative and business decisions with embedded complexity. Four operative scenarios to be considered.
	Standardization: Applicability of eigenvector centrality and assortativity to study time-variant developments in standardization. Real-time data science provides new tools for dynamic and sustainable policies and business leadership.	Identification of mobile communications and internet standardization as resilient and roughly exponential and scale-free collaboration networks, whereas collaboration in Wi-Fi has some specific flavors.	Importance of path dependency and systemic behaviors in standardization collaboration. Hybrids include high risks of failure.
Complex Value System evolutions and transitions	Complexity in value network: Complex value system state model and transition matrix for ICT-driven value system scenarios. Template to elaborate the desired systemic behaviors, including possible hybrids and “disorder” states.	Systemic approach used map the historical evolutions of mobile communications and internet value systems.	Misalignments in complex value systems always require a solution, either alignment or separation of the misaligning subsystems.
	Complexity in Standardization: Evolution and disruptions in standardization.	Only one clear system transition found in standardization (IETF), while other temporary dynamic behaviors observed and analyzed. SSOs are very stable and operate according to their rules and by-laws.	Internal system state transitions in SSOs are rare. Renewal in standardization materializes through replacement and emergence of new SSOs.
Terminology	Complexity in value network: System state characterizes the complex value systems.	Ecosystems are a specific subtype of value systems characterized by complex attractors.	Clarity to nurture differently value systems with different system states. All complicated and confusing value systems are not ecosystems.

6.3 Limitations

Systems thinking is a good sensitizer, drawing attention to difficulties and ambiguities in the details of ICT-driven value systems. Observed empirical and simulated system dynamics and structures can provide crucial insights into the inconsistencies within our mental models (Forrester 2007). This research, however, is limited by the factors influencing all studies of complex systems. Research on complex systems is challenging (Sterman 2002) due to the nature of complexity itself. The inherent unpredictability limits both empirical analysis as well as simulations to provide scenarios rather than explicit evidence of causality or precise predictions. Causalities in complex systems are cumulative results of the external and internal factors and are related to complex interactions through the multiple feedback loops. Therefore, for instance, the causal impact of the changes in boundary conditions depends on the internal factors, such as existing structures resisting the change of the system state. Thus, the simulated market dynamics are useful in considering possible future states of the wireless access market, but they provide only a rough estimate or scenario for the position of any single real-world actor in that market.

Different value creation constellations range from single individual contributors to vast global networks with many different types of actors. Beyond the different size and shape, such value creating systems include different levels of complexity. While the size of a collaborative network is rather easily measurable, the level of embedded complexity is often very hard to analyze. Furthermore, separating the individual actors for isolated analysis breaks the system and destroys the embedded complexity, limiting the possibilities to analyze systems on a modular level.

This research utilizes qualitative studies to formulate the specific model and framework and then focuses on two rather detailed quantitative studies as evaluations of the qualitative model. This high-level, top-down approach is a compromise between the possibilities to observe and examine meaningful system and system-of-systems level behaviors under constraints of limited resources and availability of empirical data. The model itself sets no limitations on granularity, and the following iterative cycles can focus on individual companies, and later their functions and departments could be included into the modelling. The ABM simulations of the evaluation phase take a limited step deeper and model the actors in more detail; however, only in limited scale.

The conceptual attractors of complex systems are mathematical constructs, and their direct applicability to technical systems like mobile communication and internet, and especially their implications for human organizations, must not be taken literally. Furthermore, utilizing complexity on the level of an individual actor is not relevant. Therefore, any detailed analysis of a specific value system actor, its value creation strategies, business models, or organizational structures is beyond the scope of this research.

Furthermore, this research considers ecosystems as a specific complex value system state with strange attractor characteristics. As ecosystems are often considered to evolve continuously and facilitate emergence of new phenomena, this sets certain challenges for specific system state thinking. It is hard, maybe impossible, to always make a clear separation between fluctuation in the ecosystems characterized by a strange attractor and value-destroying disruptions between the system states in general.

Additionally, while the studied value systems span over all the ICT clusters, the partially ambiguous cluster interfaces blur the boundaries and consequently the structures in the value system. Therefore, fully aligned complex value systems implementing all the critical interfaces between the clusters are rare. The applicability of the model and the tools of this research requires careful considerations.

Beyond the complexity, limitations can be divided into several other categories. First, the general scope of this research is the ICT-driven value systems, but in practice, only wireless access and partially broader mobile communications and internet value systems have been studied both qualitatively and quantitatively. Therefore, the empirical background of the created model and its evaluation covers only a part of the overall ICT-driven value system. On the other hand, the mobile communication and internet value systems are truly global and thus represent a significant technical infrastructure and economical backbone of modern society. As it relates to the transportation value system under the influence of ICT, the research approach is qualitative only, and the research focuses on developments only in Finland. The possible application areas of ICT are much broader, and those considerations are clearly for further study.

