Samuel Costa Ci An

Mobile Offloading in Residential Wireless Access Markets

Aalto University, School of Electrical Engineering

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Technology

Supervisor:
Professor Heikki Hämmäinen

Instructor:
M.Sc. Michail Katsigiannis

Aalto University
School of Electrical
Engineering

Aalto University **ABSTRACT OF THE MASTER'S THESIS**

Author: Samuel Costa Ci An

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The growth of mobile data traffic has been increasing at a tremendous pace. Currently, mobile broadband is mostly served by macro base stations. Strong attenuation occurs when the signals penetrate through buildings affecting the quality of service. Hence, mobile operators need to enhance the capacity to minimise congestion problems and improve the coverage on their macro networks for better network operation. As most of the mobile traffic occurs indoors, there is a need for indoor network deployments.

A qualitative analysis employing the combination of various research methods (value network configuration, system dynamics, expert interviews) has been carried out to investigate various factors besides mobile offloading, which could lead to a large-scale deployment of femtocells in homes with the focus on Finland. This study also discusses several options to cope with the mobile traffic growth and examines different indoor network deployment scenarios. Furthermore, the scenarios of Femtocell-as-a-Service are highlighted and its possible impacts on mobile operators' business are covered as well. The analysis is also conducted to illustrate how different actors are interrelated in the home network business.

The analysis reveals that the primary factor that will contribute to the success of femtocell deployment in homes is the need for future mobile offloading. However, many other factors have important implications which require careful consideration by mobile operators. With the presence of good macro network capacity like in Finland, new services and partnership with third party providers has been identified as the most important factor. Mobile operators need to offer an incentive to attract end-users to adopt a femtocell service due to the strong positioning of WiFi in homes. Therefore, new services would also enable the penetration of femtocells into homes to compete with WiFi access points. Three factors (interference mitigation and interoperability, femtocell management system, backhaul) are also important as these are needed to ensure the femtocell networks operate reliably. As lowering the cost is essential for building scale, the model of Femtocell-as-a-Service is useful as it reduces capital investments for mobile operators. Interviews with the experts found that major mobile operators are less likely to adopt this model. This is better suited for smaller mobile operators that want to quickly enter the femtocell business.

Keywords: mobile offloading, mobile traffic, indoor networks, WiFi, femtocell, LTE, spectrum, Femtocell-as-a-Service

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Espoo, 2nd July 2014

Samuel Costa

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Acronyms

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AAA	Authentication, Authorisation, and Accounting
ASA	Authorised Shared Access
CAPEX	Capital Expenses
CSG	Closed Subscriber Group
DAS	Distributed Antennas System
DSL	Digital Subscriber Line
EAP	Extensible Authentication Protocol
EOS	Economies of Scale
EPS	Evolved Packet System
FAAS	Femtocell-as-a-Service
FMC	Fixed-Mobile Convergence
FMO	Fixed-Mobile Operator
GERAN	GSM Enhanced Data Rates for GSM Evolution Radio Access Network
GGSN	Gateway GPRS Support Node
GSM	Global System for Mobile Communications
HD	High Definition
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IWLAN	Interworking-Wireless Local Area Network
LA	Local Area
LSA	Licensed Shared Access
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MIMO	Multiple In and Multiple Out
MO	Mobile Operator
MVNO	Mobile Virtual Network Operator
NSN	Nokia Solutions and Networks
OFDM	Orthogonal Frequency-Division Multiplexing
OPEX	Operating Expenses
OTT	Over-The-Top
PDG	Packet Data Gateway
PMSE	Programme Making Special Events
PON	Passive Optical Network
QoS	Quality of Service
RANs	Radio Access Networks
RNC	Radio Network Controller
SGSN	Serving General Packet Radio Service Support Nodes
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SON	Self-Organising Networks

TDD	Time-Division Duplexing
TTG	Tunnel Termination Gateway
UMA	Unlicensed Mobile Access
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
USA	United States of America
UTRAN	UMTS Terrestrial Radio Access Network
VNC	Value Network Configuration
VoIP	Voice over Internet Protocol
VoLTE	Voice over LTE
WEP	Wired Equivalent Privacy

1. Introduction

1.1 Background

There has been a huge growth in mobile traffic and it will continue to increase in the coming years as more devices get connected to the internet via mobile networks. Mobile broadband allows end-users to have internet connection on the go. Initially, voice traffic dominated the mobile traffic volume. However, the introduction of third generation (3G) and fourth generation (4G) cellular networks has led to an increase in mobile applications. Thus, mobile subscribers started using a myriad of services over the internet. In addition, more devices (smartphones, tablets, laptops, etc.) are now connected to mobile networks and mobile subscribers request faster internet connection speeds. As a result, data traffic has become the driving force for the demand of mobile traffic. Most of the mobile traffic is generated indoors [1] and this is more evident during cold seasons. Various actors, such as fixed and mobile operators (MO), want to have a share of the lucrative mobile data communication business.

Since the power strength of signals is reduced during transmission through buildings, the coverage is strongly affected due to the penetration loss. This is more of a concern for 3G and 4G networks such as Long-Term Evolution (LTE), notably when higher frequencies are allocated for data services. Consequently, the received service quality for indoor end-users becomes worse. Especially in densely populated areas, it poses a challenge for mobile operators to cope with the huge demand for mobile traffic. The growth of mobile traffic will increase congestion in macro networks.

Increasing the network capacity depends on many factors and there are different options in which mobile operators can pursue. The traditional method is just to increase the capacity on their macro networks. The introduction of LTE over 3G networks might provide a short-term solution for congested macro networks. However, nowadays there are other available ways in which mobile operators may look at, before deciding which proves the best option. Offloading mobile traffic from macro to indoor networks is an attractive solution, since the bulk of mobile traffic occurs indoors. At the same time, this solution improves the quality of service (QoS) for indoor usage. Fig. 1 shows a summary of various options to increase network coverage and capacity [2].

Mobile offloading definitely brings real business value. There are several technical solutions for offloading to indoor networks; however each of them generates different business cases for different actors in the broadband ecosystem. Most people have a mobile broadband subscription which could make LTE, with its lightning fast broadband speeds and secure connection, the network for indoor usage. However, currently indoor mobile traffic is mostly carried over Wireless Fidelity (WiFi) networks. Therefore, LTE is likely to create a battle between femtocells and WiFi access points for the indoor networks. Mobile operators would want to retain their subscribers and ensure that revenues remain high. Therefore they have to carefully make strategic business decisions on how to cope with this increase in mobile traffic.

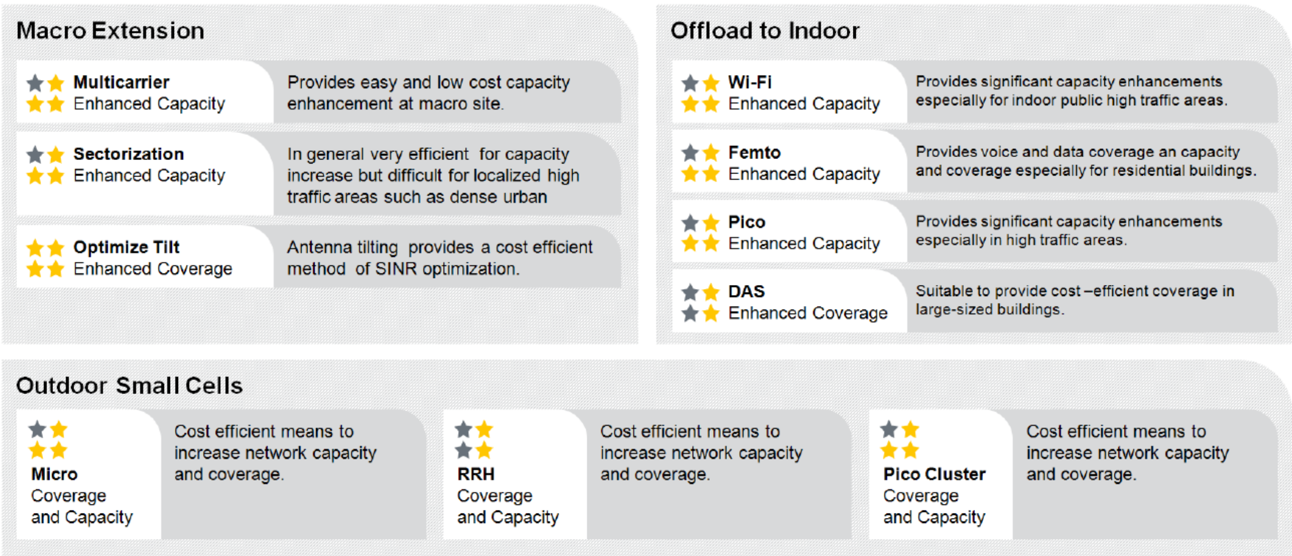

Fig. 1. Network upgrade options (stars represent benefits)

1.2 Motivation

Mobile operators have to address the concerns and challenges of providing sufficient capacity on their networks. Furthermore, they have to weigh the potential economic benefits of deploying indoor networks in homes. The integration of indoor networks in homes with the macro network may bring about new business opportunities for mobile operators and better service quality to end-users. The cost of implementing home networks may also be more cost-effective than expanding the macro network in the long run.

1.3 Purpose

The purpose of this thesis is to identify and compare various mobile offloading indoor technical solutions and analyse their business configurations for residential wireless access markets. This study also aims to gain an understanding on the success of WiFi access points for home networks and would this be a barrier for future femtocell deployments. Furthermore, focusing on Finland, a systemic analysis is also conducted to determine how femtocells can be deployed on a large scale and become a successful business in homes. In this thesis, the network that femtocells connect to is LTE.

A top down approach is carried out to illustrate how the various actors in residential wireless access markets relate and respond to each other. Various mobile offloading solutions and how different technologies provide internet access to different end-user groups in homes are studied. Benefits for the different technologies are also discussed and how each technology influences mobile operators' business role and decision making. As femtocells are designed for homes but are not deployed in great numbers, an in-depth analysis is also conducted from both business and technical perspective with regards to various factors supporting and restricting femtocell deployment.

1.4 Research Questions

The main research question is as follows:

- Would mobile offloading drive a large-scale deployment of femtocells to compete with WiFi access points in residential wireless access markets?

The other sub research question is as follows:

- What is the impact of Femtocell-as-a-Service (FAAS) on mobile operators' business?

1.5 Methods

The methods used in this thesis are value network configuration (VNC), system dynamics and expert interviews. Initially, literature review is conducted to give a solid grasp of the various indoor wireless technical solutions and in particular the ones concerning mobile offloading for homes.

VNC provides a good visualisation of the relationship among the actors in residential wireless access markets. System dynamics is used to examine how various dynamic forces affect the deployment of femtocell networks. VNC sets the basis for the expert interviews. Finally, expert interviews are used to discover facts and opinions to better understand the current situation and future trends about the residential wireless access markets.

1.6 Outline

- Chapter 1 covers the problem description including the research questions and presents the research methods.
- Chapter 2 describes mobile offloading and the evolution of mobile data usage.
- Chapter 3 presents the technologies for the mobile offloading solutions in homes.
- Chapter 4 covers the research methods.
- Chapter 5 shows and discusses the results based on interviews.
- Chapter 6 contains the conclusion.
- Chapter 7 shows the limitations and possible future research work.

2. Mobile Offloading

2.1 Overview

Mobile offloading is the use of complementary network technologies to deliver mobile traffic originally planned for transmission over macro networks. There have been remarkable studies related to mobile offloading both from technical and business perspective.

[3] has considered many operational scenarios and has investigated the benefits of offloading the macro network resulting from deployment of femtocells. [4] has shown a comparative analysis of having joint deployment of macro-femtocell in LTE-Advanced. [5-7] have used game theory models to showcase the economics of offloading using WiFi and femtocell networks. [8] has conducted a case study on the Helsinki region using a mathematical model and how cost parameters and demand in the future influence the profitability of mobile offloading have been shown. [9] has investigated the conditions of traffic demand, deployment cost and energy consumption and how these may lead to femtocell deployments by mobile operators. [10] has analysed the various cost factors related to infrastructure and found that it is driven by deployment and maintenance cost. A study related to cost and capacity of femtocell and macro networks was done in [11] to analyse wireless broadband deployment in a newly constructed office that had many end-users. [12] has studied the effect of interference coordination on total deployment cost for local access providers. The findings have found that coordinated systems do bring economic benefits for dense networks. The savings of total deployment cost is significant for coordinated systems over fully uncoordinated ones especially when very high area spectral efficiency is needed. For high capacity requirements, interference coordination is needed. Non-cooperative spectrum sharing is possible on the condition that the power transmitted by access points have proper regulation.

[13] has investigated the impact of energy consumption when mobile traffic is offloaded from LTE to WiFi networks. Its findings have concluded that the phones' battery lives are not an issue for integration between WiFi and cellular networks. [14] has described the management and provisioning of large scale of small cells in residential areas. Also, the architectures of residential small cell networks in current and future generations have been discussed.

Studies have also been conducted with regards to cognitive radio for mobile offloading. The viability of using of cognitive femtocells to provide mobile broadband has been studied in [15]. It has shown that the coverage range for cognitive femtocell is more important in suburban areas than urban areas. Subscription fee and operating expenses (OPEX) are the most important assumptions in the analysis of the business case. Cost of cognitive femtocells plays a critical influencing role on the profitability. [16] has done an analysis on using cognitive femtocells to offload the LTE macro network. A major finding from this study has shown that the cost for the backhaul, coverage and number of end-users it can support are the most important factors for cognitive femtocells.

Operator business cases have been carried out by studies such as in [17, 18]. Business models have been developed and studied regarding wireless access provisioning which includes mobile offloading. [18] has considered how various business model options implicate the different multi-operator solutions. [19] has looked into how business models are created for telecommunications and tuning it for the case of femtocells. [20] has conducted a study on the actors that are likely to appear for local wireless internet access provisioning for public places. Their analysis has revealed that local wireless internet access provisioning differs greatly from a traditional mobile operator business.

[21] has shown mobile data offloading solutions with the focus on WiFi and femtocells. It has stated opportunities on how to monetise these mobile offloading solutions. Operator and vendors' strategies are also mentioned. Further studies also have investigated the various factors and scenarios that influence the determination of suitable business models of using femtocells [22, 23]. [23] has concluded that by introducing femtocells, the traditional business landscape and models will change in terms of fixed and mobile broadband provisioning.

As mentioned in the previous chapter, due to the fact that mobile data usage have been increasing tremendously and will only continue to increase over the coming years, many mobile operators have already deployed or are going to deploy mobile offloading solutions.

The typical solution for the mobile operators is to increase the capacity of their macro networks. However there are many factors to consider such as cost, site locations, radio interference which might not make it the best option. Another option is to deploy indoor networks which will complement the macro network. The indoor access points use the fixed networks such as the digital subscriber line (DSL) as the backhaul.

Broadband has changed the internet industry with the introduction of many data services. Mobile operators have also focused their business on a household-centric approach by offering home zone services. Fig. 2 shows the battle among various services in the homes [1].

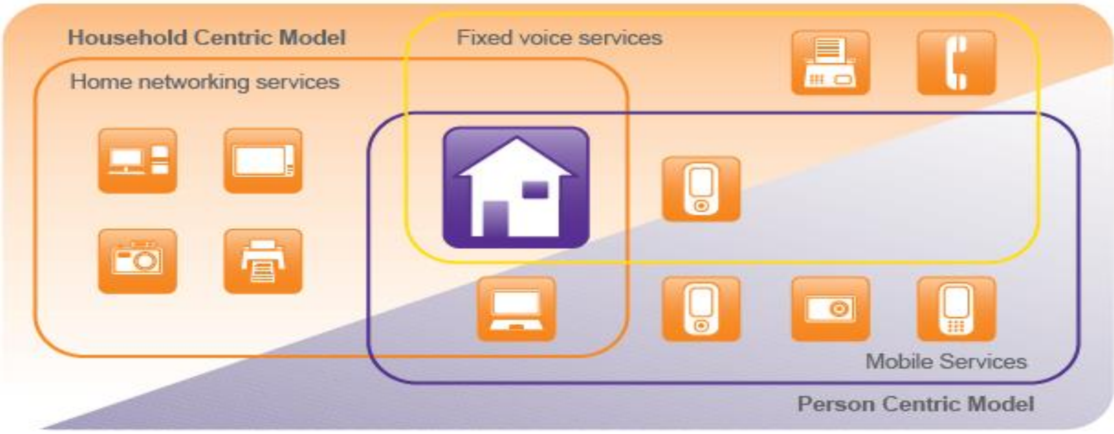

Fig. 2. Service battle in homes

There are two main technologies to solve the macro network capacity problem; WiFi and femtocells. WiFi is based on Institute of Electrical and Electronics Engineers (IEEE) and femtocells on Third Generation Partnership Project (3GPP) standards. Currently, WiFi is widely used by home owners to access internet, whereas femtocells are not. This indicates a successful business case for WiFi.

However, the deployment of femtocells has increased over the past few years and therefore it does have a bright future. We will look in further details the differences between these two technologies. A comparison between WiFi and femtocells is also presented.

2.2 Advantages of Mobile Offloading

By pursuing mobile offloading, the capacity crunch in macro network is alleviated. It might be easier to deploy indoor access points rather than installing new macro base stations. This is so as geographically it is a challenge to build new macro base station towers whereas it is not for indoor networks. In addition, having new macro base stations is costly with heavy and expensive telecommunications equipment. Besides the reduction of the capital expenses (CAPEX), the energy consumption of access points shifts to end-user's electricity bills resulting also to the reduction of the OPEX for mobile operators.

Mobile operators will enjoy the benefits when their subscribers offload from their networks to fixed broadband providers' networks. In this way, their revenues can be increased as they continue to charge the same subscription fee but part of the mobile traffic is directed elsewhere.

Furthermore, mobile operators do not even need to deploy their own network to alleviate its macro network capacity crunch. By minimising congestion in the networks, this will enable them to provide better service quality to their subscribers and ensure that they will not switch to another mobile operator because of poor network service. It also enables them to create a better user experience for their subscribers.

2.3 Growth of Mobile Data Usage

The evolution of mobile data growth is attributed by key drivers such as more end-users of mobile networks, more connected devices to the internet, faster mobile broadband speeds and mobile video streaming. These drivers contribute to the need of mobile offloading. Table 1 and the following six graphs (Fig. 3 – 8) are derived from Cisco Visual Networking Index [24].

Table 1. Comparison of growth in mobile data traffic to growth in devices

Device Type	Growth in Devices, 2013–2018 CAGR	Growth in Mobile Data Traffic, 2013–2018 CAGR
Smartphone	18%	63%
Tablet	41%	87%
Laptop	13%	30%
M2M Module	43%	113%

The growth rate of mobile data will far outweigh the growth rate of connected devices to the internet (Table 1). The greatest growth in mobile data traffic compared to the growth of devices is the smartphone which is 3.5 times.

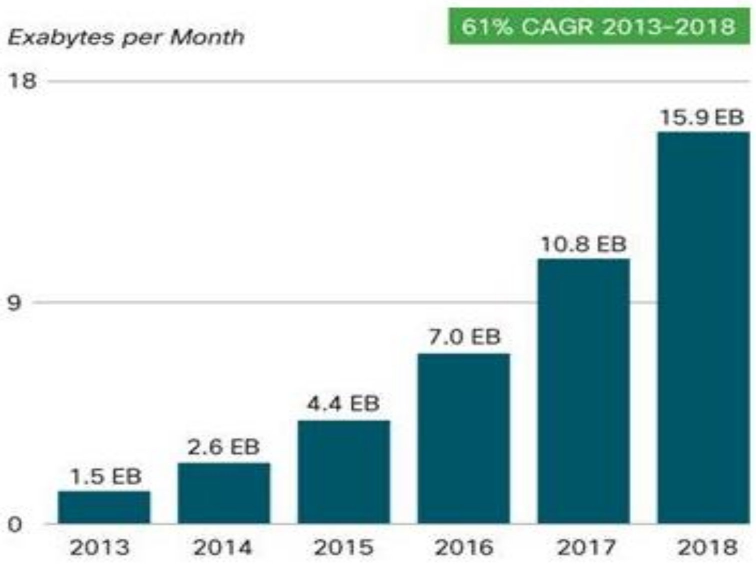

Fig. 3. Growth of mobile data traffic by exabytes

It can be seen from Fig. 3 that the growth of mobile data traffic will increase exponentially over the next few years. This is most likely due to an increasing number of end-users using mobile data. This increase in mobile data usage proves that mobile broadband is becoming an integral part of our everyday lives. New devices with wireless mobile connectivity will also contribute to this increase. The introduction of new services will also encourage end-users to make use of mobile broadband more. End-users can have the option of using multiple devices with each device performing different roles. This leads to an increase in number of devices using mobile data traffic which is also a significant contributor for higher demand of mobile data traffic.

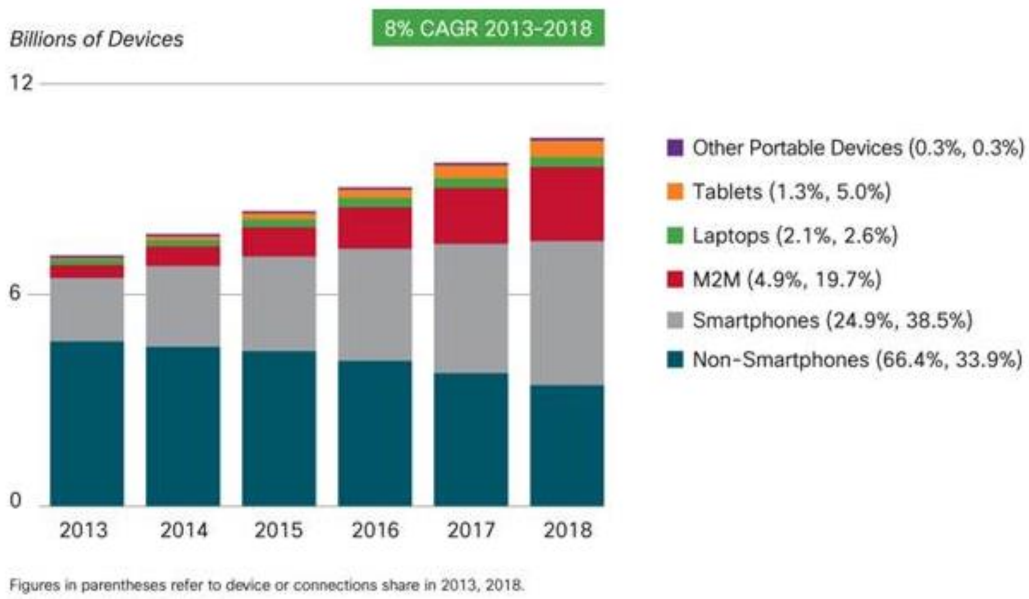

Fig. 4. Growth of mobile data usage by devices

Fig. 4 shows that the smartphone usage of data traffic has surpassed that of laptops in 2013. With smartphones being able to serve the basic needs of end-users, coupled with its portability, it proves to be a more popular choice for mobile connectivity. The use of embedded Subscriber Identity Module (SIM) cards to electronic devices does contribute to the increase of data usage due to Machine-to-Machine (M2M) communications. The vision of the Internet of Things will eventually lead to the increase of M2M devices.

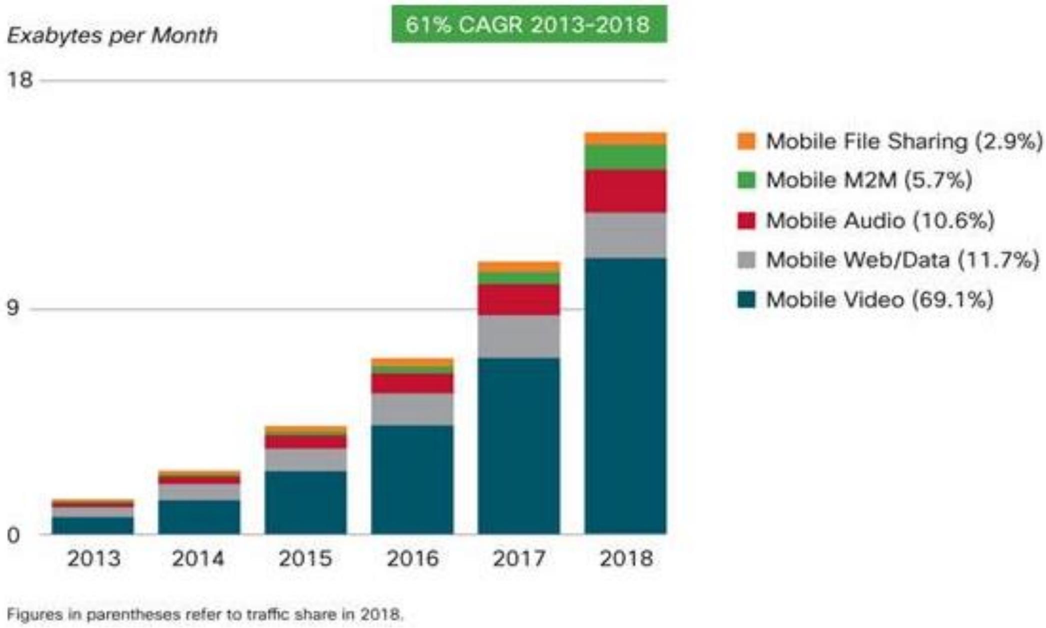

Fig. 5. Growth of mobile data traffic by applications

The increase in data rates creates a shift towards on demand mobile video and entertainment services. Newer and future generation of mobile networks will have higher data rates to ensure real-time services can be smoothly delivered with low transmission delays. Video services such as YouTube are being widely used over mobile broadband and there is an increase in number of video content providers such as Netflix. Fig. 5 shows that mobile video is the main contributor for higher demand of mobile data traffic. Mobile operators want to ensure that they are able to provide these data rates to meet future demand.

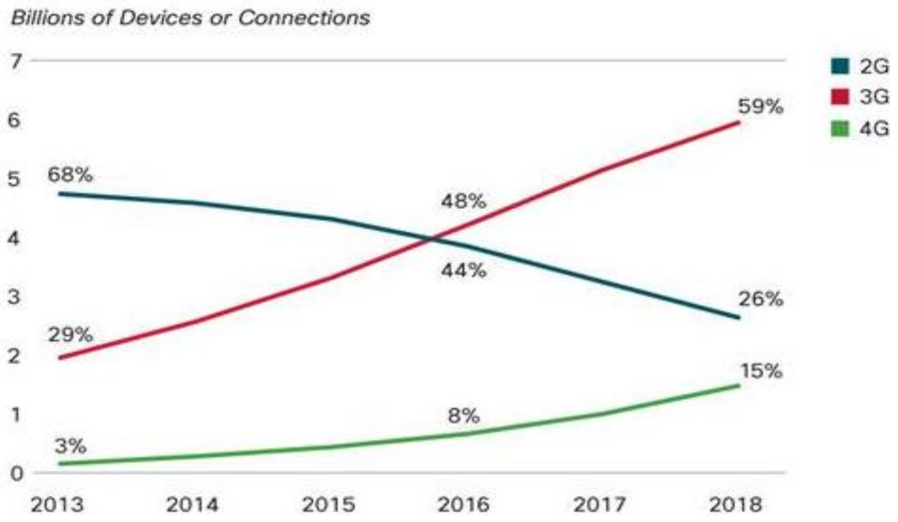

Fig. 6. Number of devices connected to different network generations

Currently, second generation (2G) networks still have the greatest number of devices connected to it. However in the next few years, it is expected that 2G networks will experience a downtrend and the number of devices connected to 3G networks will dominate. 4G networks such as LTE will also see an increase in connected devices (Fig. 6).

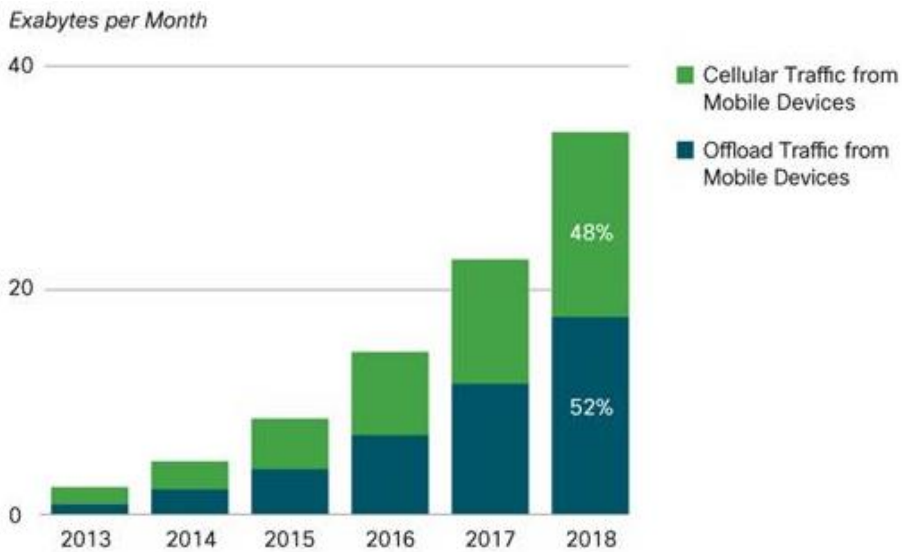

Fig. 7. Percentage of mobile offloading

In the coming years, it is predicted that the percentage of offload traffic from mobile devices will increase (Fig. 7), probably due to the fact that the most of the mobile traffic is generated indoors. Therefore indoor locations are important areas for mobile operators to consider and mobile offloading is an important tool to enable, in order to cope with the ever increasing mobile data volume.

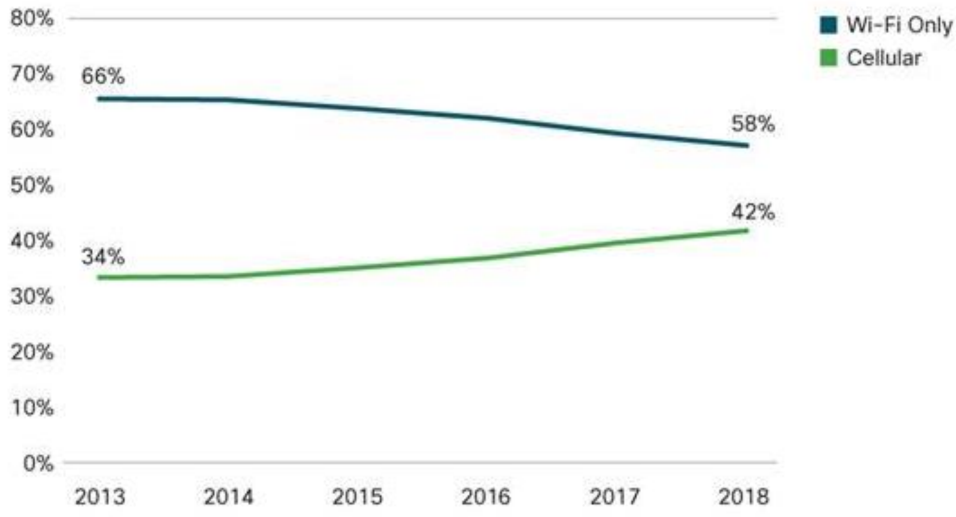

Fig. 8. Ratio of tablets (WiFi only vs cellular)

Finally, Fig. 8 illustrates that the share of tablets which are able to connect to cellular networks will gradually increase over the next few years, whereas the share of tablets which are WiFi-enabled only will decrease.

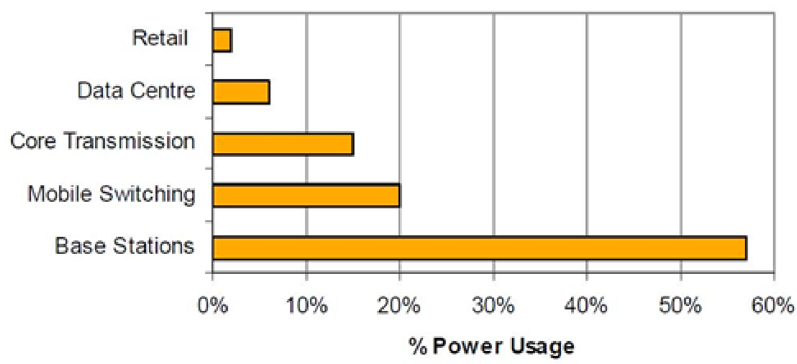

Fig. 9. Energy consumption of a cellular network

Fig. 9 shows the energy consumption of a cellular network with the base stations consuming the most energy [25]. Energy consumption in cellular networks is also expected to increase with the increase in mobile data rates. The increase in energy consumption is going to cause an increase in the OPEX for mobile operators. Energy efficient cellular networks are required to deal with the future increase of mobile data rates. With regards to the phone's battery, in the past it could easily last for days but the battery of a smartphone/tablet today can only last for about a day.

3. Technologies

3.1 WiFi

Overview

WiFi is widely deployed technology for wireless local area (LA) communication mainly in indoor locations such as offices, public places and households. Nowadays, WiFi can be found not only computers, but also in consumer electronics. The trade association that encourages the use of WiFi and certifies WiFi-enabled products is WiFi alliance. It ensures that the products meet the standards of interoperability.

End-users of WiFi need to authenticate a WiFi network every time when a connection is initiated. In 2012, the WiFi certified passpoint was introduced in order to streamline hotspots' networks and enable a seamless connection for mobile devices. It was developed in the WiFi alliance by having partnership among actors such as manufacturers, vendors and operators. The security is ensured by WiFi Protected Access (WPA) 2.

Carrier grade WiFi is another term that had been used in the telecommunications industry. Carrier grade differs from tradtional WiFi in the sense that it is developed to deliver better QoS and ensure a better user experience. It also allows Internet Protocol (IP) mobility.

802.11x Standards

WiFi is based on the IEEE 802.11x standards. These standards aim to provide wireless connectivity as well as high data rates to end-users. Ad-hoc networks and mobility are some other features which are available with these standards. Table 2 shows the different 802.11x standards and their respective technical specifications.

Table 2. Versions of IEEE 802.11x standards

IEEE 802.11x standards	Release	Peak Data Rate (Mbps)	Frequency (GHz)	Bandwidth (MHz)
802.11a	1999	54	5	20
802.11b	1999	11	2.4	20
802.11g	2003	54	2.4	20
802.11n	2008	150	2.4/5	20/40
802.11ac	2014	700	5	80/160

802.11a was introduced with the purpose of providing higher data rates. However 802.11a is not compatible with 802.11b.

802.11b is the least expensive standard. Several devices such as mobile phones, Bluetooth devices can cause interference easily and this affects the transmitted data rates. Transmission scheme used is Orthogonal Frequency-Division Multiplexing (OFDM).

802.11g is like a combination of 802.11a and 802.11b. It is also compatible with 802.11b, uses OFDM and experiences similar interference issues with 802.11b.

802.11n arrived with the aim of providing even higher data rates than the previous standards as it is embedded with Multiple-In and Multiple-Out (MIMO) technology. However it might require more bandwidth.

802.11ac is the latest wireless networking standard using also MIMO technology. It provides even higher data rate than 802.11n. It can eventually replace wired gigabits Ethernet networking in homes. This latest standard is also fully compatible with the two previous versions. At present, even though 802.11ac has a peak data rate of 700 Mbps, the available devices can provide 170 Mbps at most. The reason is that two 80 MHz cannot be bonded to 160 MHz. The maximum speed over one 80 MHz channel is 433.3 Mbps and chipsets can support a maximum of four streams.

Modes

There are three different modes for 802.11 networks; infrastructure, ad-hoc and point-to-multibridge. In infrastructure mode, one access point is the controller that supports many end-users. In ad-hoc mode, 802.11 enabled devices can connect directly to each other without the access point. In point-to-multibridge mode, one access point connects to various access points.

Architecture

Fig. 10 shows the architecture for a wireless local area network using WiFi [26]. The authentication of end-users is performed by the servers. An access controller is to provide IP addresses to end-users. The access points are where the devices communicate with to gain access to the internet. WiFi also allows such distributed capacity network to be established.

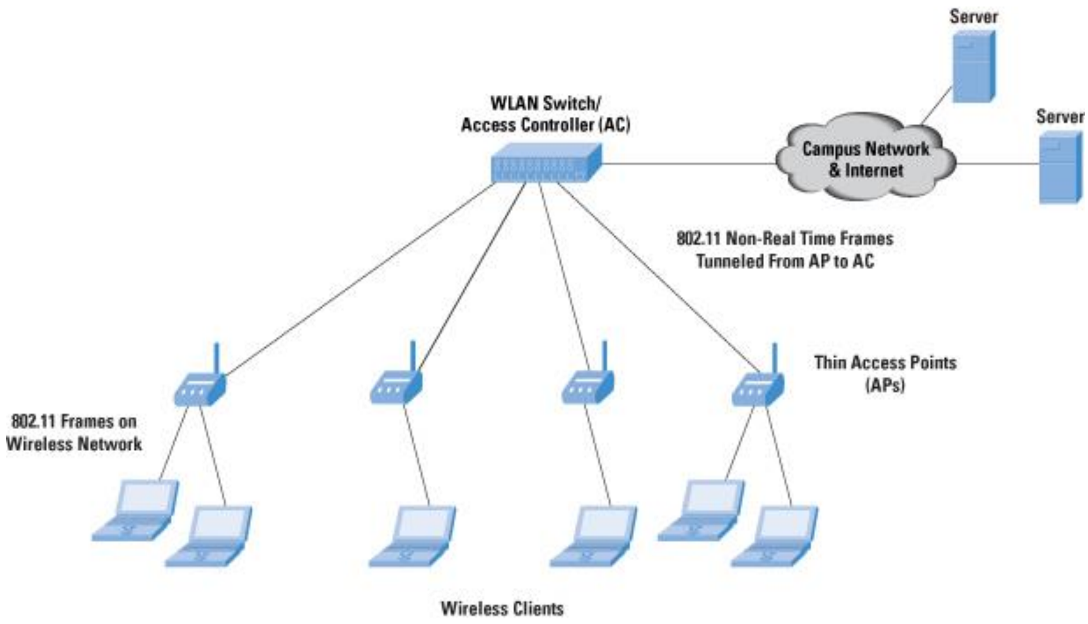

Fig. 10. WiFi network architecture

Spectrum Management

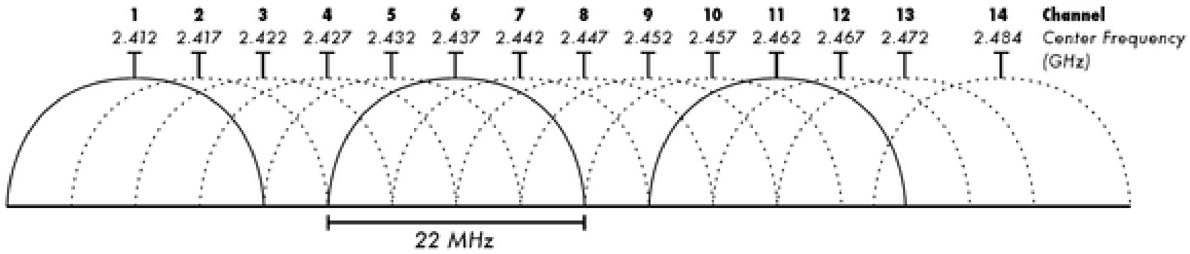

Fig. 11. 802.11 2.4 GHz spectrum band channels

The frequency bands in 802.11 are divided into channels. Fig. 11 shows how the most commonly used frequency band (2.4 GHz) is divided into fourteen channels [27]. The channel bandwidth is 22 MHz and the space between two channels is 5 MHz. It can be seen that only three of the channels are not overlapped. For the 5 GHz band, there are more channels available and the overlap among them is less, but there is a shorter communication range.

WiFi operates on unlicensed spectrum. This allows any WiFi-enabled device to access the spectrum and therefore it might cause interferences among devices accessing the spectrum.

Security

Different keys have been introduced to ensure the security of WiFi. The first was Wired Equivalent Privacy (WEP) which receives a text message from clients. This message is encrypted and sent back using a pre-shared key. WEP was not very secured and was easily hacked. New solutions WPA and WPA2 were then introduced with better encryption mechanisms.

Access Method

WiFi access can be deployed as either secured or unsecured. In secured access, the network is considered as closed since only the end-users with access to a security feature such as a password can access the network. In unsecured access, the network is open and any end-user with a WiFi-enabled device can access it. Another common access method is the use of SIM-based authentication which is deployed by mobile operators that allow their subscribers to access the WiFi network.

Deployment

WiFi is mainly deployed by subscribers of fixed broadband providers. However if a mobile operator also owns fixed networks, they can offer WiFi service through their fixed broadband network. Furthermore, they also can integrate the WiFi networks with their macro networks.

Challenges

Since WiFi is operating in unlicensed band, it is susceptible to radio interferences and it is important to manage this properly. Future versions of the 802.11x standard may need to find new frequency bands to operate on.

Benefits

As WiFi allows wireless connectivity, temporary end-users can easily connect their devices without the need of a having a wired connection to the access point. This enables a cost-effective way of handling more end-users. Furthermore, as it uses the fixed networks, changing installation of the wiring of the indoor space is not required. It is also easy to install and is able to deliver high data rates to end-users. There is no spectrum cost involved as it operates on unlicensed spectrum. Finally devices that are both embedded with cellular and WiFi modules can also be converted into a WiFi hotspot.

3.2 Femtocells

Overview

Femtocells are low powered (around 20 mW) small base stations/access points that use the fixed network as a backhaul to connect to the mobile operator's macro network. Femtocells are considered as one of the various small cells technologies. The idea of having base stations in homes was first studied at Bell Labs in 1999. Three years later, the first 3G home base station was announced by Motorola. Fig. 12 shows that it is forecasted that shipments of femtocells will increase [28].

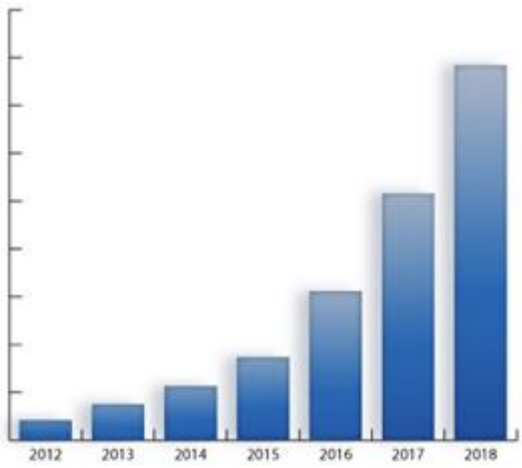

Fig. 12. Femtocell shipments forecast (2012-2018)

3GPP Standards

Femto forum which is now known as Small cell forum began discussion on the architecture for femtocells in early 2008. There were fifteen different variations back then. It was agreed that one common standard is needed to ensure that the product can be successful. A single architecture was established in May 2008. Further details of the standardisation can be found in [29].

LTE is a cellular network and is currently the latest standard being deployed by 3GPP. LTE provides higher data rates and spectral efficiency than High-Speed Downlink Packet Access networks. LTE makes use of evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access which is the access part of the Evolved Packet System (EPS). EPS is based purely on IP. LTE uses OFDM access for access in downlink which makes it less susceptible against multipath interference, whereas it uses Single Carrier-Frequency Division Multiple Access in uplink to deal with high Peak-to-Average Power Ratio. LTE has flexible channel bandwidth ranging from 1.25 MHz to 20 MHz. LTE also supports MIMO which enables higher throughput to cope with the increased traffic demand. Theoretically, the highest data rate can be 75Mbps on uplink and 300Mbps on downlink. Fig. 13 shows the difference among 2G, 3G and 4G networks [30]. In 4G networks, the Radio Network Controller (RNC) is integrated with the eNodeB unlike in 3G networks.