Secondly, as the value systems are developing, this research focuses on situations in mobile communication and internet value systems during the first decade of the third millennium, while the structures and dynamics of the MaaS value system have been developing only recently. Radio communications and radio spectrum as the critical resource are an important combination in value creation in the empirical studies of this research, while artificial intelligence and personal data form a similar bundle for the value systems of the future, including MaaS. The nature of the raw materials like radio spectrum, consumer data, and possibly the space required for roads and railroads is initially different. There are obvious similarities, but as a significant limitation, the strength of the analogy depends on many issues that are currently not defined.

Thirdly, the research identifies four stable complex value system states which lead to sixteen possible transition scenarios. Therefore, a significant limitation is that only seven of the sixteen transitions have been addressed, some of them only partially. System simulations shed some further light on other transitions, but still there are many transitions which require further work beyond illustration.

Methodologies used in this research include three main areas of limitations. The case study approach with semi-structural interviews and other less structural qualitative data, such as business data, regulation, and standardization documents, further limits the possibilities to use the research results quantitatively. The broad scope of ICT includes large variations of experiences, opinions, and views, which makes any statistical efforts rather difficult. Therefore, no statistical studies are used related to the qualitative sections.

This leads to the next area of limitations in methodologies related to the social network analysis in Publication III. The first limitation relates to the data set used in the SNA. The data set is in one sense complete, including all the documents used in those forums between 2003 and 2008. More recent developments are uncovered. Furthermore, the studied SSOs are relevant for mobile communication and internet value systems, but there is no similar data available related to transportation value systems. The SNA methodology is broadly used in similar earlier studies, but most of the SNA methods can address behaviors of the connected actors only. The role of disconnected actors, or standardization contributors in this case, escapes from such models. The additional simple methods, such as collaboration profile and visual maximum spanning tree, aim to compensate this limitation. The fundamental problem relates to the other collaboration methods in standardization beyond the written documents. The limited semi-structural interviews for Publication III bring some light to this problem. The SNA analysis is useful when complemented with adequate domain knowledge, which leads to a conclusion that even if there are many limitations related to SNA, the findings in this thesis using SNA are still useful. This research utilizes SNA to focus only on the structures of the collaboration rather than behaviors of the individual actors in the network. This limits the research scope and ignores the analyses of individual companies and their strategies (Jiang & Jiang 2014). On the other hand, this approach focuses on the dynamics of the SSOs and therefore is not sensitive to considerations related to companies implementing different strategies in different SSOs. Social network analyses are utilized in the context of complex systems theories only, and therefore, the detailed quantitative results related to SNA metrics, such as eigenvector scoring distributions, are used to provide information to identify the similarities between the SSOs qualitatively and to evaluate the qualitative model.

Similarly, there are several methodological limitations related to dynamic ABM simulations. The most important concern relates to agent-based modelling in general. Even if the model is calibrated using good quality data, the ABM simulations are not even in theory able to provide accurate predictions in the case of complex systems. Beyond this, the quality of the input data, such as the market shares of service providers can contain inaccuracies. When simulations are used for scenario building and complemented with expert views, the results can be used for policy considerations (Manson 2007). Qualitative expert interviews can answer "why" and "how" questions, while quantitative questions like "how much" are out of reach regarding the future scenarios. Detailed system simulations related to hyper-complex, random systems are in practice useless (Grösser 2017).

Multidisciplinary research, which utilizes concepts and methods from several different scientific disciplines is challenging by default. This thesis utilizes concepts and methods which were initially set to solve some specific business issues. Complexity theory has been the underlying inspiration, but as such, it is far too broad to be used as the only reference, and therefore, literature on competition, value systems, ecosystems, complex systems, agent-based simulations, social network analysis, and data from many businesses, regulation, standardization, and other industry collaboration is used. The evident limitation, therefore, is that it is difficult to position this research directly in any discipline, while the benefit is that the broad system thinking approach tries to connect the dots and aim toward consilience rather than reductionism.

The decade between Publication I (2007) and the last Publication VI (2017) raises further difficulties. Observations which are ten years apart are addressing different events by default, so making them directly comparable is difficult. On the other hand, the empirical studies in Publications I, II, and III are all focusing on events which have the same focus period roughly between the years 2000 and 2010. The explorative studies related to transportation and cognitive radio address situations without any specific needs for time frame alignment. This dualism removes some of the concerns related to the long research period. Furthermore, a long perspective can even be considered as a strength; for instance, at the time of writing the Push to talk over Cellular publication, the business success of PoC was unclear. Today, both the process and commercial status of PoC are public knowledge, and therefore, it is possible to assess ex post the results and consequently to better see the factors which finally made the case to settle. Research of Push services is, however, quite topical again, as the 3GPP community is considering Push over 5G as a “new” emerging business opportunity.