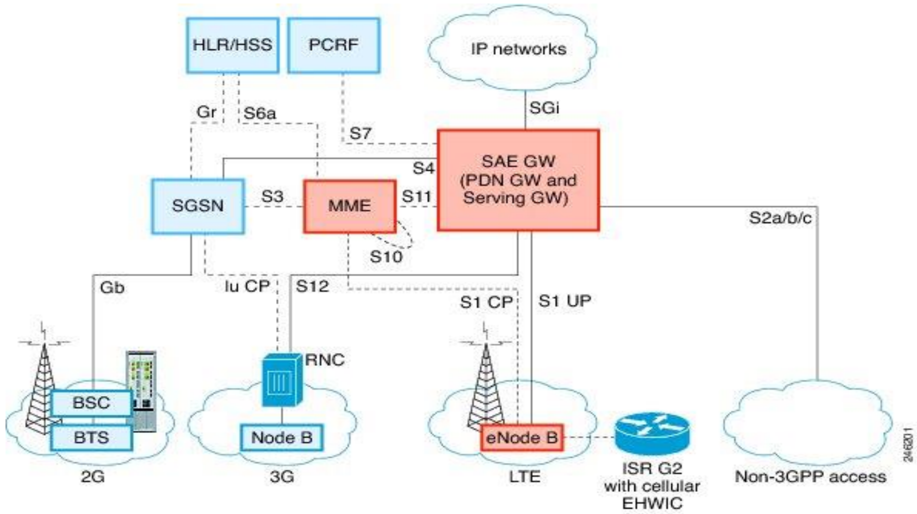

Fig. 13. Cellular networks architecture

<u>Architecture</u>

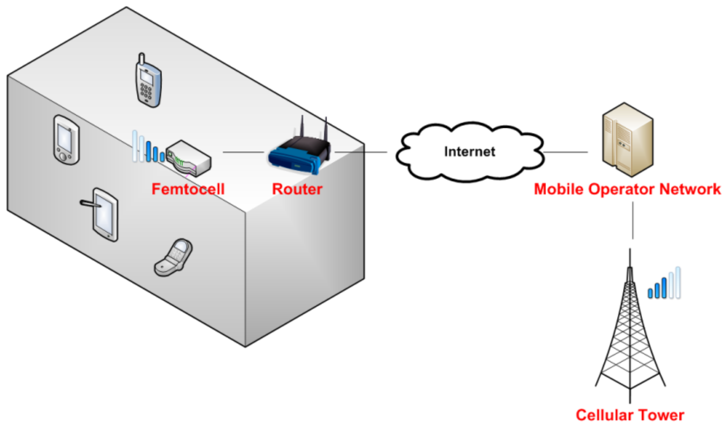

Fig. 14. Femtocell network architecture

Femtocells are not connected directly to the macro base stations. Instead, as shown in Fig. 14, they are connected to the mobile operator's network via a router and fixed IP network (internet) [31]. Femtocell service provisioning requires a femtocell gateway in the mobile operator's network.

Spectrum Management

Femtocells use licensed frequency bands which are usually the same as the macro network. Therefore management of the spectrum to prevent and minimise interference is important. According to [32] there are three main interference issues.

Desensitised femtocell or device: Devices and base stations are made to operate within a certain dynamic range in mobile networks. When the device and a femtocell are close to each other, this creates high signal levels which are beyond the receiver's sensitivity range. The device's receiver is saturated on the downlink and in turn degrades the performance of the demodulation. A very high noise rise can be created on the uplink and this will make the whole system not stable.

Interference between macro and femtocell: Both uplink and downlink can experience interferences caused by the femtocell. To illustrate this, a femtocell can cause a significant interference on the downlink to other devices not served by it. On the uplink, those devices served by the femtocell can cause significant interference to those devices served by the macro network.

Inter-femto interference: Femtocells can cause interference to each other. Femtocells deployed near a wall which separates two apartments can cause interference to the nearby apartments. This is probably due to unplanned deployment.

One possible solution to solve the issues is to tune the signal power between the femtocell and the macro network. The solution is called "Femtocell Downlink Transmit Power Self calibration". In short the femtocell receives the downlink measurements from other femtocells and/or the macro network to determine the power level for transmission.

Handover

For femtocell deployments, there are three types of handovers which were well defined in 3GPP specifications. Proper specifications are needed for each case. Hand-in refers to handover that happens from macro to femtocell network. Hand-out is opposite from hand-in as handover happens from femtocell to macro network. Lastly is femtocell to femtocell handover refers to the device moving from one femtocell region to another femtocell region.

Security

The backhaul link that femtocells are connected to is unsecured. Therefore the strength of the encryption algorithm between the femtocell and the security gateway must be robust enough to ensure confidentiality is kept and security not breached.

Backhaul

Femtocells are mainly backhauled through the fixed networks and then through a femtocell gateway to the mobile operator´s core network. Speed and delay are important factors for high performance End-to-End backhaul. Table 3 describes the requirements for the backhaul for small cells including femtocells [33].

Table 3. Backhaul requirements for small cells

Backhaul Requirement	Compared to Macrocells	Notes
Cost	Cheaper	Cost per link should be lower. Cost per bit may be similar.
Capacity	Traffic load is lighter but burstier	Small cells generate less backhaul traffic than multi-cell/mode/band macrocells, but the traffic is much burstier.
Scalability	More scalable	Faster growth requires rapid deployment despite shorter lead times.
Latency	More delay tolerant	Delay sensitivity depends on service level expectations. Femtocells are designed to cope with lower quality connections. Femtocell handover is less important.
Availability	“Five Nines” not needed	Small cells will form an offload underlay to a higher-availability macrocell.
Size & Weight	Smaller and lighter stations	Small cells require deployment in locations with limited space availability. Compact backhauling solution is essential.
Access to Backhaul	More difficult	Small cells are close to users – on the street and indoors, relatively far from backhaul sites. These sites are harder to reach than tower-based macrocells.
Installation & Commissioning	Faster, simpler, cheaper	Consumer femtocells are plug-and-play. Femtocell backhauling should also work this way.

Small cells can also be backhauled wirelessly. The advantage of using a wired backhaul is that it more predictable. For wireless backhauling, choosing the right frequency is important especially in the case of femtocells if it is to be used.

Access Method

There are three different modes of access methods for femtocells which are listed as follows:

1. Open access – Any subscriber of the same mobile operator is allowed access.
2. Closed Subscriber Group (CSG) – The femtocell subscriber has the power to decide which other mobile subscribers of the same mobile operator are allowed access.
3. Hybrid – Similar to CSG only that the temporary end-user does not receive the same network performance as the femtocell subscriber.

Deployment

There are four different ways of deploying femtocells (Fig. 15); single-operator, multi single-operators, multi-operators and multi-operators (roaming) [34]. Mobile operators in Fig. 15 are represented by different colours (green, red and blue) and the colours of the faces represent their respective subscribers.

In single operator deployment, one mobile operator installs a femtocell network in indoor venues to serve its own subscribers. Other mobile operators' subscribers which are present are not allowed access to these femtocells.

Multi single-operator deployment requires access points from each mobile operator. Therefore subscribers from multiple mobile operators can have femtocell access. However this can prove costly for venue owners.

The deployment of multi-operators femtocell network does reduce the number of access points. However the access points need different allocated carriers to each mobile operator. There is no standardisation for this by 3GPP.

The final deployment scenario is similar to the multi-operators case, just that it uses roaming agreements instead of separate carriers.

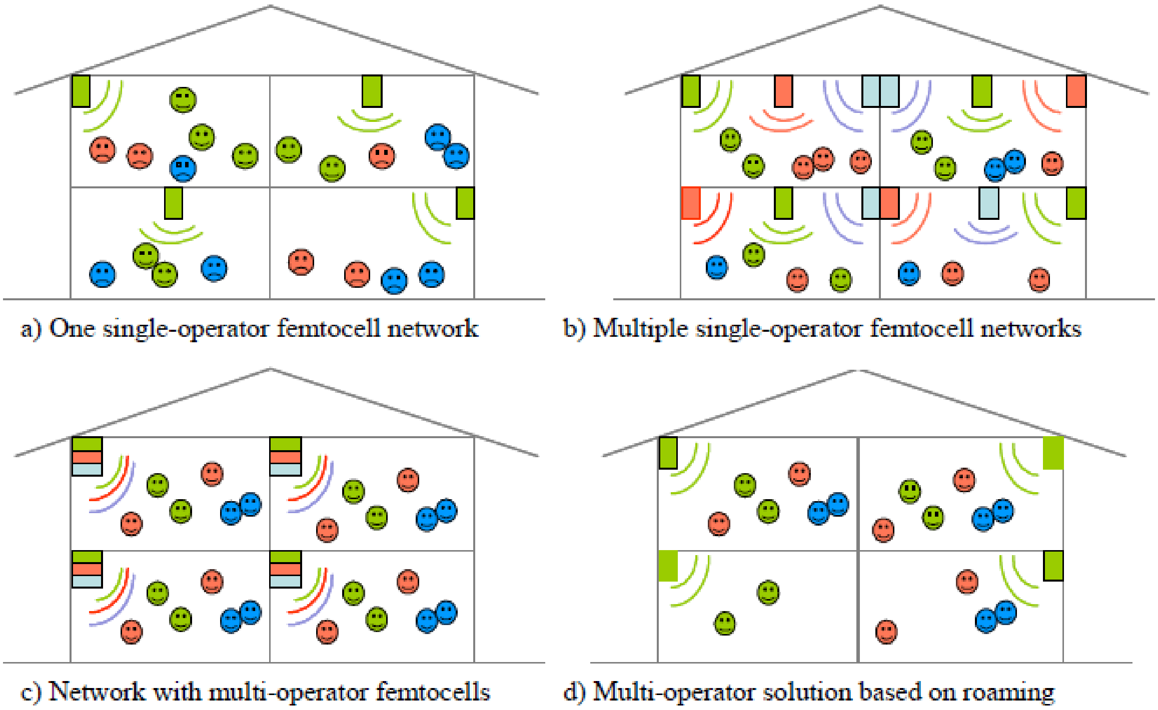

Fig. 15. Femtocell deployment options

Self-Organising Networks

Femtocells can leverage the use of Self-Organising Networks (SON) technology to enable optimization and better management of the network. Network can monitor its own performance and adapt to changing conditions. SON has three main functionalities as shown in Fig. 16 [35] (self-configuration, self-optimisation, self-healing).

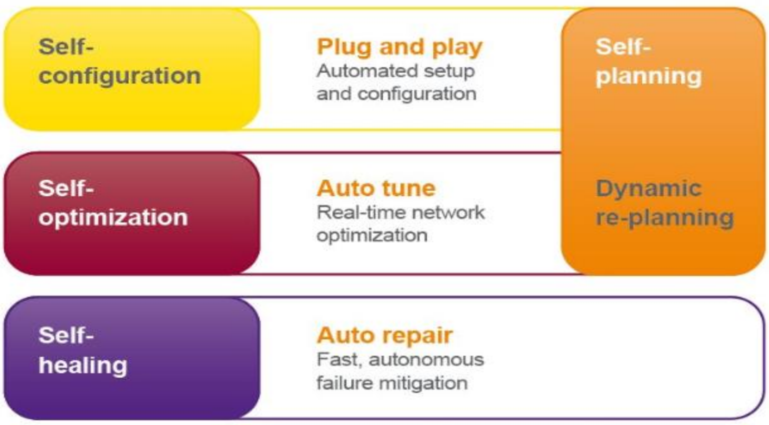

Fig. 16. Components of Self-Organising Networks

New Services

Femtocells can provide new services [36]. Femtocells can act as the platform to distribute multimedia services around the home. Location based services also enables to home owner to know once a family member enter the home by sending a notification. Security service is also enhanced as femtocells will act as a gateway by integrating with sensors and cameras. [37] further mentions how femtocells can be used for public safety and emergency telemedicine scenarios. A smart @ home services LTE femtocell portal solution by Nokia Solutions and Networks (NSN) is shown in Fig. 17 [38].

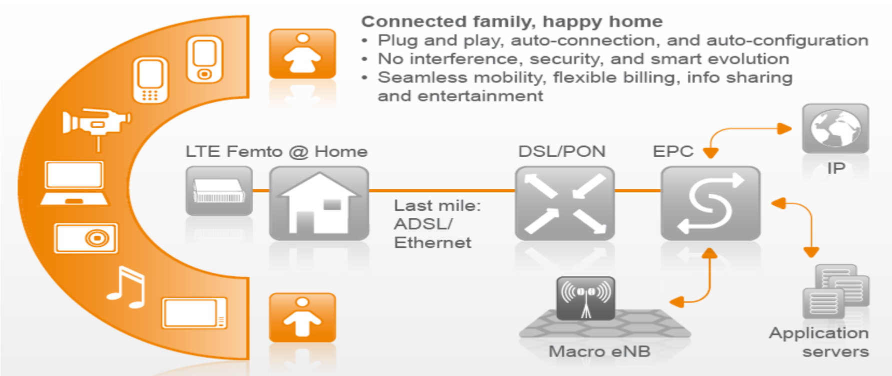

Fig. 17. Smart @ home services LTE femtocell portal

Challenges

Management of femtocells deployed on a large scale is crucial. Improved coverage algorithms have to be developed to tackle the issue of mobility management as deployment of femtocells will lead to many handovers between femtocells and the macro network. As end-users begin installing femtocells, synchronisation is needed to ensure that the received signals are aligned to avoid interference. Managing interference among femtocells and between macro network and femtocells is a key challenge as well. A lot of research has been concentrating on suppression and cancelling techniques such as channel assignment, downlink power management, power capping of end-user maximum transit power and dynamic receiver gain management [39].

Benefits

One of the benefits of a femtocell network deployment is that the end-users can continue to enjoy mobile broadband in homes with high data rates without concerning about penetration loss or data congestion on the macro network. Femtocells at homes can be easily installed by the end-users in the fixed network with simple cable infrastructure. They are small low-powered devices and they do not take up a lot of space. Femtocell can help operators to fill in the coverage holes and there can be seamless connectivity between indoors and outdoors. Finally, new services can be created and provided to end-users.

3.3 Fixed-Mobile Convergence

Fixed-mobile convergence (FMC) is delivering mobile services over the fixed line network. It is the integration of fixed networks with the macro network. As many homes now have fixed broadband internet access via wireless access point, a mobile operator can take an advantage of this to decrease the amount of traffic through their macro network.

3GPP has defined two FMC architectures which are Unlicensed Mobile Access (UMA) and Interworking-Wireless Local Area Network (IWLAN).

- UMA – This uses Global System for Mobile Communications (GSM) signalling for voice services over the circuit-switched radio access network GERAN (GSM Enhanced Data Rates for GSM Evolution Radio Access Network) as well as the IP WiFi access network.
- IWLAN – This uses GSM signalling for voice services over circuit-switched UTRAN (UMTS Terrestrial Radio Access Network) access but Session Initiation Protocol (SIP) signalling for voice services over WiFi access.

UMA uses existing mobile switching centres. The mobile core network is also mostly the same. Therefore this allows transparency of service and seamless roaming between GSM and WiFi.

IWLAN on the other hand is future oriented and was specified for 3G Radio Access Networks (RANs). The devices require SIP and investment for core IP Multimedia System (IMS) infrastructure. The voice continuity server is needed to ensure there is roaming between WiFi and GSM networks. IWLAN addresses the capability to handle roaming of operator. Being closely integrated with IMS, there is access to new services which the IMS core infrastructure delivers.

Both architectures require the security gateway. It is used to authenticate the devices as well as to terminate secured tunnels from devices when they are connected to a WiFi network. UMA was not specified for growing base of 3G services but instead for 2G RANs. As IWLAN is the architecture for current and future technologies, we will focus on it and shown below is a diagram of the IWLAN architecture.

There is SIM authentication in IWLAN. This means that the SIM card on the device is used for authentication. The Internet Engineering Task Force will extend the Extensible Authentication Protocol (EAP) to enable new methods such as EAP-SIM for 2G networks and EAP-Authentication and Key Agreement for 3G networks to be created.

Voice and data traffic both have to flow through the same access network. Voice is served by Mobile Switching Centres while data are served by Serving General Packet Radio Service Support Nodes **(**SGSN) and Gateway General Radio Packet Service Support Nodes (GGSN) as it flows through the IP part of UTRAN.

In IWLAN, there is a new entity called Tunnel Termination Gateway (TTG). Its purpose is to perform functions such as authenticating devices through authentication, authorisation and accounting (AAA) and allocating IP addresses. TTG can terminate the WiFi transport tunnel and connects it to GGSN. This way the operator hosted services is exposed behind the GGSN. The Packet Data Gateway (PDG) on the other hand allows access to the internet itself and manages the session. GGSN traffic can be offloaded this way. Seamless handover between macro and WiFi networks can be seamless by the use of underlying IP-mobility based methods. Fig. 18 shows the IWLAN architecture [40].

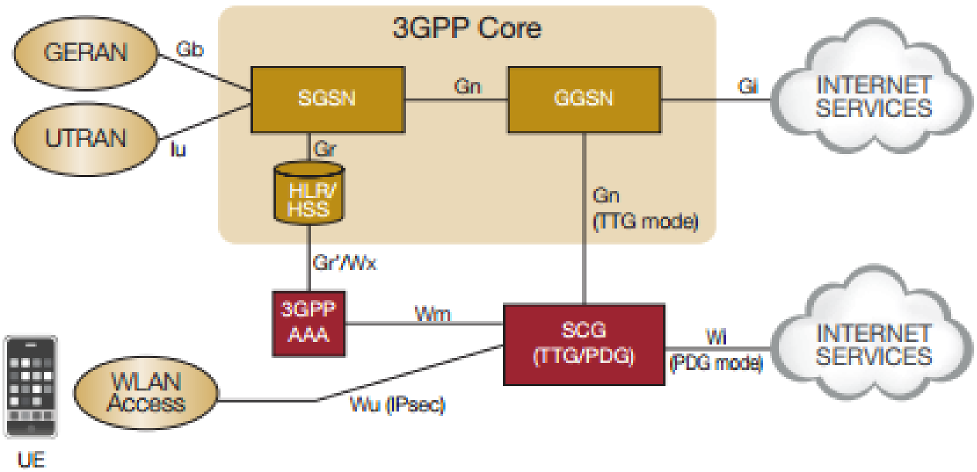

Fig. 18. IWLAN architecture

For FMC, there are two types of access defined in 3GPP for WiFi. They are trusted and untrusted access.

- Trusted: This was introduced in 2008 under 3GPP Release 8. It is usually assumed to be operated by the operator (e.g., operator-built WiFi access). There is sufficient security mechanisms integrated such as a secure authentication method.
- Untrusted: It was first introduced in 2005 under 3GPP Release 6. It is when the operator does not have control over the network. It can also be seen as access to the network does not have sufficient security features embedded into it.

Fig. 19 and Fig. 20 illustrate the differences between the trusted and untrusted model [41].

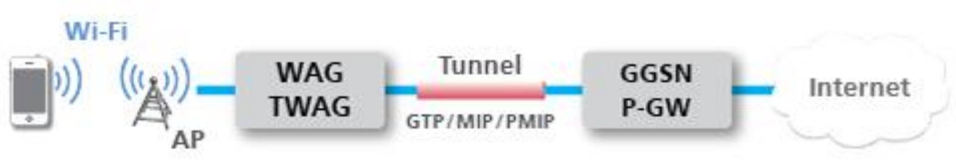

Fig. 19. Trusted access in 3GPP for WiFi

Fig. 20. Untrusted access in 3GPP for WiFi

IWLAN enables mobile operators an opportunity to have more control over their subscribers when they use WiFi networks. The subscribers will still have to access 3GPP services. Mobile operators can easily increase their capacity through the WiFi networks. It also allows them to easily offload the mobile traffic to the WiFi networks. Usability, security and mobility are then improved. There can be a continuation of session and applications will not be affected when the user moves from one WiFi network to another. This is so as the exact IP address is kept. For LTE networks, IWLAN has evolved to include evolved packet core which in turn brings out the trusted and untrusted access architectures. Fig. 21 and Fig. 22 show NSN solution for over trusted and untrusted WiFi access that have integration with the packet core network [42].

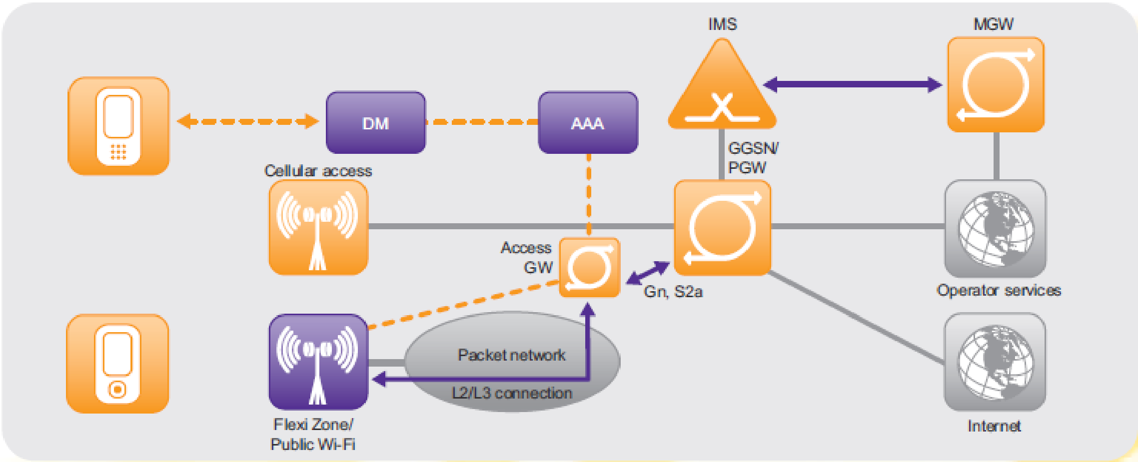

Fig. 21. Trusted WiFi access (packet core network integration)

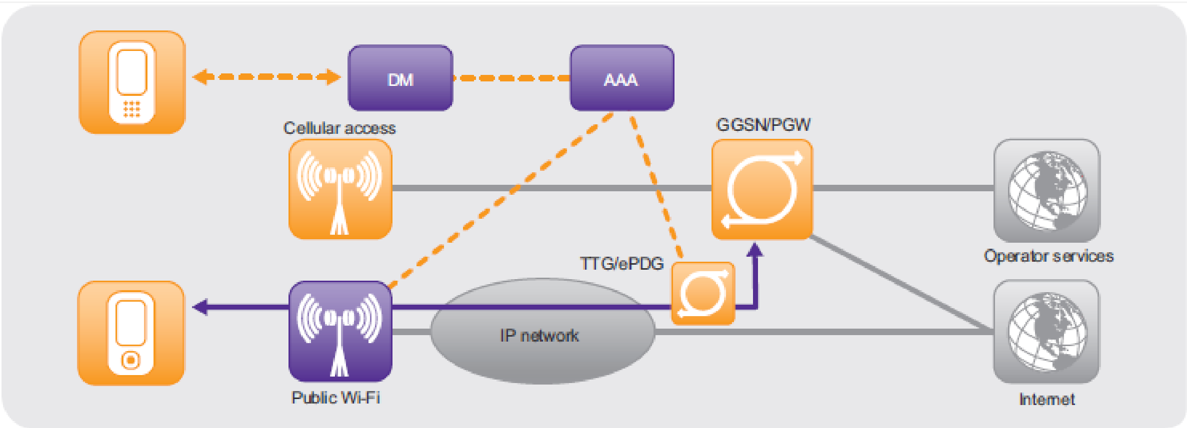

Fig. 22. Untrusted WiFi access (packet core network integration)

3.4 Cognitive Radio

Cognitive radio is a revolutionary concept which promises ensure that wireless spectrum resources are used more efficiently. The definition taken from [43] is known as:

- "Cognitive radio identifies the point at which wireless personal digital assistants and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to, detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs."

Cognitive radio networks differ from traditional networks in the sense that devices need to have awareness of the dynamic environment around them. Then they will have to adapt their operating parameters with their interactions with the environment which includes other devices. Traditional ways of sharing the spectrum cannot apply to cognitive radio networks as there is an assumption that all devices in the network are in a static environment and they unconditionally cooperate.

For a cognitive radio network, the devices' performance can be optimised and act upon when necessary. This is so as they have the intelligence to learn and observe the dynamic environment. However if the devices are pursuing different goals and are under different authorities, there might not be fully cooperative behaviours. The authorities will only allow cooperation if it brings them benefit.

Dynamic spectrum access can be divided into three classes. Dynamic exclusive use model is similar to a static model where the users of the spectrum have exclusive licence to access it. However the difference is where there is dynamic allocation of channels among the licences. For open sharing model, there is equal competition among users for spectrum use. For hierarchical access model, those that own a licence for spectrum usage (primary users) have higher priority than those without (secondary users) [44].

3.5 Summary

Table 4 shows the comparison of different aspects between WiFi and femtocells. Although WiFi and femtocells can be perceived as very similar in nature, they have many differences. Each technology has its own benefits and drawbacks.

Future solutions should always look to ensure that the quality of the delivered service is at respectable level. At the same time, new ecosystems could emerge. In the future, there should be flexibility to use the spectrum to meet the quality of service and capacity needs. High value and QoS sensitive traffic should be able to route to WiFi networks. Regardless of having multiple end-users or being in a multi-cell, future solutions should be found to ensure that the experience of high data rates and coverage are not compromised. There should also be a cost benefit solution when combining the macro network with indoor networks. Power efficiency and better battery life should constantly be improving.

Table 4. Comparison between WiFi and femtocells

Aspects	WiFi	Femtocells
Spectrum utilisation and QoS	Operates on unlicensed bands (2.4 GHz and 5 GHz)	Operate on licensed band (e.g., LTE 2.6 GHz)
	More spectrum and bandwidth available	Might be able to use unused licensed Time-Division Duplexing (TDD) bands
	QoS not guaranteed	QoS guaranteed
Data Rates, Capacity, Coverage	Provides high data rates	Provide higher data rates and coverage
	Interference among devices	Macro-femtocell interference issues
	Around 10- 15 end-users	Small number of end-users (around 4-8) for homes
Cost (Capex/Opex)	No cost for spectrum	Spectrum cost
	Proprietary network management	Able to integrate SON
	Access point is cheap	Access point more costly than WiFi
Business opportunities	Huge number of devices	Limited to handsets/tablets
	Allow virtual usage of fixed line	New services available (e.g., location based)
Power Efficiency	High power consumption of terminal (case of nomadic mobility)	Power efficient idle mode
Networks	Limited mobility	Seamless mobility
	Traffic directed connected to internet via fixed lines	Traffic through mobile core network
	No international roaming	International roaming (SIM card)
Applications and Content	High data rate priority	Coverage and QoS over data rate
	Voice over IP (VoIP)	High voice quality
	Best-effort high data	QoS as high priority
Business Model and Competition	Unbundled from services	Bundling of services
	Easy to enter device market but hard for network market	Difficult to enter network and device markets
	No gatekeepers	Operators act as gate keepers

A new ecosystem could emerge based on various factors. There could be certificate-based authentication both on national and international roaming. The priority will be focusing on high data rates and not on voice. Handover should be conducted to VoIP only if necessary. Bundling would not only exist in pure network operator models. Operators will add value by bundling, roaming, service management & control.

4. Methods

4.1 Value Network Configuration

Value network analysis is used to study and understand internal and external value networks in complex economic systems. The idea of using value chain as a tool for the representation of discrete but interlinked activities was introduced by Porter [45]. It forms part of a business strategy. A value chain consists of sequential activities that a firm operates to create value in products or services. Several value chains can be combined together to form a value system. [46] discusses how different actors in a market can co-operate to co-produce value. Roles and relationship among the various actors might also be reconfigured. [47] criticises the traditional value chain method and instead supports value network as a web of relationships that generates value via dynamic and complex exchanges.

A tool has been introduced by Casey et al. [48] to study value networks, illustrating the different actors, their roles and the technical components. One of the most important components which define what roles can be assigned to the actors is the technology. A VNC presents all the relevant actors and their interrelation. Business interfaces (e.g., contracts and transactions) are established among the actors and technical interfaces (e.g., radio protocols) show how the technical components are connected and related to each other. Fig. 23 shows the notation that is used to illustrate the building blocks for VNC [48].

The definition by Casey et al. of the roles and technical components are as follows [48]:

- Technical component: “A collection and realisation of technical functionalities, including the technical interfaces to other technical components.”
- Role: “A set of activities and technical components, the responsibility of which is not divided between separate actors.”

The technical interface may appear in three different colours and they are listed as follows:

- Black interface: A connection between technical components (general)
- Blue interface: WiFi connection
- Red interface: Cellular (3GPP) connection

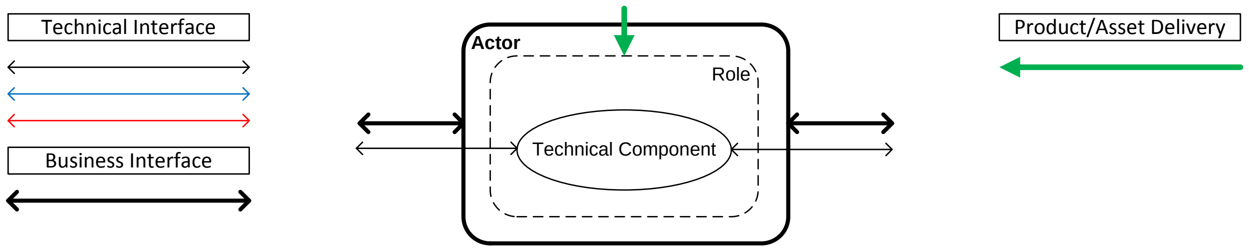

Fig. 23. VNC notation

4.1.1 Indoor Technical Solutions

Indoor coverage can be served either by having a local area network indoors or by macro networks. There are many different solutions to ensure that end-users get sufficient coverage indoors. Each indoor technical solution not only poses difference in architecture but also have different business roles among the actors. Some offer mobile offloading solutions while others simply extend the range of the macro network.

Table 5 lists the various indoor technical solutions and the accessibility of different end-user groups. However only the first six scenarios which include both WiFi and femtocells are shown in this section as they are the ones which are most likely to be deployed in homes and have the capability to offload the macro networks. These six scenarios are known as “mobile offloading wireless access provisioning in homes” in this thesis. The other remaining indoor technical solutions are mentioned briefly.

- Distributed Antennas System (DAS) – It is a system where the antenna nodes are connected to a common source. These nodes are spatially separated and able to support different frequency bands. Typically, DAS is deployed in large indoor locations such as enterprises.
- Picocells - These are low-powered (200 mW) single-sectored small cells, which are usually deployed in indoor areas such as shopping malls.
- Microcells – These are slightly larger cells than picocells which are usually installed in urban areas. Their typical maximum transmission power is 2 W.
- Relays – Relays receive and retransmit the signals between base stations and mobiles increasing throughput and extending coverage of cellular networks.
- Fixed Receivers – Outdoor antennas are installed on the building’s roof to increase coverage (especially in rural areas).

Table 5. List of indoor technical solutions

(cross - definitely have access, blank – no access, circle – access if granted, asterisk - network access to internet shows 3GPP situation while for IEEE situation, it is same as case 1, fixed-mobile operator (FMO), mobile virtual network operator (MVNO), passive optical network (PON))

Scenario		1	2	3	4	5	6	7	8	9	10	11
Indoor Technical Solutions		WiFi non-integrated fixed-mobile operator (secured/unsecured)	WiFi integrated fixed-mobile operator (secured/unsecured)	WiFi cellular integration – home owner controlled (secured/unsecured)	WiFi cellular integration – MO controlled	Femtocell open access	Femtocell CSG/hybrid	Distributed Antennas System	Outdoor Microcell and/or Picocell	Relays on windows	Outdoor Relays close to houses	Fixed Receivers indoor and/or outdoor
END-USER GROUPS	Home owner	x/x	x/x	x/x	x	x	x	x	x	x	x	x
	Family with same MO	x/x	x/x	x/x	x	x	x	x	x	x	x	x
	Family with different MO	x/x	x/x	x/x	○							
	Guests with same MO	○/x	○/x	○/x	x	x	○	x	x	x	x	x
	Guests with different MO	○/x	○/x	○/x	○							
	Invaders with same MO	/x	/x	/x	x	x		x	x	x	x	x
	Invaders with different MO	/x	/x	x	○							
Indoor Access Technology		IEEE	IEEE	IEEE	IEEE	3GPP	3GPP	3GPP	3GPP	3GPP	3GPP	*IEEE/3GPP
Access Control		Home owner	Home owner	Home owner	MO	MO	Home owner and MO	MO	MO	MO	MO	Home owner (IEEE) Home owner and MO (3GPP)
Mobile Offloading		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Deployment		Home owner	Home owner	Home owner	Home owner	Home owner	Home owner	MO	MO	MO	MO	Home owner
Mobile Operator Type		non-integrated FMO	FMO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO	FMO, MO or MVNO
Backhaul Connectivity		Fixed Network (xDSL, xPON, cable, etc)	Fixed Network (xDSL, xPON, cable, etc)	Fixed Network (xDSL, xPON, cable, etc)	Fixed Network (xDSL, xPON, cable, etc)	Fixed Network (xDSL, xPON, cable, etc)	Fixed Network (xDSL, xPON, cable, etc)	Wireless connection (3GPP) or fixed connection	Wireless connection (3GPP) or fixed connection	Wireless connection (3GPP)	Wireless connection (3GPP)	Wireless connection (3GPP)

All the indoor technical solutions can be shown through VNC representation. The actors, their roles, the technical components as well as the business and technical interface have to be identified. Table 6 shows the relevant actors while Table 7 presents and analyses the important roles which can be found in a VNC of mobile offloading wireless access provisioning in homes.

Table 6. Relevant actors for mobile offloading wireless access provisioning in homes

Actor	Relevance
End-user	usage of internet (mobile subscriber and/or WiFi end-user)
Mobile Operator	providing mobile broadband service
Fixed Broadband Provider	providing fixed broadband service
Home Owner	owner of building space who deploys/owns the access points

Table 7. Role analysis of mobile offloading wireless access provisioning in homes

Role	Drivers for Role Importance
Equipment Provisioning	+: demand for technical enhancements, locked-in effect -: open technologies
Device Provisioning	+: demand for new innovative devices and services, ‘smart’ connectivity applications -: open technologies
WiFi Usage	+: increasing number of WiFi-enabled devices -: increasing number of services requiring QoS
Cellular Usage	+: good mobile coverage, new services requiring QoS -: bad mobile coverage
Home Access Network Operation	+: demand of locally operated home networks -: availability of open access WiFi networks, good cellular QoS in homes
Access List Client Operation	+: access control of initiating requests to internet -: femtocells in open access mode
Access List Server Operation	+: fragmented authentication requests, responding to requests for internet access -: femtocells in open access mode
Fixed Internet Access Operation	+: few fixed broadband providers, usage of unlicensed spectrum -: improvement in cellular technologies
Wide Area Network Operation	+: few mobile operators -: MVNO, regulation
Network Integration Access Operation	+: femtocell and WiFi-cellular integration networks -: standalone indoor network operation

Equipment provisioning for wide area and home networks is important. Intellectual Property Rights can limit the market to just a small number of actors. The vendors for such equipment can enable a locked-in effect by offering many propriety extensions on top of their basic offering. However, open technologies such as WiFi reduce the importance of this role.

As technology advances, more new services can be offered to end-users. This will lead to an increase in devices that can offer such services. The future devices have to support various technologies to provide seamless connectivity and ensure a smooth end-user experience when end-users are moving from a coverage area of one supporting technology to another. However the use of open technologies could reduce the importance of device provisioning.

The proliferation of only WiFi-enabled devices leads to the increase of WiFi usage for internet access. However, the increasing number of content providers who offer services that require QoS such as streaming of media (e.g., IP Television) decreases the importance of the role of WiFi. Mobile subscribers request sufficient coverage and good capacity for these high data rate services from the cellular networks. Without these two elements, cellular usage is restricted and mobile operators may end up losing their subscribers.

Home owners are likely to strongly prefer to fully control the access over their own home networks when they establish a subscription contract. However, if there are open WiFi networks available, the role of home access network operation is reduced. With good cellular QoS in homes, it also reduces the need for femtocells.

The important function of the access list client operation is having the control over end-users who want to access the internet through the home access point. In femtocell open access, the home owner loses this role. In the access provider side, the access list server operation responds to requests made by clients and has to handle fragmented authentication requests, particularly for WiFi-cellular integration (MO controlled). For femtocell open access mode, this role is removed.

The role of fixed internet access operation is taken by companies which own the infrastructure for fixed networks. With few actors offering fixed internet networks, it makes this role more important. Additionally, another factor that gives this role more importance is the utilisation of unlicensed spectrum for wireless access through fixed broadband networks.

The role of wide area network operation is taken by few mobile network operators. Due to few mobile operators, this role gets more important. Improvements in cellular technologies such as LTE may reduce the role of WiFi for mobile devices and fixed internet access operation. The presence of MVNOs reduces the importance of wide area network operation.

Finally, network integration access operation is needed when there is integration of home and macro networks. Also, how to manage and route the WiFi and cellular traffic is also essential when WiFi-cellular integration takes place. For standalone home networks such as WiFi networks, this role is redundant.

Based on the accessibility of different end-user groups in cases 1 to 6 (Table 5), relevant actors (Table 6) and aforementioned important roles (Table 7), a generic VNC of mobile offloading wireless access provisioning in homes is constructed (Fig. 24). Six figures (Fig. 25 - 30) further describe the potential VNCs which could emerge.

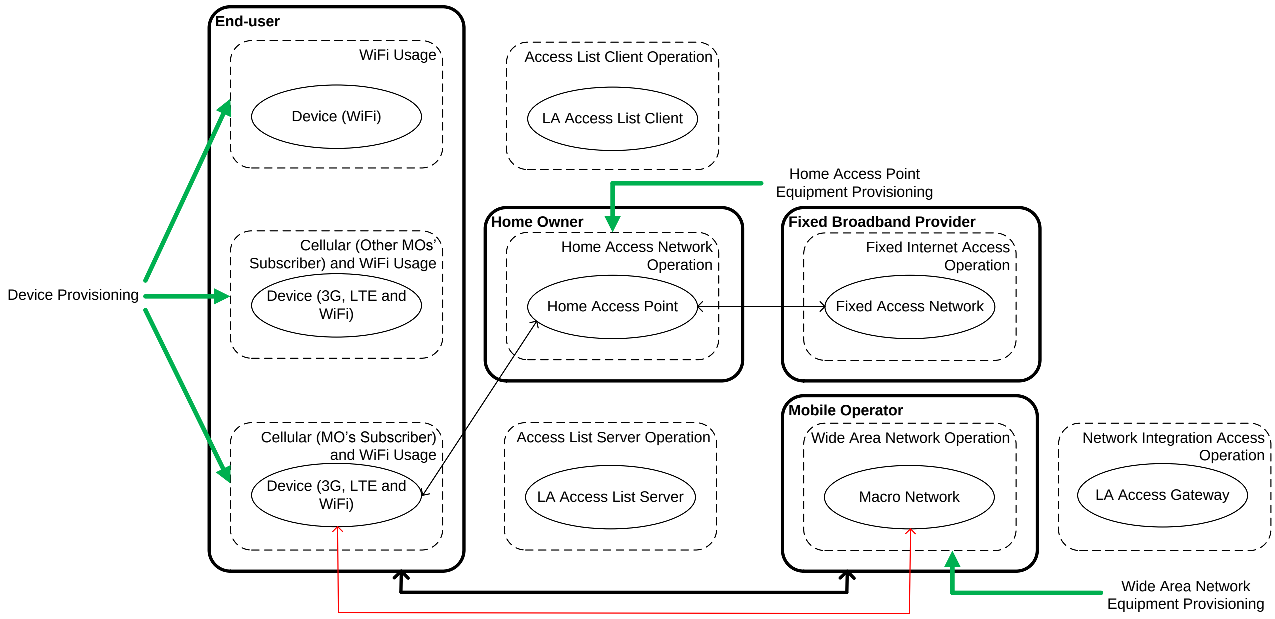

Fig. 24. Generic configuration for mobile offloading wireless access provisioning in homes

WiFi (scenarios 1 and 2)

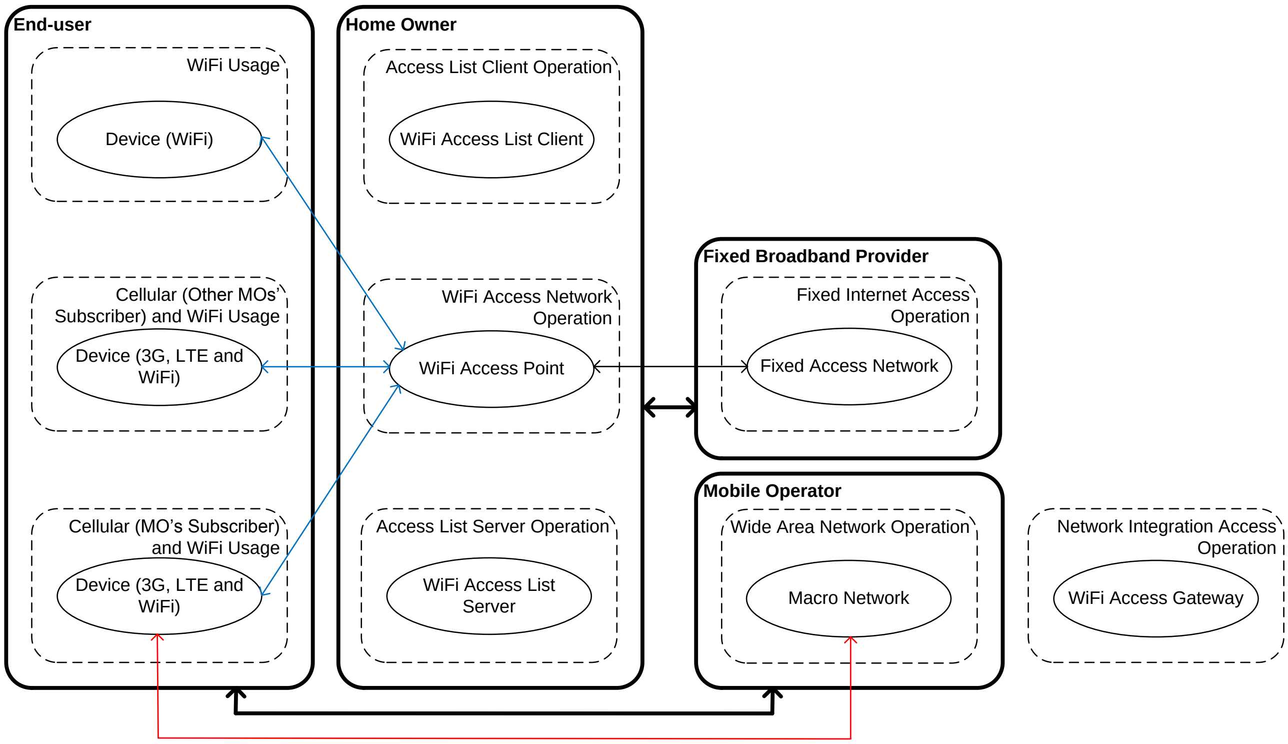

Fig. 25. WiFi access VNC (scenario 1: non-integrated fixed-mobile operator)

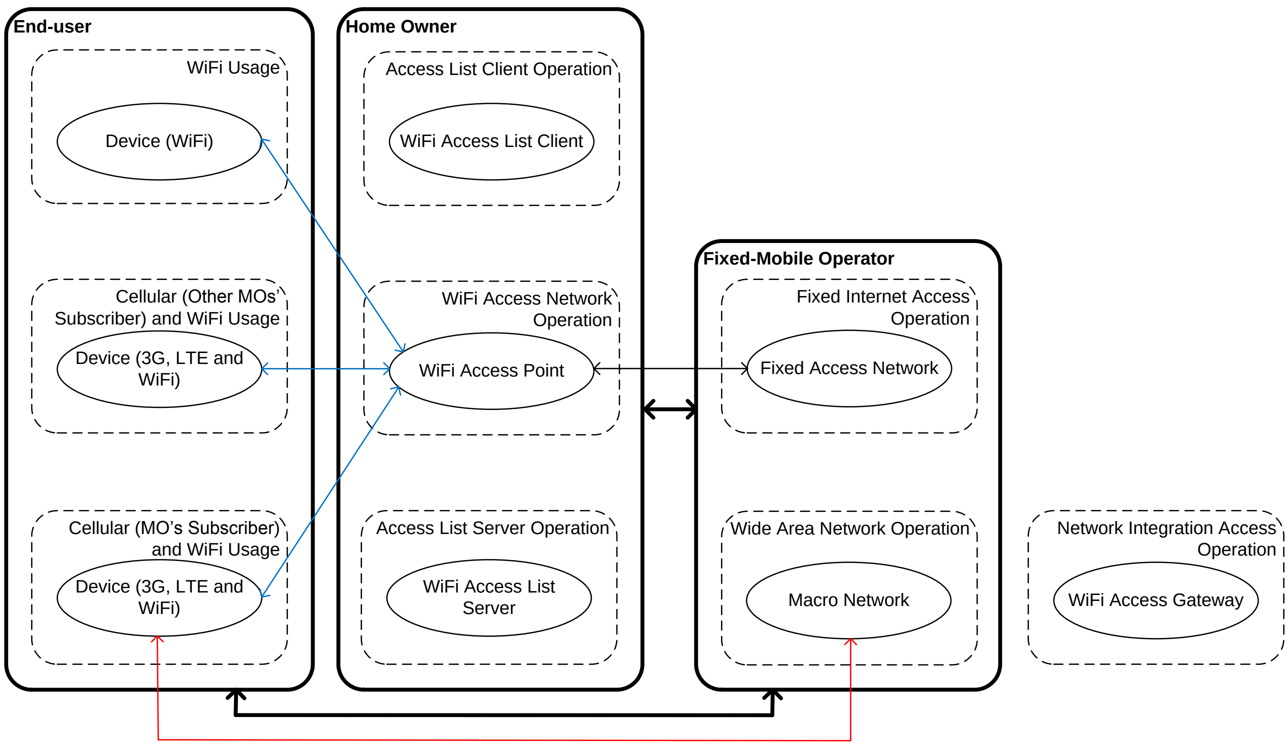

Fig. 26. WiFi access VNC (scenario 2: integrated fixed-mobile operator)

Scenarios 1 and 2 (WiFi access VNCs) are the classical ones which are widely currently adopted by home owners. As WiFi access points are easy to use, install and with open interfaces, it is a good and affordable solution for home owners to adopt for internet access in homes.