The close relationship between research and business activities, where each publication addresses also relevant business issues, is considered to be a strength. This approach makes the research relevant in the business community and for policymaking. Additionally, this approach has provided a good access to resources and data, like in the case of empirical data on standardization. As the research topics are long-term systemic problems, which many companies and policy makers are interested to solve for better performance of the overall complex value systems, the possible conflicts of interests during the research period are a minimal concern.

6.4 Further work

The developed model and methodologies are only scratching the surface. As the ICT-driven value systems increasingly often show characteristics of ecosystems, including virtually unlimited resources such as big data and machine learning driven by Moore’s law, unregulated interfaces, complex feedback loops, and strong network effects, the need to model and understand the system level behaviors is growing continuously. When exploring the existing literature, it becomes evident that fundamentally new theoretical models addressing complexity in business life are rare. The chosen approach to focus on complex value systems and their transitions, instead of the recent popular debate on ecosystems in general, is a low-risk approach relying on the solid set of theories. Building the bridge from value systems with embedded complexity to ecosystems will require further work in characterizing the systems in more detail. A value system does not change its characteristics to an ecosystem only by changing the name. Future work should therefore address ecosystems as a super- or sub-concept of value systems thinking., Furthermore, complementing the developed model with some practical decision-making tools, like decision hierarchies even machine learning could facilitate adoption of complexity consideration significantly. This research encourages the future studies to consider strange attractor oriented complex value systems as ecosystems, while all the other value system dynamics are either simple or hyper-complex.

As this research is multidisciplinary, also the items for further study may focus on many different things. The current value systems in our society are utilizing ICT only in a limited way. Some business sectors such as telecommunication and entertainment are rather mature, while many other sectors like transportation, healthcare, education, and developments in smart cities in general are only testing the ICT capabilities and related value system configurations. All the sectors in our society will face similar complex state transitions, where the concepts and methods of this research can be further developed and utilized. Especially, it will be important to identify dynamic methods to spur value creation in digital value systems and at the same time control the negative impacts of powerful, non-transparent, multi-sided platforms.

On a more detailed level, the social network analysis is a promising approach, especially when more real-time data sources become available. SNA and other data mining methods can reveal knowledge which is invisible to the human eye. The alignment of eigenvector analysis and other forms of principal component analysis like page-ranking give deeper and better understanding of the drivers and dynamics of business competition and collaboration than has ever been possible before. A large amount of further work is needed to make the data available as well as to develop and utilize the new algorithms. For instance, the eigenvector centrality used in SNA utilizes typically only the first eigenvector, while there is more information available in the vectors associated with the other eigenvalues. Further analyses can be used to study collaborative systems in a more versatile manner, for instance, looking at their internal cohesion and its variations, where the second and third eigenvectors represent the second and third principal components of the variance in the collaboration. This type of analysis provides insight into the other potential priorities of the standardization or any other collaborative group. Other possible short-term actions include extending the scope of standardization research to cover a broader set of SSOs, including recent data sets to explore the developments until the present day. There are many open questions, such as cohesion of the actors in the SSOs, where SNA is able to provide new insights beyond the existing knowledge, for instance, on impacts of competition between two standardization organizations on member adhesion (Daidj, Grazia & Hammoudi 2010).

Furthermore, social network analysis can be used extensively to study standardization collaboration between the SSOs by combining separate SSO-specific data sets into one larger set. Focus on interoperability as the driver of network effects is critical in the future research on standardization, especially to address the issues of collaboration of multiple standardization initiatives (Wiegmann, de Vries & Blind 2017). In an opposite way, more detailed information can be found by analyzing the text in each standardization contribution using SNA and studying, e.g., information flows during the early stage (Technical Reports) separately from the late stage (Change Request) of the process.

As the Internet of Things and other data collection mechanisms evolve and provide better and deeper data about all living and non-living things, the simulation models become more capable to model the system-level behaviors. Combining system dynamic simulations and social network analysis by connecting the simulated "social networks" of the agents could provide further insights and make the modelling develop concurrently in both areas. More detailed information allows deeper focus on single actors, like companies or even their internal organizational units, as the next cycle of the iterative complex system modelling (Jiang & Jiang 2014).