Home owners can easily install and operate the access points. Furthermore, they can control the access interface for their homes. There is also a lot of device flexibility. This is particularly so as WiFi is embedded into many consumer electronic products. The WiFi access VNCs (Fig. 25 - 26) are therefore an attractive proposition for the home owners. There is also no locked-in effect as WiFi access points are independent of any broadband provider.

The main difference is that in scenario 1, mobile operator and fixed broadband providers are two separate companies, whereas in scenario 2, fixed-mobile operator is one company which runs two separate businesses (these two businesses have different billing systems). Home owners can have different contracts with the fixed broadband provider and mobile operator (scenario 1) or one unified contract with fixed-mobile operator which bundles both fixed broadband and mobile subscriptions (scenario 2). In terms of mobile offloading, this will be the first option that mobile operators and fixed-mobile operators will deploy.

In both VNCs, if the WiFi access is unsecured, any end-user with a WiFi-enabled device can connect to the internet over the access point. This is usually evident in public places where WiFi access is provided as a value added service. However, in the context of homes, the home owners have the control to either provide free WiFi service to visitors or to set up security features such as a password to allow only trusted people to access the internet through these access points.

WiFi-Cellular Integration (Home Owner Controlled)

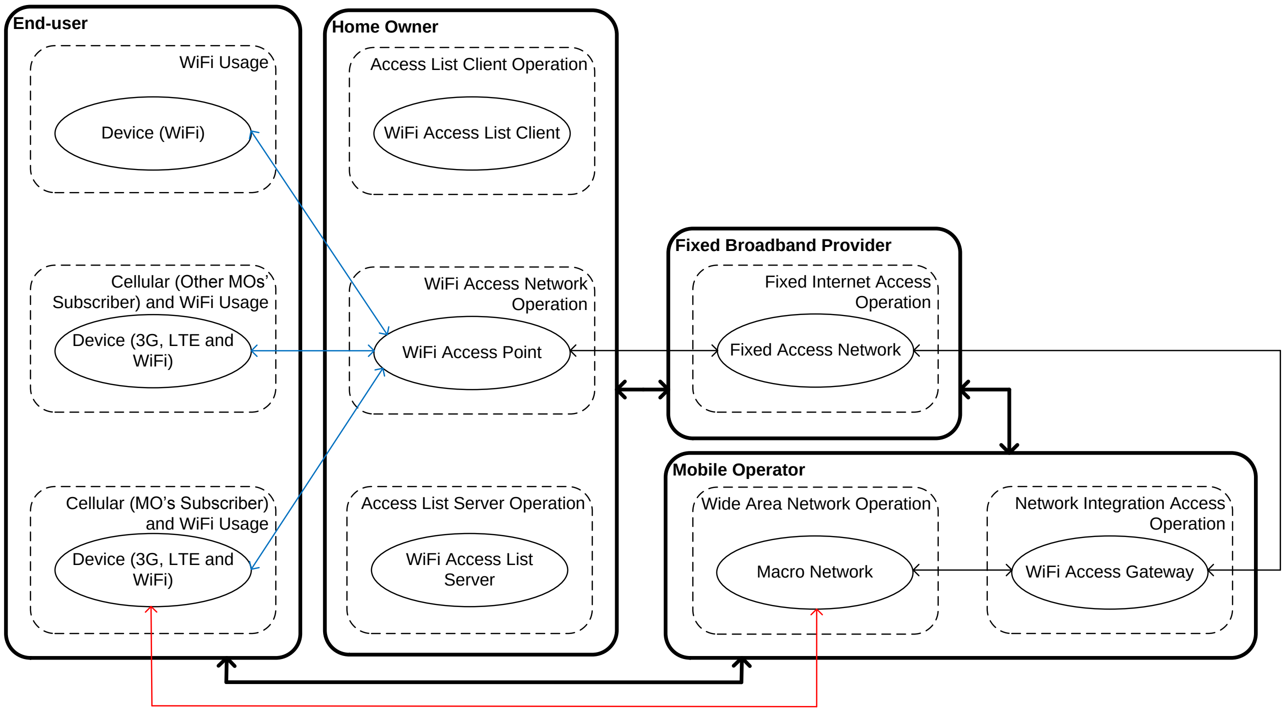

Fig. 27. WiFi-cellular integration access VNC (scenario 3: home owner controlled)

This VNC in Fig. 27 presents the scenario where WiFi and cellular networks are integrated. Internet access in homes is provided over WiFi. Similar to scenarios 1 and 2, the home owners control who can access the internet. This solution is most likely to be followed by fixed-mobile operators, as it is easier for them to integrate the cellular network with the fixed access network. It can also happen when a mobile operator and a fixed broadband provider make an agreement to integrate their networks. If a fixed-mobile operator integrates WiFi and the cellular network, there should be a unified billing system for its subscribers. Integration of both networks may also drive up deployment cost.

This integration allows end-users (mobile subscribers of the same operator as the home owner) who are granted access by the home owner to use 3GPP services over WiFi by the usage of SIM-based authentication. Thus, the WiFi access point needs to support SIM-based authentication. A WiFi access gateway is needed to divert the traffic of different end-users. Its main purpose is to create a local breakout of non-SIM authenticated devices that had been granted internet access by the home owners directly to the internet and not over the mobile core network.

With regards to mobile offloading, WiFi-cellular integration enables mobile operators to push mobile traffic to the fixed networks. This is a capacity problem solution for congested macro networks. This does not solve coverage problems especially in circuit switching domains where voice is the killer application. Where there is no coverage or when voice traffic is also offloaded, using best effort services such as VoIP is the only solution in this VNC.

In 4G networks which allow VoLTE, the integration needs further consideration. Voice traffic in VoLTE uses packet switching which is treated as data traffic. Therefore some form of application is needed to ensure that voice traffic is provided over the cellular network as VoLTE uses licensed spectrum. All other data traffic is routed over WiFi.

<u>WiFi-Cellular Integration (MO Controlled)</u>

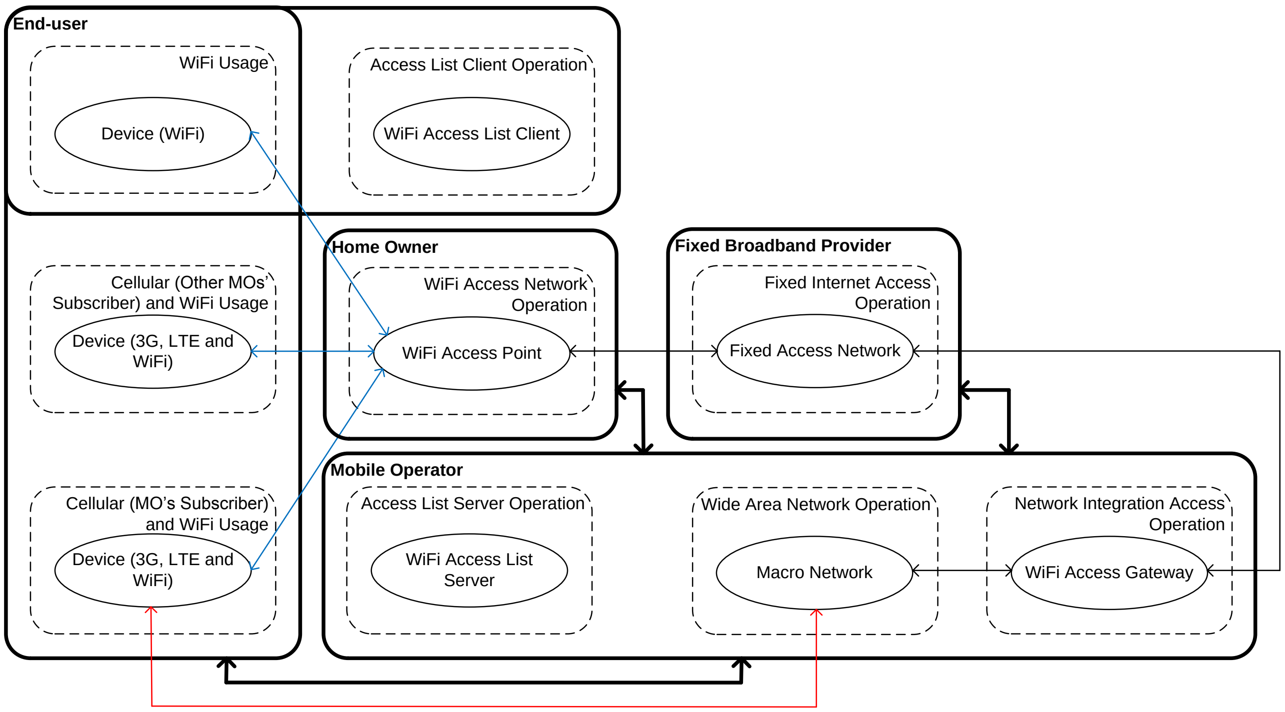

Fig. 28. WiFi-cellular integration access VNC (scenario 4: MO controlled)

Fig. 28 shows the scenario when WiFi-cellular integration is initiated by the mobile operator. The mobile operator provides WiFi access points to its subscribers and makes an agreement with the fixed broadband provider to get the right to use the fixed networks. Home owners deploy WiFi access points but do not have the control on who get access to internet. All the subscribers of the mobile operator automatically get access to the internet through SIM-based authentication.

However, WiFi is used for internet access and hence other non-SIM authenticated devices have the possibility of connecting to the internet over such WiFi access points. In such a case, the mobile operator could be able to monetise these connections. For example, WiFi-enabled but non-SIM authenticated devices could be able to access the internet by making a payment to the mobile operator through an application. A portal based authentication is one authentication method that is most likely used here.

This scenario is favourable when the household of home owners have multiple mobile subscriptions from the same mobile operator. However other widely used consumer electronics which are only WiFi-enabled such as laptops and tablets are not able to gain internet access. The mobile operator has to provide the household a fixed number of SIM-based Universal Serial Bus (USB) dongles to enable such devices to gain access to the internet.

Femtocell Open Access

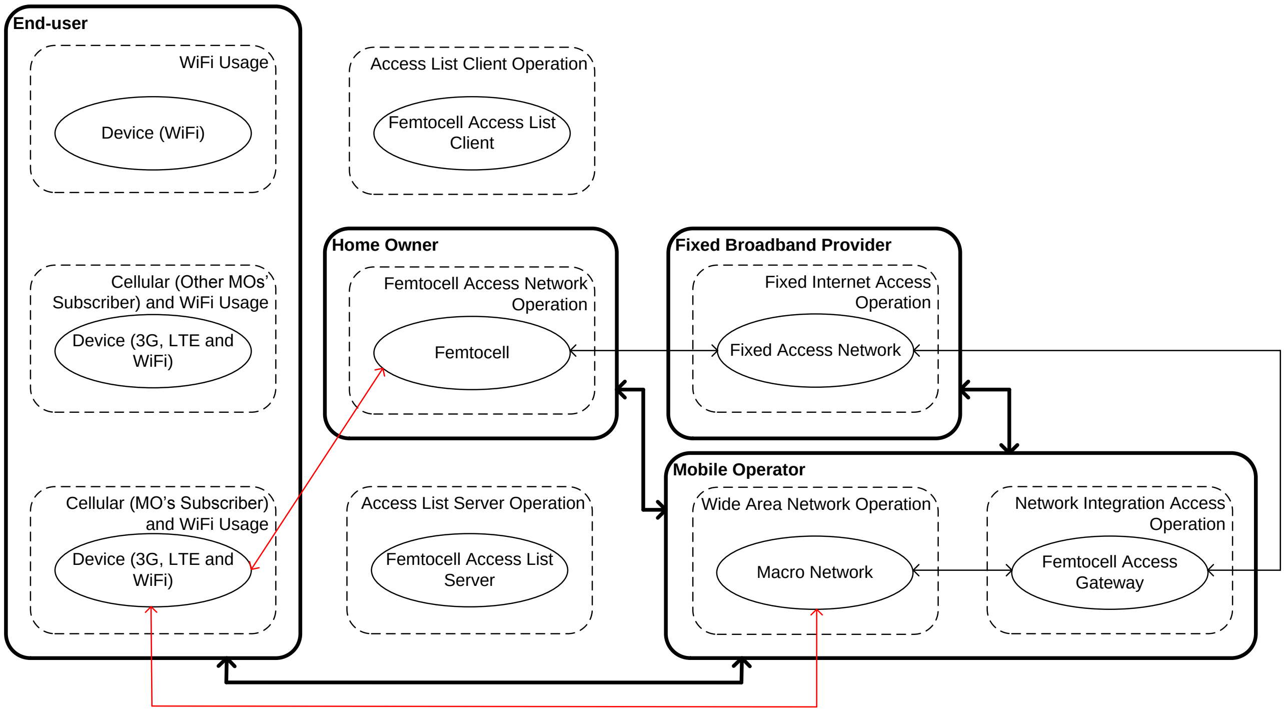

Fig. 29. Femtocell open access VNC (scenario 5)

Femtocell services at homes are provided by mobile operators to improve good capacity, coverage and QoS over licensed spectrum. This strictly means that only the subscribers of the same mobile operator can have mobile broadband access via the femtocell. For mobile operators, this is the best solution in terms of mobile offloading, since their subscribers are retained in their networks. Femtocells use the fixed access network as a backhaul, and therefore the mobile operator needs to have an agreement with the fixed broadband provider. A femtocell access gateway is needed to direct the mobile broadband traffic over its core network.

In Femtocell open access VNC (Fig. 29), home owners cannot have control which MO's subscribers can gain access. All subscribers of the same mobile operator are permitted to be connected to the internet via the femtocell. However, there is limited number of mobile subscribers a femtocell can support. Femtocells in open access mode may be successful in public places rather than homes because, home owners might prefer to have some control over their home networks.

If there is a macro network coverage or capacity problem in the home, the home owner would prefer a femtocell to solve these issues. Femtocells are more expensive than WiFi access points and the mobile operators are likely to charge their subscribers for the access point and/or the femtocell service. On the other hand, regular mobile subscribers pay for mobile services and expect or require adequate coverage from macro network in their homes. Therefore, it would not be a good pricing policy for a mobile operator to ask from their subscribers extra money for better coverage indoors through femtocell service and simultaneously other subscribers can access this femtocell. Consequently, a free femtocell can be the main reason for a successful open access femtocell deployment. It is a win-win situation for both subscribers and mobile operators as mobile operators can quickly improve capacity and coverage problems and probably with low cost.

Femtocell Closed/Hybrid Access

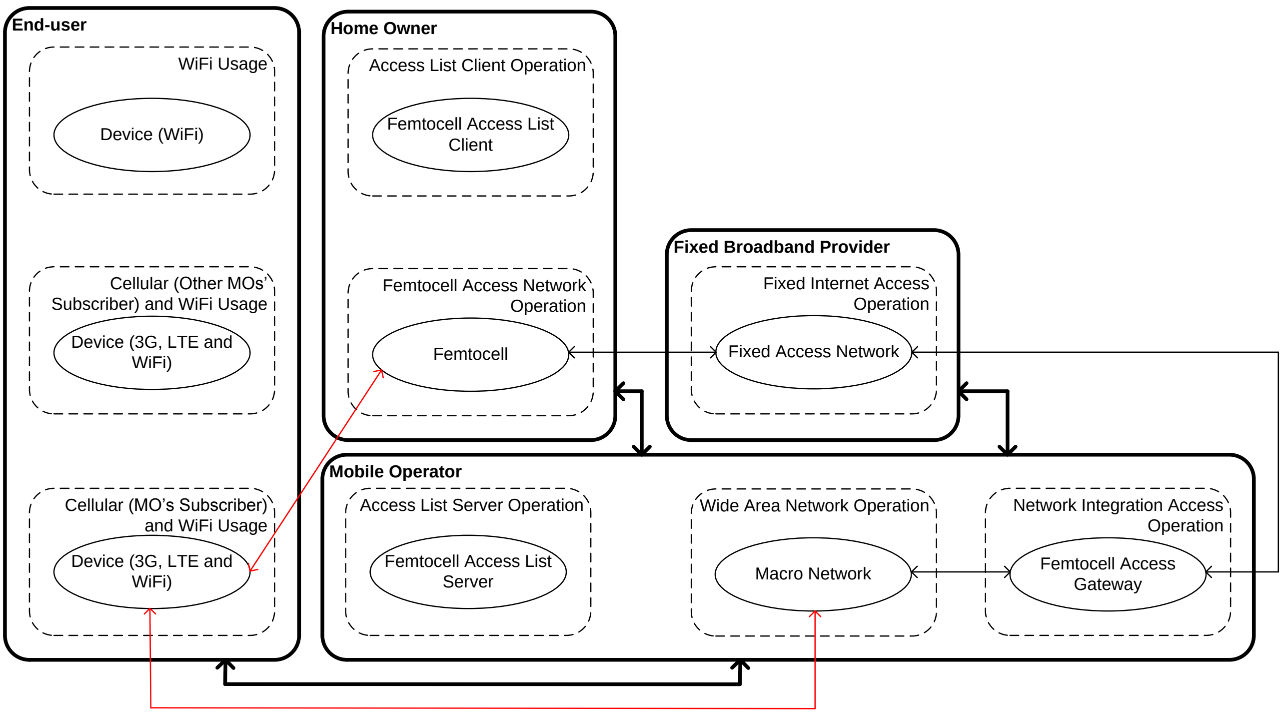

Fig. 30. Femtocell closed/hybrid access VNC (scenario 6)

The Femtocell closed/hybrid access VNC (Fig. 30) might be more preferable for home owners who want to have some level of accessibility control over the femtocell service. This is best suited for a household where all the family members are subscribers of the same mobile operator. Therefore only one femtocell is needed in the home.

If mobile broadband subscriptions are competitively priced and are able to provide good data rates indoors via femtocells, then it allows the possibility for home owners to only subscribe to a single broadband service. In such a situation, the mobile operator may provide USB dongles to home owners to enable their consumer electronics to gain internet connectivity via femtocells. Even though the initial cost of the purchasing a femtocell access point is high, there might be huge savings on broadband subscription fees for home owners with only a femtocell subscription in the long run.

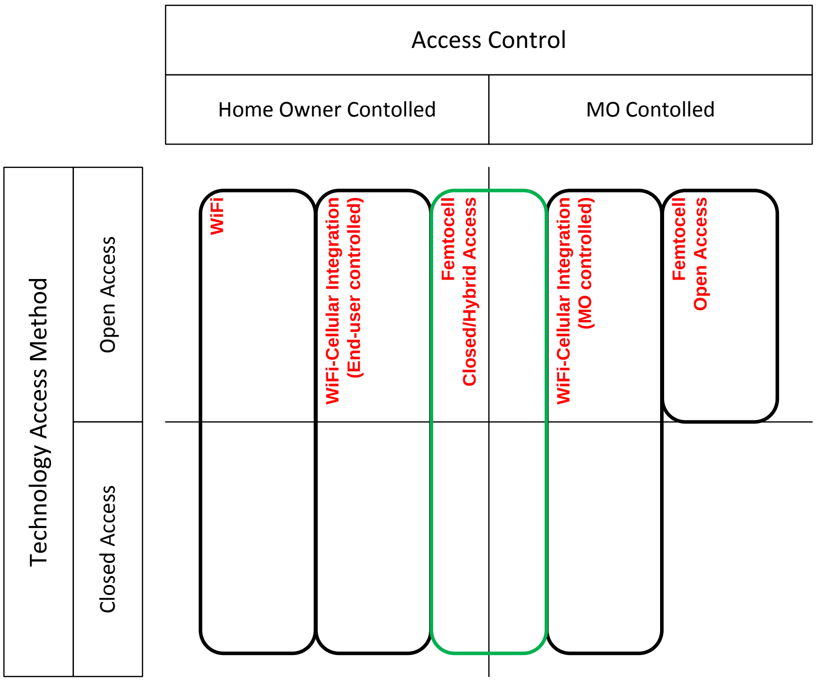

Fig. 31. Scenario matrix of mobile offloading wireless access provisioning in homes

Fig. 31 shows how the different VNCs (Fig. 25 – 30) are mapped into a scenario matrix. For example, WiFi grant home owners full control over the home networks and they could allow anyone to access the network by allowing the network to be open. They could also enable closed WiFi access by restricting the access to a fixed number of end-users by setting up a password. Femtocell closed/hybrid access is boxed in green as it is not either home owner or mobile operator controlled but instead the access control is a combination of both the home owner and mobile operator.

4.1.2 Femtocell-as-a-Service

Femtocell-as-a-Service is a business model in which an actor takes on the main role of providing and maintaining the infrastructure that is needed to roll out femtocell services. It is not necessary for such an actor to be providing femtocell services. The main component of this model is the femtocell core network infrastructure including the femtocell gateway. Any actor, that is capable of building the core infrastructure and rolling out the femtocell service, might take on the role of providing FAAS. Table 8 shows the relevance of each actor in FAAS and Table 9 shows the role analysis of FAAS. Only the new roles, related to FAAS, are mentioned in Table 9 complementing Table 7.

Table 8. Relevant actors for FAAS

Actor	Relevance
End-user	subscriber of the femtocell service
Mobile Operator	femtocell networks will help complement the macro network
Fixed Broadband Provider	femtocells require a backhaul
Service Provider	various types of services may be provided over a femtocell
End-to-End Solution Vendor	management of femtocell deployment including interference

Table 9. Role analysis of FAAS

Role	Drivers for Role Importance
Service Application Provisioning	+: greater value and incentive in services
	-: increasing number of service providers
Femtocell Network Service Management	+: large-scale deployment of femtocells
	-: no deployment or deployment of femtocells on a small scale
Femtocell Network Operation	+: demand for better data rates and coverage indoors
	-: good data rates and coverage indoors
Femtocell-as-a-Service Operation	+: high initial deployment cost
	-: no demand for femtocells

The added value of femtocell services creates incentives to actors to provide such services, making the role of service application provisioning more important. However, if there are many service providers, the importance of this role is reduced. The level of importance for the role of service management depends on the femtocell deployment scale. A large scale drives the need for robust femtocell service management. Femtocell network operation is driven by a demand for better data rates and coverage indoors. However, the experience of good data rates and coverage indoors reduces the need for this role. Finally, the high initial investment for femtocell deployment leads to the role importance of FAAS operation. The role of FAAS operation is redundant if there is no demand for femtocells.

Based on the identification of suitable existing roles (Table 7), relevant actors (Table 8) and new roles for FAAS (Table 9), a generic FAAS VNC is constructed (Fig. 32). Four scenarios which could emerge are described from Fig. 33 - 36.

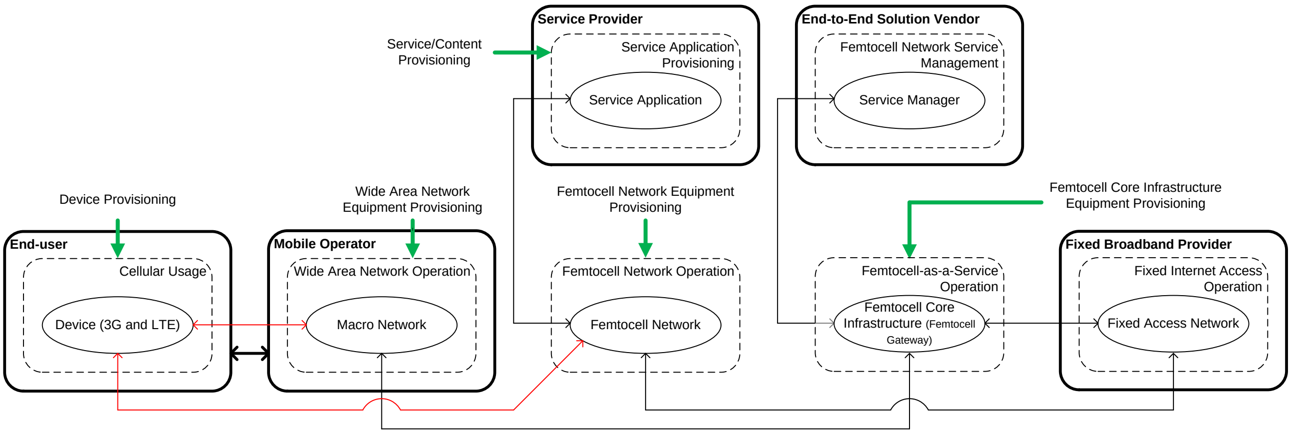

Fig. 32. Generic configuration for Femtocell-as-a-Service

Mobile Operator Driven FAAS

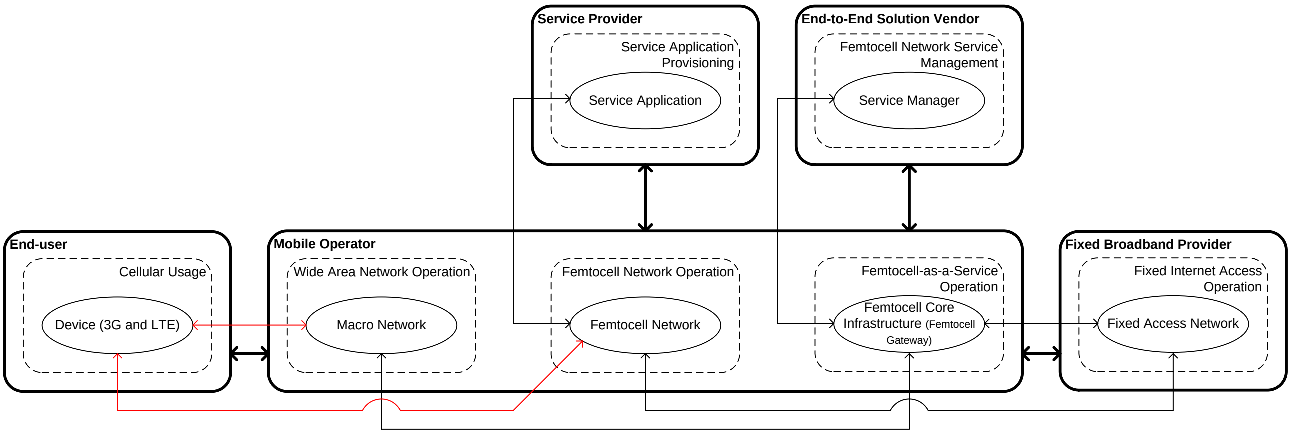

Fig. 33. Mobile operator driven FAAS VNC

A mobile operator driven FAAS is the most likely scenario for the FAAS model (Fig. 33) given that femtocells are mobile operators' business. A mobile operator with a higher market share is likely the one that takes the lead of rolling out its own femtocell network in both retail and wholesale business. Other mobile operators may utilise this femtocell core infrastructure. The mobile operator offering FAAS has control over the infrastructure and may set certain conditions (e.g., better QoS for own mobile subscribers) to ensure that it is not at a disadvantage when other mobile operators start offering femtocell services.

If the mobile operator offering FAAS does not own any fixed access networks, it has to make agreements with a fixed broadband provider to use its fixed access network as a backhaul. There is a need for agreement establishment with an End-to-End solution vendor who provides the service manager system. This system is needed to manage femtocell network and monitor its performance, especially for a large-scale deployment.

Mobile operators that own femtocell networks would likely partner with service providers to provide additional services via femtocells.

Fixed Broadband Provider Driven FAAS

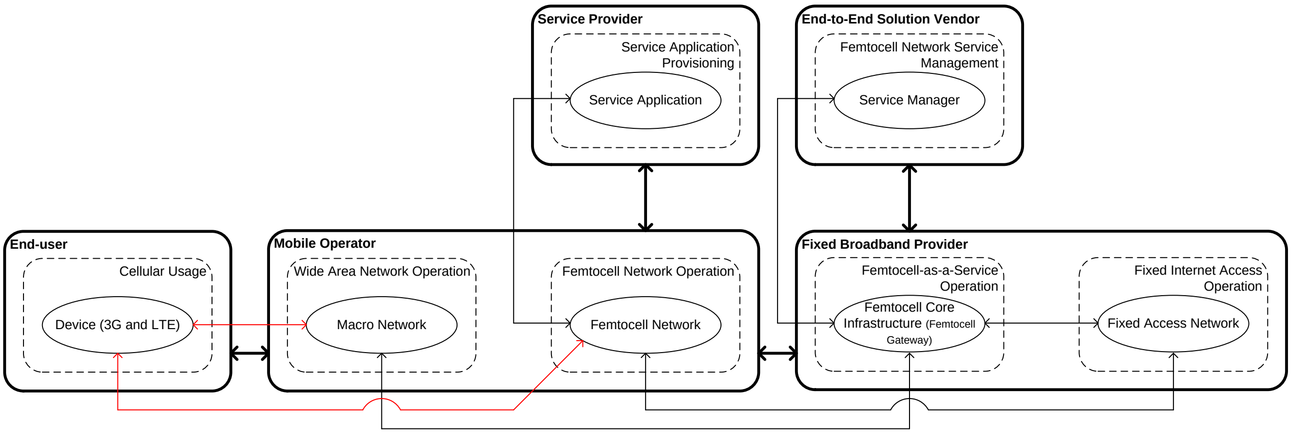

Fig. 34. Fixed broadband provider driven FAAS VNC

FAAS provides an opportunity for non-mobile operators such as the fixed broadband provider to enter the cellular business by taking the role of FAAS operation (Fig. 34). For example, a fixed broadband provider may find the FAAS business attractive. The backhaul is to be provided by the fixed broadband provider. This would mean even fixed-mobile operators who want to roll out a femtocell service will have to use the fixed access network from the fixed broadband provider.

If the fixed broadband provider is offering other services, these might be bundled and offered together with FAAS. As the fixed broadband provider is offering FAAS, it is necessary to make a business agreement with End-to-End solution vendor who provides the service management system.

End-to-End Solution Vendor Driven FAAS

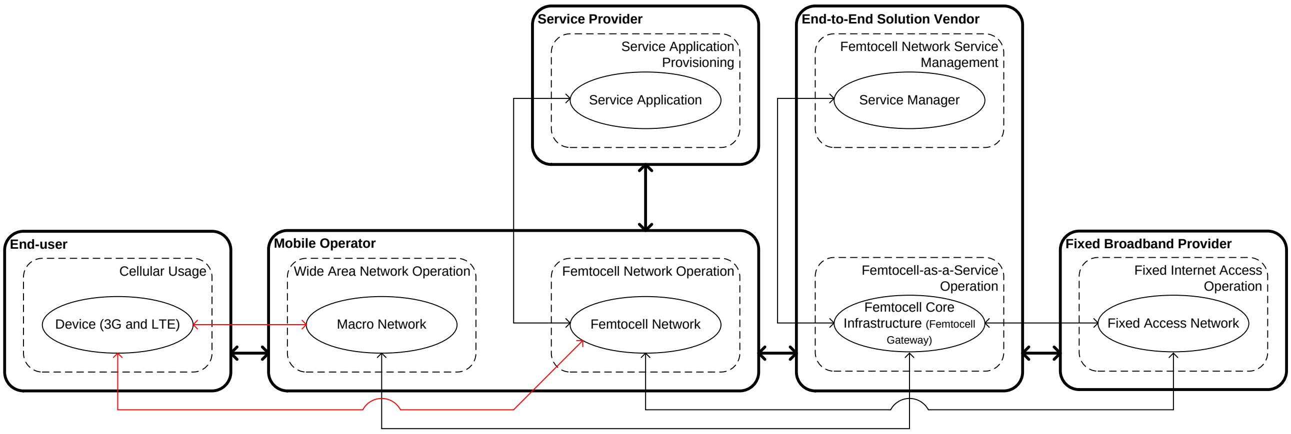

Fig. 35. End-to-End solution vendor driven FAAS VNC

The need for an effective management of femtocell network deployments drives this VNC (Fig. 35). The End-to-End solution vendor takes the main role (FAAS operation) by using its vast experience and expertise in femtocell management systems. This includes the use of analytics as the main driving force for others to use their platform.

As the End-to-End solution vendor would not own fixed access networks, a business agreement with the fixed broadband provided is needed as femtocells require a backhaul.

Service Provider Driven FAAS

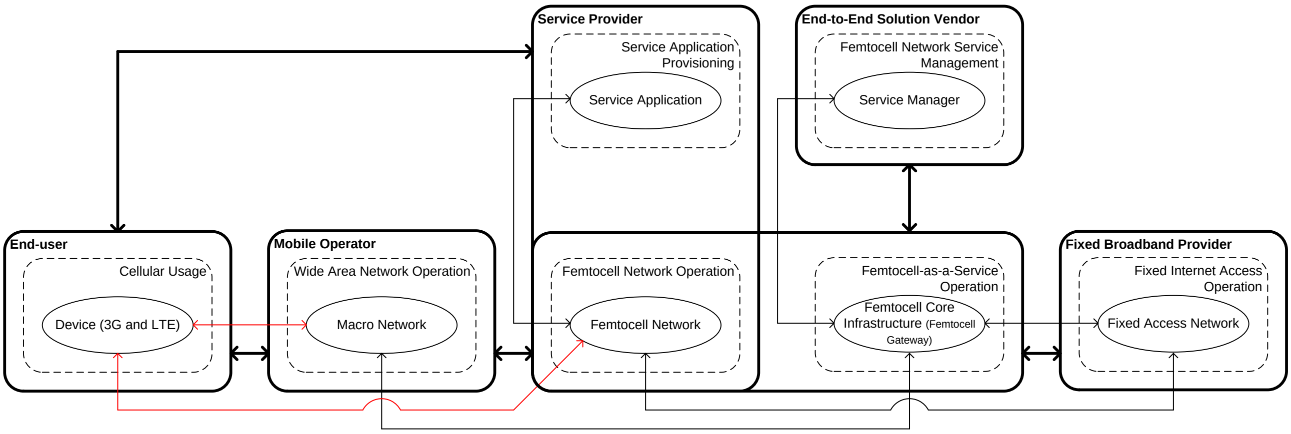

Fig. 36. Service provider driven FAAS VNC

The Service provider driven FAAS VNC (Fig. 36) could emerge when more value is added by from the service itself than the access to the service. Service providers offer wireless access to valuable services for the homes. Major internet service providers such as Google and Amazon have launched their own devices and operating systems and have shown interest in getting licensed spectrum. Service providers who have a large base of subscribers are possibly interested in bundling their platform services together with femtocell service.

Mobile operators also should not take the role of service providers lightly. In the USA (United States of America), AT&T whose main business is providing fixed and mobile broadband lost the contract to Google to provide WiFi services to end-users at Starbucks joints.

Business agreements are needed with fixed broadband provider (using fixed access networks as the backhaul) and End-to-end solution vendor (management of femtocell networks). Service providers are likely to act as MVNOs to gain access to licensed spectrum. This changes the dynamics of the mobile business environment as new actors whose main business is in other industries now operate cellular networks.

This VNC presents the worst case scenario for mobile operators as service providers are the ones who owns the end-users of the femtocell service in addition to providing FAAS. End-users of other mobile operators that leverage the femtocell core infrastructure from service providers may not want to be bundled too tightly with their interfaces. This is so as there might be a locked-in effect which is more evident if propriety software is being used.

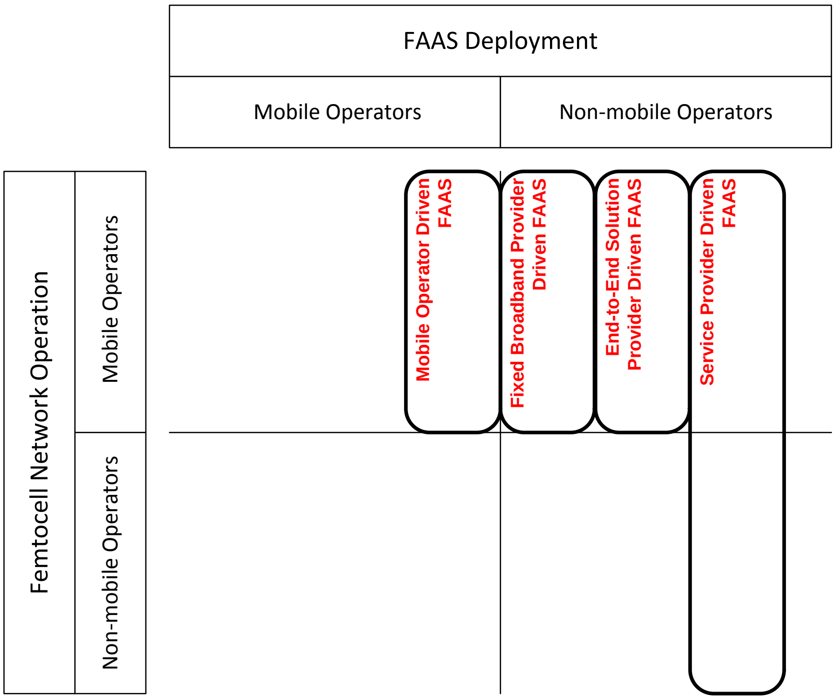

Fig. 37. Scenario matrix of FAAS deployment

Fig. 37 shows how the four FAAS deployment scenarios are mapped into a matrix. For example, fixed broadband provider driven FAAS is deployed by a fixed broadband provider but femtocell subscribers are those of mobile operators as mobile operators own the femtocell networks.

4.2 System Dynamics

The use of system dynamics focuses on the description of endogenous feedback structures of systems [49]. It is a technique used to observe and analyse complex systems in a holistic manner. It is also used to understand the structure of systems, and how different constituent elements interact with each other. Furthermore, it shows how changes in any part affect the system as a whole. Feedback structure modelling is an important component of system dynamics as it provides a better understanding of dynamic complexities that are found in situations and it shows the same actions having different effects over time. System dynamics have been applied to study the dynamic behaviour of systems in several research fields including telecommunications [50].

In any system dynamic model, the fundamental component considered is the casual loops. Casual loops consist of nodes and edges. Nodes denote the variables and the edges denote the links (depicted with blue arrow). Casual loops can either be positive or negative. Positive casual loops are known as reinforcing (depicted with R) and the negative ones are known as balancing (depicted with B). There is an even number of negative links in reinforcing loops. This creates a positive feedback which depicts either an exponential increase or decrease. Balancing loops have an odd number of negative links. This creates a negative feedback which depicts reaching a plateau and balancing behaviour.

Fig. 38 shows an example of how reinforcing and balancing loops affect the growth of a population [51]. The variables in this example are births, population and deaths. An increase in the number of births in the population leads to population growth. On the other hand, an increase in the number of deaths leads to population decline. To ensure that the dynamic system does not collapse, the number of births has to be greater than the number of deaths.

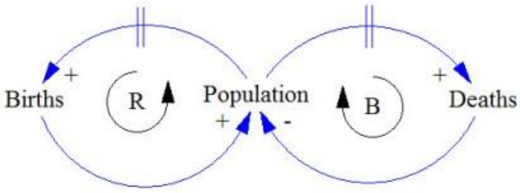

Fig. 38. Casual loops affecting population size

4.2.1 Management of Unsatisfied Mobile Traffic

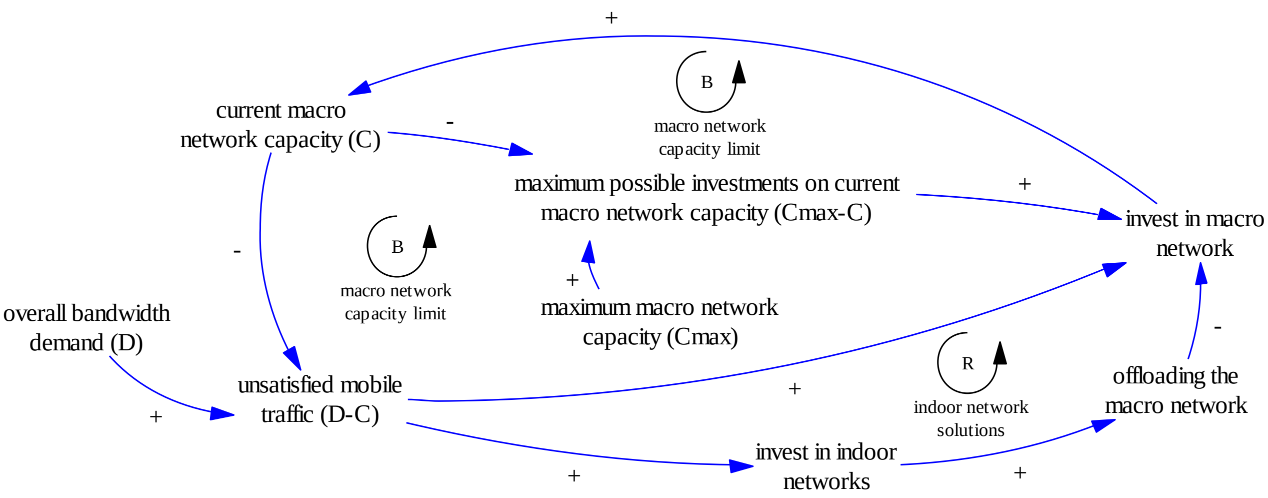

Fig. 39. Conceptual model of unsatisfied mobile traffic management

Fig. 39 shows the conceptual model of managing unsatisfied mobile traffic. This figure focuses on factors that describe when the decision will be made to invest on indoor networks to offload the traffic of the macro network. This model consists of one reinforcing loop that drives indoor network investments (mobile offloading solutions) and two balancing loops that limit investments on the macro network to handle unsatisfied mobile traffic. Fig. 40 provides a graphical view of the evolution of the demand for mobile traffic over time and the handling of unsatisfied mobile traffic.

- **"Macro network capacity limit"** - *balancing loops*: As long as the macro network can serve the current demanded traffic (D<C), there is no need to invest in capacity expansion. While the traffic increase, the unsatisfied mobile traffic forces mobile operators to investment on macro network capacity expansions (Cmax>D>C). However, because of technological, economic or other reasons, there is a limit on future macro network capacity expansions.

Once the expansion of current macro network capacity has reached its limit (Cmax=C), the deployment of indoor network solutions is the direction to embark on for solving capacity issues.

- **"Indoor network solutions"** - *reinforcing loop*: An increase in unsatisfied mobile traffic leads to an increase in investment in indoor networks. More investments in such solutions result in more offloading of the macro network, which, in turn leads to a decrease on investment on the macro network.