A vertical way of working is important in the early days of new businesses. Vertical bundling between the applications and consumer devices is currently strong due to the loosely defined interfaces between some ICT clusters, as seen in the case of the application stores bundling consumer device hardware and software and in the case of social networking bundling consumers' data and identity with the content platforms. Application ecosystems seem to follow the path of the walled garden MNOs. New legislation to protect consumers' rights is emerging, and therefore, new value system states and state transitions may materialize. One important area of future work is to extend the research on system boundaries from radio spectrum to other key resources such as consumer data, myData[110]. As an extension of Negroponte's vision, all physical objects will get a digital shadow attached to them, enabling the objects to have their virtual presence in the data cloud either as part of Big data or to benefit people in the form of even more valuable Little data[111].

As it relates to mobile communication, the role of net neutrality has been fundamental in shaping the value systems and their dynamics. The new service concepts planned for 5G will require new interpretations regarding net neutrality, while such debate is extremely difficult due to high business interests and political ambitions. For 5G, the service bundling may be necessary at least in some new 5G-specific service segments, such as for very low-power Internet of Things ecosystems and low-latency Industry 4.0[112] ecosystems. Further work to support a fruitful dialogue in this area is needed. Understanding the possible scenarios and adopting flexible and dynamical ways to guide the competition and collaboration of actors would help the business leaders and policy makers to set the landscape for sustainable value creation. This research provides some basic concepts which need to be further developed to address ever-larger systems as a "whole" even in smaller details (Stolterman 2008).

As a further observation, there is a fundamental systems-thinking reason to enforce the symbiotic interfaces because each ICT cluster shows inherently different innovation clock cycle due to their different degrees of freedom and constraints. There is an interesting paradox, that needs further work. Despite the faster innovation cycle of the content cluster application, the system state dynamics for that cluster seem to develop one step behind the developments in the network cluster. For instance, the current 4G network operates as a horizontal

[110] myData initiative. http://mydata2016.org/. Accessed March 27, 2017.
[111] https://ec.europa.eu/digital-single-market/en/news/enabling-data-economy-europe. Accessed November 10, 2016.
[112] Industry 4.0 is a reference model of the future fully connected and data-driven business, driven mainly by the European manufacturing industry. http://www.plattform-i40.de/I40/Navigation/DE/Home/home.html. Accessed March 16, 2017.

platform, while the applications are consolidated to 2–3 competing platforms and ecosystems, i.e. following the competition model of the 3G networks. The content-driven ecosystems, the so called GAFA[113] group, show little or no interoperability between the platforms, as was the case for the separate 3G mobile network systems utilizing W-CDMA, CDMA-2000, and TD-SCDMA wireless technologies.

A healthy and sustainable market economy of the Programmable World[114] does not emerge by accident. As the communication networks have lived through cycles of multiple system states, similar developments are anticipated to happen in all areas utilizing ICT. Negroponte noted the critical role of consumers' choice and the role of "Daily Me". As the consumers' real-time data are a scarce resource of the future, the emerging legislation fortunately puts the choice in the hands of the consumers. The Programmable World will become a reality when both the static big data and the real-time personal data are utilized and processed for the benefit of the people. There are several ways how to build the new world, where the role of different actors and their preferences of the complex value system states are important ingredients. The need for simple tools to tackle complex problems with new scarce resources and new disruptive technologies never ends to emerge.

Understanding the dynamical behaviors of the business requires new knowledge continuously. As Heraclitus said many centuries ago, *No man ever steps in the same river twice, for it's not the same river, and he's not the same man*. The modern connected digital value creation is developing toward strange complex value systems, which can change their internal structure and dynamics even if their external appearance looks unchanged. The need to understand these systems better drives the need to improve also methodologies, especially when the data age makes meaningful new data sets available.

[113] Google, Apple, Facebook, and Amazon are sometimes referred to as GAFA.
[114] "The Programmable World" has been in use for at least two decades to describe a time when everything is connected and programmable. More recently, the Programmable World sets a broader vision for the software-driven Internet of Everything by, e.g., Nokia Corporation.

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Aalto-DD 43/2019

Information and Communication Technologies enable companies to provide critical services and products to their customers globally. Consequently, understanding the complex interrelations between the technologies and value systems of the companies has become crucially important. In this thesis, a qualitative complex value system model is developed and evaluated. The thesis models the ICT-driven complex value systems through the technical and operative structures, boundary conditions, and dynamic behaviors observed in those value systems. The research examines global mobile communications and internet value systems complemented by studies on emerging ICT driven value systems of transportation in Finland. Agent-based simulations and social network analyses applied to the boundaries of the value systems set by regulation and standardization, respectively, provide a quantitative environment for the limited evaluation of the developed model.

9789526084497

ISBN 978-952-60-8449-7 (printed)
ISBN 978-952-60-8450-3 (pdf)
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

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