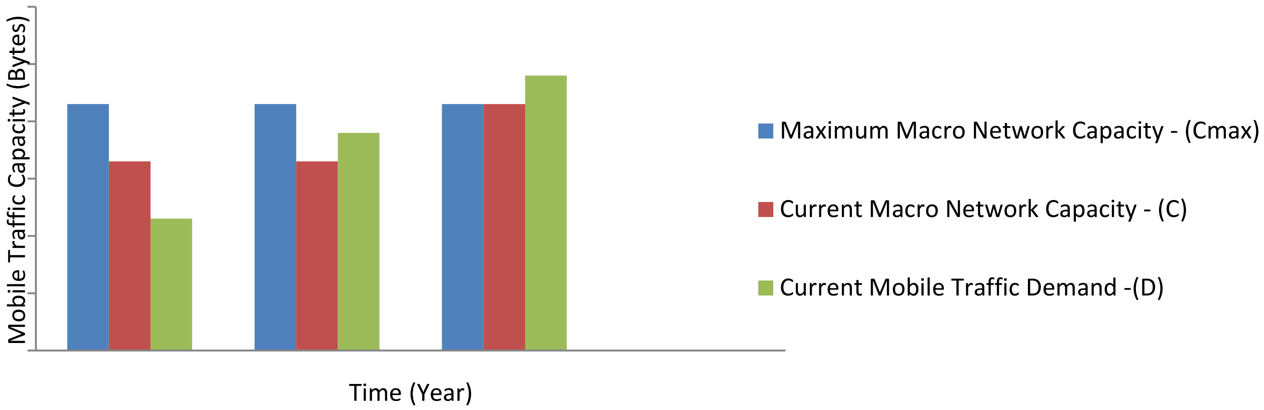

Fig. 40. Evolution of demand for mobile traffic

4.2.2 Femtocell Adoption

A conceptual model for femtocell adoption has been constructed. Three actors (femtocell subscribers, service providers, mobile operators) are represented in this model. The model is broken into three smaller systems (Fig. 41 - 43) to highlight the different effects each actor has on femtocell adoption. This model in total consists of eight reinforcing loops that drive femtocell adoption and three balancing loops that restrict the growth (Fig. 44).

The effects of the actors are presented in different colours for the casual loops which are listed as follows:

- Femtocell subscribers: Black
- Service providers: Green
- Mobile operators: Red

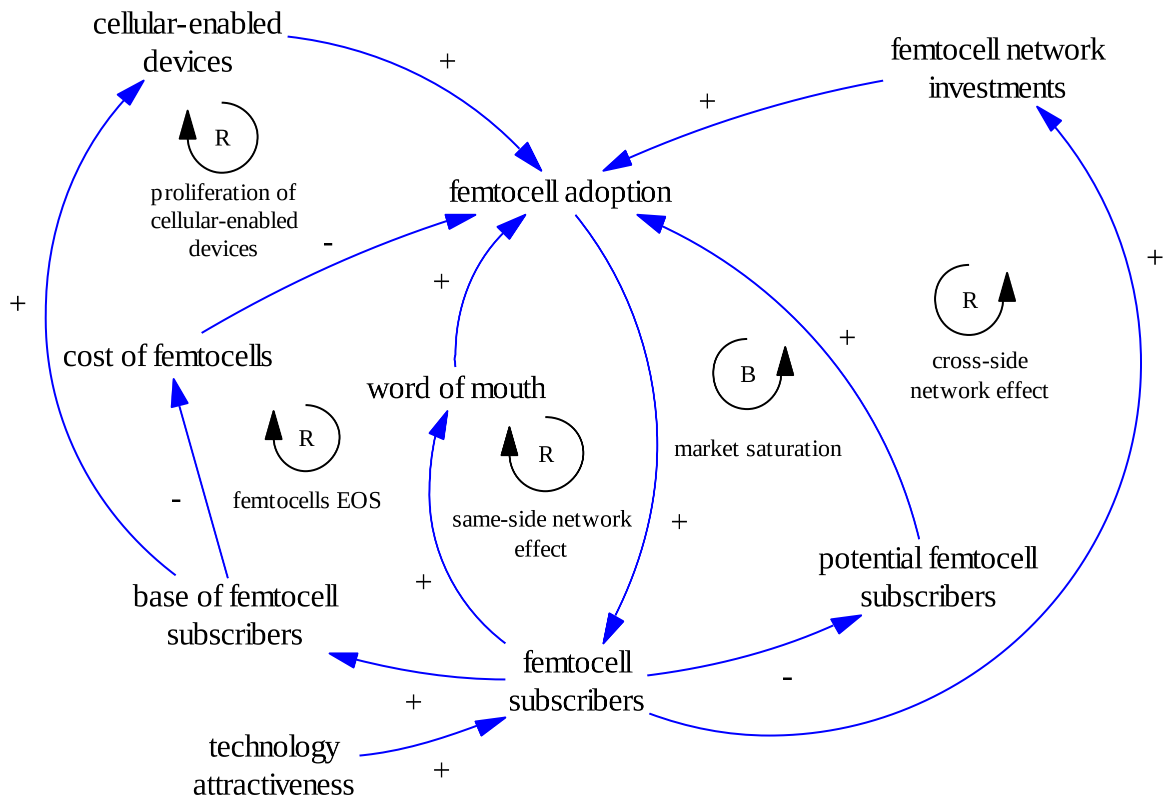

Fig. 41. Conceptual model of femtocell adoption (1)

Fig. 41 shows the first part of the conceptual model of femtocell adoption regarding the effect of femtocell subscribers that influences the adoption of femtocell services. It includes factors that describe how potential subscribers of femtocells will interact with the active ones. This part consists of four reinforcing loops that drive femtocell adoption and one balancing loop that restrict the growth.

- **"Market saturation"** - *balancing loop*: As the number of femtocell subscribers increase, the number of potential femtocell subscribers drops. As a result, the rate of femtocell adoption decreases.
- **"Proliferation of cellular-enabled devices"** - *reinforcing loop*: An increase in number of femtocell subscribers leads to more devices embedded with cellular technologies. This in turn drives femtocell adoption and once the critical mass is exceeded more femtocell subscribers are willing to subscribe the femtocell service.
- **"Femtocells Economies of Scale (EOS)"** - *reinforcing loop*: As the number of femtocell subscribers increases, the base of femtocell subscribers increases which leads to lower prices of femtocells. Low cost femtocells make the femtocell service more attractive and increase the possibility to be adopted.

- **“Same-side network effect”** - *reinforcing loop*: The active femtocell subscribers may share their experience with mobile subscribers who are potential adopters of femtocell service. Word of mouth facilitates femtocell adoption and increase number of femtocell subscribers.
- **“Cross-side network effect”** - *reinforcing loop*: This loop depicts an increase in femtocell subscribers which forces mobile operators to invest more in femtocell networks.

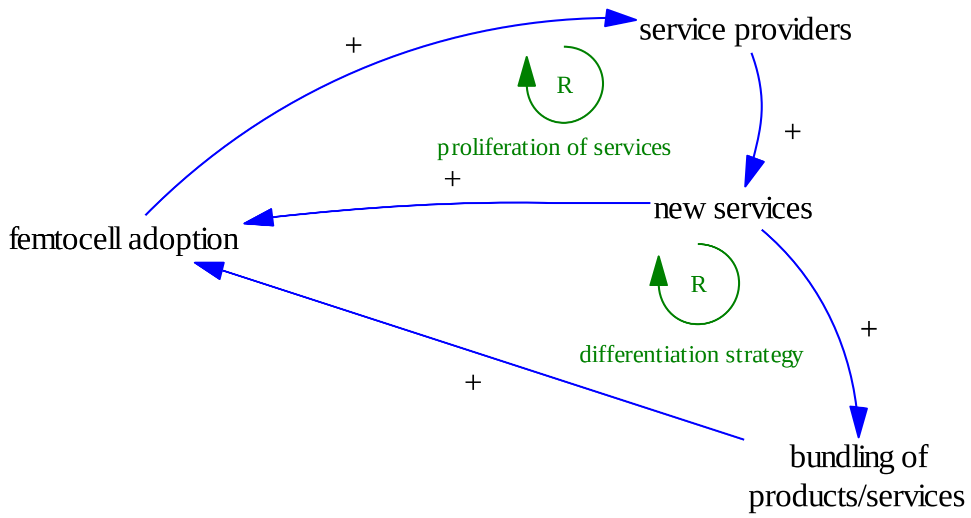

Fig. 42. Conceptual model of femtocell adoption (2)

Fig. 42 shows the second part of the conceptual model of femtocell adoption. This part focuses on the effect of service providers that influences the adoption of femtocell services and it consists of two reinforcing loops that drive femtocell adoption.

- **“Proliferation of services”** - *reinforcing loop*: Larger femtocell adoption leads to an increase of service providers who want to enter the femtocell business by offering more new services. In addition, the new services provided via the femtocell, makes femtocell more attractive to be adopted by end-users.
- **“Differentiation strategy”** - *reinforcing loop*: More new services from service providers enables mobile operators to bundle these services with the femtocell service. Thus enabling mobile operators to differentiate their services from competitors.

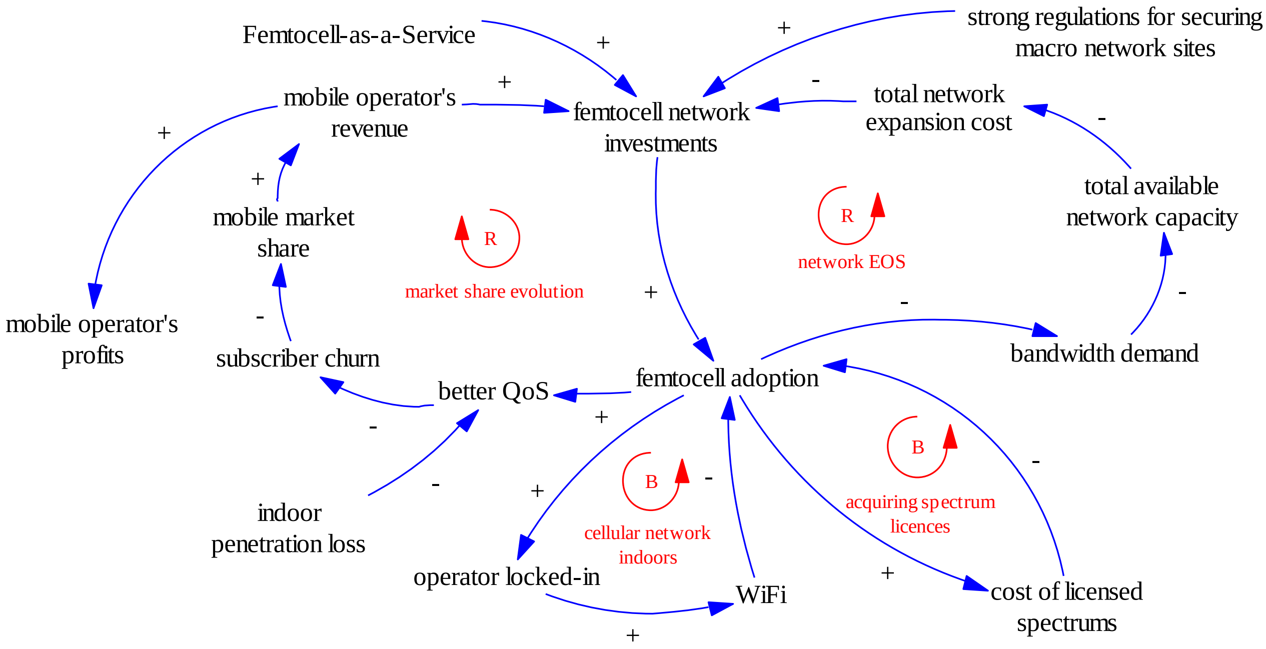

Fig. 43. Conceptual model of femtocell adoption (3)

Fig. 43 shows the final part of the femtocell adoption conceptual model which shows the effect that mobile operators have on femtocell adoption. This part consists of two reinforcing loops that drive femtocell adoption and two balancing loops that restrict the growth.

- **"Cellular network indoors"** - *balancing loop*: Femtocell adoption creates a locked-in effect because it is tied to the mobile operator offering it which in turn leads to an increase of WiFi deployments. While the usage of WiFi gains popularity, end-users adopting the femtocell service decrease.
- **"Acquiring spectrum licences"** - *balancing loop*: As femtocell adoption increases, more licensed spectrums are eventually needed resulting in increased cost for licensed spectrums. As cost of acquiring spectrum licences increases due to higher spectrum licences, femtocell adoption decreases.
- **"Market share evolution"** - *reinforcing loop*: More investments on femtocell networks helps in femtocell network expansion and adoption, enables better QoS and reduces subscriber churn. These factors prevent the drop in mobile market share and revenue. Finally, higher revenues lead to more investments on femtocell networks.
- **"Network EOS"** - *reinforcing loop*: Greater femtocell adoption, the less the demand for bandwidth in the macro network. Thus, the total available network capacity increases and there is less need for investments resulting to less capital expenses. Further investments in femtocell networks enable an even higher rate of femtocell adoption.

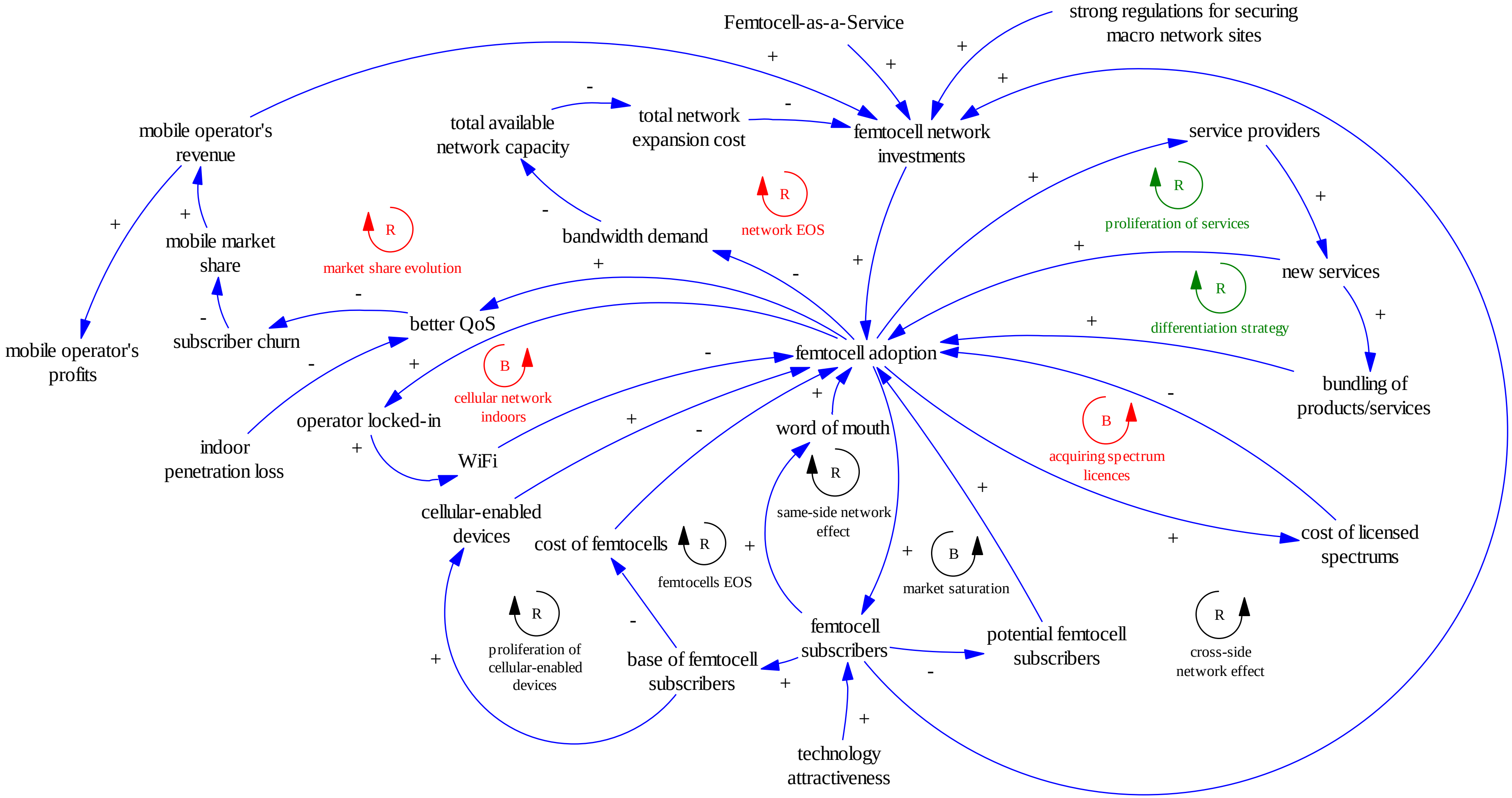

Fig. 44. Conceptual model of femtocell adoption (4)

4.3 Expert Interviews

As this thesis uses qualitative research, the use of expert interviews helps to gain new or unknown information about the industry. Furthermore, it provides a quick way to gain in-depth knowledge and it adds a human element to impersonal data. There are three main formats used for conducting interviews. They are fully-structured, semi-structured and unstructured [52]. Fully structured interviews are those that strictly follow the order of the predetermined questions. The questions are also hardly changed or skipped. Semi-structured interviews also have a list of predetermined questions but they are instead only used as a guideline. Unstructured interviews are those that are informal and may freely move towards any direction of the interest area.

Table 10. List of interviewees

Field of Expertise	Position in Company
Academia and Research - Smart City Systems	Project Manager
Academia and Research - Radio Communications	Professor
Vendor - Technology and Innovation	Principal Innovator
Mobile Operator - Technology	Vice President
Mobile Operator - Radio Network Planning	Head of Radio Network Planning
Mobile Operator - Products and Services	Head of Products and Services

4.3.1 Procedure

In this thesis, six expert interviews were conducted to gain further insights into the wireless access market and the factors that influence the adoption of femtocells. The interviewees as seen from Table 10 have been chosen from three different fields of expertise (academia and research, vendor, mobile operator). Semi-structured interviews were conducted for this thesis. The order of the predetermined questions kept changing to adhere to the flow of the discussion. The interviews were conducted over a period of one month during the spring of 2014. The average time per interview was around one hour.

4.3.2 Summary

The usage of both WiFi and femtocells are suitable solutions for mobile offloading. However, currently in Finland there is very good macro network capacity. Therefore, mobile operators do not consider using femtocells as a mobile offloading solution.

Mobile operators mainly focus on providing sufficient nationwide data network coverage before deploying any offloading solution (there is no mobile offloading without any macro network coverage). Femtocells have the edge over WiFi as it helps coverage problems. This is particularly useful near the cell borders of the macro network. Even though voice revenue is going down, voice is still the primary need for communication of end-users and having good coverage is important. However, for wireless internet service in the homes, WiFi currently serves the needs of most end-users plus it is not costly to deploy them.

Also, mobile operators have adequate licensed spectrums for many years in Finland. Lately, the three major actors acquired the licence (started on January 1, 2014) for spectrum at 800 MHz frequency band for twenty years. Besides this spectrum band, they have spectrums at 900 MHz, 1.8, 2.1 and 2.6 GHz as well. 700 MHz is also going to be auctioned off in 2015. 800 MHz, 1.8 and 2.6 GHz currently are the spectrums that could be used for LTE in Finland.

From end-users' perspective, WiFi can provide wireless internet service and sufficient data rates. Currently, there are no strong incentives for end-users to choose a femtocell over WiFi or together with WiFi.

Although the deployment of femtocells will definitely help to ease the capacity crunch, there are many other factors other than offloading that will drive a successful large-scale femtocell deployment. Other actors in the telecommunication industry may each also play an important role in driving a large-scale femtocell deployment which is discussed in the next chapter.

5. Results and Discussion

The following findings were found as a result of the qualitative analysis in previous sections, combining the three methods; value network configuration, system dynamics and expert interviews.

The main research question is “Would mobile offloading drive a large-scale deployment of femtocells to compete with WiFi access points in residential wireless access markets?” Indeed, benefits such as alleviating the capacity on macro networks obtained by mobile offloading make the deployment of femtocell networks an attractive solution for mobile operators. Particularly in Finland, the mobile data traffic increases rapidly but does not follow an exponential growth. Also, the quality of the macro networks is at an acceptable level and there are hardly any capacity problems. Therefore, under these present conditions, there is no strong need for a large-scale deployment of femtocells for mobile offloading. A huge number of homes also have WiFi connections which help in mobile offloading and serve the current internet usage needs of most end-users. Therefore, many other factors which could influence femtocell adoption should be considered. Table 11 shows the importance and categorisation of these factors.

Table 11. Factors influencing femtocell adoption (categories)

<table>
<tr><th>Importance</th><th>Technical</th><th>Business</th><th>Legal</th></tr>
<tr><td>Very High</td><td colspan="2">New services and partnership with third party providers</td><td></td></tr>
<tr><td>High</td><td>Interference mitigation and interoperability</td><td></td><td></td></tr>
<tr><td>High</td><td>Backhaul</td><td></td><td></td></tr>
<tr><td>High</td><td>Femtocell management system</td><td></td><td></td></tr>
<tr><td>High</td><td></td><td colspan="2">FAAS deployment</td></tr>
<tr><td>Medium</td><td></td><td>Cost of femtocells</td><td></td></tr>
<tr><td>Medium</td><td></td><td>Pricing</td><td></td></tr>
<tr><td>Medium</td><td></td><td>Complementary technologies</td><td></td></tr>
<tr><td>Medium</td><td></td><td>Education about femtocell and usage benefits</td><td></td></tr>
<tr><td>Medium</td><td></td><td>Target segment</td><td></td></tr>
<tr><td>Medium</td><td colspan="2">Device availability</td><td></td></tr>
<tr><td>Medium</td><td>Internet of Things</td><td></td><td></td></tr>
<tr><td>Medium</td><td colspan="2">VoLTE</td><td></td></tr>
<tr><td>Medium</td><td colspan="3">Licensed spectrum availability</td></tr>
<tr><td>Low</td><td></td><td>Bundling of femtocell service with other services</td><td></td></tr>
<tr><td>Low</td><td colspan="2">Integrated WiFi-Femtocell access point</td><td></td></tr>
<tr><td>Very Low</td><td>Poor coverage</td><td></td><td></td></tr>
<tr><td>Very Low</td><td></td><td></td><td>Regulations for macro network sites installation</td></tr>
</table>

5.1 Factors Influencing Femtocell Deployment

New services and partnership with third party providers

The launch of new services is the factor which will make femtocells stand out from WiFi due to its strong positioning in homes. Offering something new or different would probably arouse end-users' interest. This is most likely to drive demand for femtocells in homes. One example that could lead mobile operators as the "winners" is the case of a family tariff as femtocells allow a virtual home telephone number service which reduces the need for having a fixed telephone line service. If services, such as content-related and location based services take off, then a large-scale femtocell network deployment can possible happen. New services also enable differentiation from WiFi which helps marketing efforts. Mobile operators could differentiate themselves by offering exclusive services to their subscribers via femtocells. New services could increase the mobile data traffic but these new traffic would be carried via femtocells.

Moreover, they should also partner with big players in the service industry who have a notable established base of end-users (service providers, content providers and Over-The-Top (OTT) players). As the killer application for femtocells is still unknown, forming alliances could help mobile operators handle uncertainty in the market. Identifying the killer application definitely brings in new subscribers of femtocells. Femtocells support location based services but in Finland, there is no strong need for such services. Service providers develop such services and the mobile operator has to create a partnership with them to quickly launch any new service when there is a demand. This partnership is beneficial not only for the mobile operator, but also for the service provider. Mobile operators can offer many other services to service providers other than just "bandwidth", ending up in a win-win situation. They could provide assets such as data about network performance and activity, information about behaviour of end-users (e.g., locations of end-users and type of device used, billing know-how). Forming alliances plays also an important role in generating revenue. For instance, mobile operators may partner with content providers which enable end-users to enjoy having smooth flow of content. The main component of content is that of mobile video where good QoS is needed and this further supports the femtocell business case.

New applications exclusively for femtocells could also lead to a femtocell applications store which creates another revenue stream for mobile operators and application developers. These new services also have to bring in profit for the mobile operators to ensure they will be implemented and offered to subscribers.

Interference mitigation and interoperability

Interference mitigation is essential to ensure that femtocell services delivered to end-users are reliable. The average home area is relatively small. The allocation of higher frequencies for femtocell networks would be suitable and adequate to cover the home area. This reduces the interference between femtocell networks and the macro network even if both use the same frequencies. A dedicated frequency band could also be allocated only for femtocell deployment. Femtocells as network expansion elements have to be considered as part of the total cellular network they have to be included in any future network planning. One might argue that having a dedicated frequency could cause interference among femtocell networks. However the power transmitted by femtocells is very low and it should not pose as a huge interference problem.

Interoperability between femtocell networks and the macro network can be an issue as different vendors come with different specifications. Interoperability has always been as issue in the telecommunications industry and this should not be a major drawback of deploying femtocells. However, it is still important that this issue is sorted out to ensure both the macro and femtocell networks can operate smoothly alongside each other.

Backhaul

Managing the backhaul is an important component for deploying femtocells. In a large-scale femtocell network deployment, there is high risk for congestion problems. Therefore, management of the backhaul to prevent bottlenecks is critical to prevent degradation of femtocell service quality. Femtocells could also use wireless backhaul instead of the fixed access network. However this poses a challenge in terms of spectrum usage. Due to high cost of acquiring licensed spectrum, mobile operators probably would prefer using unlicensed spectrum for wireless backhauling.

Femtocell management system

The need to effectively manage femtocell deployment is important. The implementation of Self-Organising Networks is essential in a large-scale femtocell deployment, especially if it is using the same frequency as the macro network. Good management is needed to prevent Ping-Pong cell handovers too. Even if the femtocell network operates on a different frequency from the macro network, management of a very dense femtocell network requires SON. SON is essential and useful as managing the femtocell network alongside the macro network requires a certain level of complexity.

SON also helps in operating and implementing cost reduction. The network can self-organise without the need for someone to be physically present to rectify a problem. SON will probably be more of an interest to femtocell vendors than macro network vendors.

The problem of rejection in femtocell closed/hybrid mode arises when the device is in idle mode as the device will try to camp on the best possible cell. The device will recognise a femtocell just like another macro network cell. So it will keep getting rejected every time it passes such femtocells (even passing same ones again). This kind of rejection is not optimal for the network. Mobility parameters could be set but it is a daunting task. This is hitting straight on the femtocell dilemma which needs to be addressed. Enabling the device to have the ability to be aware of the mode of femtocell access method is definitely an issue to look at. In active mode, as the network knows where the device is, therefore it does not perform handover to femtocells in closed/hybrid mode.

FAAS deployment

As FAAS lowers the CAPEX, it has the possibility to drive faster femtocell deployment as it provides an opportunity for smaller mobile operators to offer femtocell services too. More discussion on this is made in section 5.2.

Complementary technologies

From end-users' perspective, WiFi and femtocells might be perceived or known as competing technologies. Examples of competing technologies in the past show that eventually only one technology will be the winner. For instance, the high definition (HD) optical disc format war between HD Digital Video Disc and Blu-ray Disc, ended with Blu-ray Disc as the winner. This shows that it is important that end-users perceive both femtocell and WiFi as complementary technologies to access the internet. As it can be seen that WiFi has been the leading technology so far, it is likely that end-users will be hesitant in accepting femtocells. This indicates that femtocells need to differentiate themselves. Furthermore, due to the high market uncertainty for femtocells, differentiation from WiFi by features rather than price is needed. This is likely the reason that causes heavy cost subsidies of femtocells. Being perceived as a complementary technology, it increases the chances of the femtocell business surviving. A similar example is that of smartphones and tablets. Both devices may run on a similar operating system and have similar functions; however the tablet business is still very much alive.

Education about femtocell and usage benefits

The needs of end-users have evolved hierarchically from basic to sophisticated features as technology advances. This happens as end-users become more educated about various technologies and the added advantages that the latest technologies provide. It shows that getting end-users to understand the difference between WiFi and femtocells is essential.

Target segment

As mobile operators usually have a wide spectrum subscriber base, it is necessary to have a target segment for the initial rolling out of femtocell services. This is most likely to be the most valuable mobile subscribers who will have the benefits of being the first to access such services. The household that has every family member under the same mobile operator is a good target segment as only one femtocell is needed. The mobile subscribers who are data hogs could be another likely segment. However, the mobile operators have to create a demand for these mobile subscribers. This could be done by offering femtocell services with a small subscription fee. Those mobile subscribers whose homes are fitted with fibre will also be a good choice to target. Fibre has good interference immunity and larger bandwidth which makes it an excellent choice for backhauling femtocells. In addition, bigger homes and especially those with basements is another good target segment as basements may be susceptible to coverage issues. If mobile operators decide to roll out new generation of networks in homes first, then they should target the early adopters. These could be those who adopted current and/or previous generations of networks earlier than others.

In suburban areas in Finland, new houses are constructed under new insulation obligations. This regulation for energy efficient buildings creates additional attenuation (20-30 dB) to signals when they penetrate the walls. The coverage and data rates in indoor places are then affected. Therefore owners of such green homes should be targeted.

Cost of femtocells

Cost of femtocells is significantly higher than WiFi access points due to the higher cost of cellular modules (e.g., LTE) compared to WiFi modules. LTE modules need to be lowered to better support the femtocell business case.

Even though the cost of femtocells is high, this should not be a major concern for home owners of green homes as an expert has mentioned that these home owners are usually the wealthier ones in society. With more homes eventually having better insulation materials which drive the need for femtocells, cost for subsequent femtocell subscribers will be removed as a major issue when the cost of femtocells decreases with an increasing number of femtocell subscribers.

Having multimode 3G-LTE femtocells drives up cost as it increases technical complexities in the femtocell and also more components (e.g., two antennas) are required. However this is desirable as 3G networks are still the dominant access. As the number of LTE subscriptions is lower than 3G due to higher LTE subscription fees, multimode allow end-users in the household without LTE subscriptions to have 3G access via the femtocell (based on the assumption all end-users have 3G mobile broadband subscriptions).

Pricing

With regards to pricing of femtocell services, few suggestions were mentioned during the expert interviews. It may also be possible to charge femtocell subscribers without a separate femtocell subscription fee and just the cost of the femtocell with no subsidy. For a household with family members who are all subscribers of the same mobile operator, there can be a special family tariff offered for the femtocell service. Pricing model for the femtocell service has not been discussed extensively as it is a tricky issue. Therefore, there is a need for it to be handled judiciously for optimal results.

Device availability

Many WiFi hotspots have sprung up to provide end-users internet connectivity. The growth of WiFi hotspots is primarily due to the huge number of WiFi-enabled devices. Therefore, device availability is also a major factor for the success of femtocell deployment. The proliferation of devices which support cellular technologies such as LTE could drive the need for femtocells. Currently, there are emerging devices in the form of wearables, such as smart watches and Google glass. However, these mainly use Bluetooth tethering to connect to the macro network via a smartphone/tablet. The main reason restricting the growth of devices embedded with LTE is the cost of the LTE module. Once this lowers significantly, it increases the likelihood of LTE being embedded.

Having LTE embedded on wearables increases the power consumption and could prove a challenge for battery life. This is especially for wearables which are small in size which would also mean much smaller batteries compared to smartphones. Reducing the size of LTE modules to fit to certain wearables (e.g., spectacles) could also be a challenge.

Despite the present high cost of LTE modules, more devices are still expected to be embedded with LTE in the near term. This is mainly for devices that can support voice and video applications. LTE is more efficient in radio resource management, wins in terms of latency and has better link budget than WiFi. Therefore it supports the femtocell business case over WiFi for such applications. For example, Verizon in the USA has been approaching television manufacturers about supporting LTE multicast.

Internet of Things

The vision of the Internet of Things is every device having connectivity to the internet. Femtocells bridge the home networks with the macro networks. This provides femtocell subscribers an opportunity to remotely control any device connected on the home networks. Furthermore, femtocells have the capability to serve as a secure access point for specific devices that have been determined by end-users.

In order for many LTE-enabled devices to access the internet through a femtocell network, more channels are required from femtocells. However, there are benefits for home networks delivered on LTE via femtocells such as better coverage and optimisation. If many devices are connected to a femtocell within a small area, mobile operators are able to perform localised management to optimise the home network. To remotely control devices which are usually located at the corner of homes like a sauna, femtocells would be a better choice than WiFi due to better coverage.

VoLTE

VoLTE is a premium service that delivers high quality voice calls. The number of devices supporting VoLTE will increase significantly over the coming years and the VoLTE service might take off. Indeed, migration to VoLTE release spectrum needed by older generation networks to provide voice service. To offer VoLTE, mobile operators need to invest in LTE access and core networks. However, the capital cost which is required for nationwide LTE coverage is high and the end-users who are willing to subscribe to this premium service will try to find the operator who first offers this service. Thus, femtocell provision in homes could quickly launch this service. Without nationwide LTE network, circuit-switched fallback is needed for voice calls when the device moves to areas without LTE coverage. Furthermore, due to the fact that VoLTE uses the packet-switched network, the mobile data traffic is expected to increase. VoLTE is essential for mobile operators as OTT services could render them as dumb bit pipes.

Licensed spectrum availability

Licensed spectrums availability is important for cellular networks especially for premium services over licensed spectrum such as VoLTE. In Finland, there are still licensed spectrums available for further expansion of cellular networks. The flexible spectrum usage and its proper regulation might be positive for femtocell deployment. The method of Licensed Shared Access and Authorised Shared Access (LSA/ASA) can exclusively be used for femtocells. If vacating and re-farming spectrums takes a long time, LSA/ASA is a good and quick option. This method allows better spectrum utilisation while protecting the incumbent i.e., the owner of this spectrum. LSA/ASA also allows mobile operators access to high quality spectrums at a lower cost. In Europe, the 2.3 GHz band is considered to be suitable for LSA/ASA. This band is now used by other industries (media companies) or government (military), but it is usually occupied within a localised zone. In Finland this frequency band is used for Programme Making and Special Events (PMSE). Using LSA/ASA, mobile operators in Finland could use this spectrum currently used for PMSE for femtocells and become "secondary" users. Other possible scenarios beyond LSA/ASA are the use of dynamic spectrum allocation and cognitive radio, but a suitable regulatory framework is required to allow incumbents to lease out their unused spectrum for a period of time dynamically.

As licensed spectrums are costly to acquire, another solution in seeking for available spectrums for cellular technologies such as LTE is the use of unlicensed band for femtocells in homes. Unlicensed band at 5 GHz, which is used by WiFi, is a good option in terms of bandwidth and can be used for bandwidth hungry services such as video streaming which is a popular service in homes. The LTE carrier aggregation technique can utilise the unlicensed band will to handle the capacity issue especially in downlink. Another unlicensed band that should be considered is 60 GHz. There should still be a unified LTE network with same management features even with LTE carrier aggregation. But, if LTE is used solely on unlicensed band in homes, then femtocells are similar to the WiFi use case.

Additionally, there are several unpaired frequency allocations that are being prepared for LTE TDD. For example, 3.5 GHz frequency band is well suited for femtocell deployment as there are large blocks of bandwidth available. The utilisation of TD-LTE is also beneficial because it handles interference much better and the cost for TDD is less per MHz per population. This frequency band could be used for femtocells in Finland as it has not been auctioned off.

The usage of available higher frequencies than the current ones for macro coverage such as 3.5 and 5 GHz that has been mentioned is more desirable for femtocells. This is so as femtocells are used to cover smaller areas such as homes and higher frequencies are well suited due to its shorter coverage range. For millimetre bands (e.g., 60 GHz), they have different radio propagation characteristics than traditional frequency bands (<6 GHz). This poses a challenge in terms of network infrastructure and management. However, lots of bandwidth is available over such frequencies which unlocks more spectrums to handle the mobile data traffic growth.

Integrated WiFi-Femtocell access point

Since Femtocells and WiFi both have the capability to grant access to the internet, these two technologies could be integrated into one intelligent access point which is able to transmit both LTE and WiFi simultaneously or switch from LTE to WiFi and vice versa when necessary. This would probably offered by fixed-mobile operators. Such a feature could help in a better load balance between the two networks. This kind of integration can be a winning solution in homes, but there is a need of a traffic sharing control mechanism in the backhaul by the provider. However, the operation of both technologies is very different such as system integration and packet core integration which suggests that it might be challenging to implement. This is more evident for the case of transmitting both LTE and WiFi concurrently via a single access point.

Having such integration reduces the need for multiple access points. This is beneficial for home owners as usually they prefer not to have too many access points as an expert pointed out. This also suggests that end-users may benefit from lower initial and operating cost. This is so with only the purchase of one access point and with only one access point connected to the fixed network; less energy is likely to be consumed.

However, integrating both technologies increases the cost of the access point. Having such integration also means there is a locked-in effect since LTE is on licensed spectrum which might make it less attractive for mobile subscribers.

Bundling of femtocell service with other services

Mobile operators could bundle a femtocell service together with other services to stimulate femtocell adoption. WiFi is the prevailing wireless technology accompanying this bundle service due to its low cost and ease of installation. Femtocell service currently probably would not survive as a standalone service due to the popularity of WiFi in homes. In Finland the three major mobile operators own fixed networks and can offer femtocell service as part of a quad-play service bundle.

Integrated WiFi-Femtocell access points could be offered in such a case. However, with mobile subscribers not getting services offered via femtocells that add value for them, its uptake is likely to be low.

Poor coverage

Poor coverage can occur due to e.g., the distance of the mobile terminal from the site, the geographic features and building structures, as well as the level of data rates. Coverage and capacity are interrelated and therefore to improve capacity, coverage will have to be sacrificed. In urban regions, which experience high data rates and high concentration of mobile traffic and in conjunction with the dense building structure, the macro network coverage suffers. Hence, femtocell network deployment is a preferable solution in urban areas.

In rural areas, the macro network cells are dimensioned to cover a wider area. The mobile subscribers' devices are usually located far away from the base stations resulting to low link quality and data rates (mainly in uplink). Especially in the cases where the mobile subscribers are at indoor places (e.g., their homes), the link quality is even worse. Also, homes in rural areas are usually equipped with copper wires and taking into account the long distances, the quality of fixed broadband service might get low. Thus, the backhaul for femtocells in this case is a limiting factor. Therefore, the use of relays or fixed receivers on the roof of the buildings might be a better option than femtocells in rural regions until the fixed network is upgraded (Finland national broadband plan).

It has been mentioned that new insulation obligations do affect coverage. The regulation about insulation and its effect on mobile network coverage will be more evident in the future when the older home buildings in urban and rural areas undergo renovation and refitted with better insulation materials. However, it is likely that mobile operators will use picocells to cater to such housing areas. This is so as having too many mobile subscribers with poor coverage will probably lead to customer churn.

In all geographical regions, the procession and usage of low frequency bands (e.g., LTE at 800 MHz and/or 700 MHz) can improve signal penetration in buildings. However, by improving the coverage only in this way, the capacity can slightly increase due to the lack of adequate bandwidth.

Regulations for macro network sites installation

An expert has pointed out that having strong regulations in certain countries (not Finland) like the USA in securing sites to build the macro networks to provide sufficient coverage could lead to femtocells being deployed. However, this would lead to femtocells being deployed only at problematic coverage areas. Femtocells provide a quick solution to such areas as they could be deployed in indoor locations without any network planning permission from the regulator.

Without being limited by network planning permission, femtocells also grant mobile operators an opportunity to roll out new generation of networks (e.g., fifth generation (5G)) in homes before building the new generation macro networks. However new generations of networks are likely to cost a higher subscription fee which might limit the uptake. Moreover as seen from the past, newer generations of networks alone did not lead to an uptake of femtocells by mobile subscribers.

5.2 Femtocell-as-a-Service Market Aspects

The second research question in the thesis is “What is the impact of Femtocell-as-a-Service on mobile operators’ business?” which is discussed in this section.

FAAS is a business model which will likely change the femtocell deployment business dynamics for mobile operators. Mobile operators with considerable market share are more inclined to deploy their own femtocell core infrastructure instead of leasing it from another actor. Having their own core femtocell infrastructure is the likely case for the three main mobile operators in the Finnish market. This section discusses the differences between a market having FAAS with one that does not.

FAAS offers many opportunities for various actors to enter the wireless business because there is no initial high CAPEX such as purchase and installation of femtocell core network elements. Such actors can be mobile operators with lower market share or those who do not have huge capital. These actors however have to pay royalties to the actor who has owns and operates the femtocell core infrastructure and offers FAAS.

The entry of many new actors into the femtocell business could lead the market to become very fragmented. However as more actors enter the market, this also leads to high competition. High competition would benefit potential femtocell subscribers as it drives down cost, improve service quality and creates more choices. This could lead to subscriber churn.

For bigger mobile operators, such a model does enable them to experiment with different business models without high CAPEX. As there is currently high market uncertainty for femtocells, bigger operators can quickly test the market and learn from the experience. Eventually modifications to the business model are made based on better gathered information to determine which is most suitable. It also lowers the risk for mobile operators as if they are not able to gain enough femtocell subscribers, they would not have wasted huge investments on the femtocell core infrastructure.

Actors could also provide allows multiple carrier femtocells. This is likely to be the ones offering FAAS. If such femtocells are not subsidised for end-users then any actor offering FAAS could provide this. However, if these femtocells are subsidised, then it is extremely unlikely mobile operators will provide them. Mobile operators would not want to subsidise the femtocells and allow rival mobile operators to benefit when there is customer churn.

Having such femtocells reduces the locked-in effect to mobile operators. For the end-users, this also removes the need to change to another femtocell when they switch mobile operators and this enables cost saving for them.

The regulator could make an auction for a particular frequency band (e.g., 3.5 GHz) and only award it to one actor. This actor would be tasked with providing FAAS to any other actors who wants to enter the femtocell business. In such a case, the regulator would have to set forth new specific rules that this actor have to abide with.

For mobile operators, using another actor's femtocell core infrastructure does bring about some potential threats. There is no control over the operation of the femtocell core infrastructure. In the case where the actor providing FAAS suddenly decide to stop offering such a service, this disrupts services that mobile operators are offering to their femtocell subscribers.

FAAS may bring about new business partnerships. Different actors can leverage on the expertise of the one offering FAAS. With FAAS, mobile operators are able to share in the EOS. Furthermore it is possible for them to benefit from faster femtocell deployment in the market.

Having deployed its own femtocell core infrastructure does bring about benefits for mobile operators. Firstly, they have full control over the femtocell core infrastructure and there can be tight integration with its core network. This allows them to ensure service continuity to their femtocell subscribers. No FAAS keep the market as status quo. Femtocell deployment probably remains mainly as mobile operators' business. A threat might arise from other actors such as service providers that want to envelope the actor with the infrastructure. One recent case that could be seen was that a service provider enveloped the infrastructure provider in the case of Microsoft purchasing Nokia's smartphone division.

Without FAAS, the mobile operator has to bear all the CAPEX and OPEX. Rolling out of femtocell services would then only be possible by the bigger mobile operators. This could lead to an oligopoly of the market which appears more apparent in markets with many mobile operators with large variation of market share.

6. Conclusion

This thesis has concentrated on the analysis of residential wireless access markets. It has identified the potential technologies and network architectures, the business architectures including relevant actors and their interaction, as well as market dynamics. All these were combined to explore if the market in question can emerge, focusing further on femtocell deployment in homes in Finland. The rapid mobile data traffic growth is going to create macro network capacity problem and mobile offloading seems to be a good solution which drives the deployment of small cells at homes. However, the study has additionally sought to know the other drivers which will lead to the success of femtocell networks at homes. The two research questions are "Would mobile offloading drive a large-scale deployment of femtocells to compete with WiFi access points in residential wireless access markets?" and "What is the impact of Femtocell-as-a-Service on mobile operators' business?" The methods which were used to answer the questions are value network configuration, system dynamics and expert interviews.

6.1 Key Findings

The main findings are that mobile offloading is an essential, but not the only driver to a large-scale deployment of femtocell networks. Among other factors, the business model which is going to take off the femtocell business is Femtocell-as-a-Service.

A large-scale deployment of small cells will eventually be performed to handle the data traffic because the macro network capacity will not able to carry the future mobile data traffic volume. This could eventually lead to femtocells being deployed in great numbers in homes to enable mobile offloading. At present, femtocells have not been deployed in Finland because there is sufficient capacity on the macro networks to meet the current demand. The availability of licensed spectrums would probably also be able to handle the growth of mobile data traffic in the near to medium term.

A wide variety of factors besides mobile offloading that may influence femtocell adoption have been identified. These factors each hold different roles and their importance also varies. However, five factors have more significance (stated as very important or important in Table 11) than others.

In the future, mobile offloading will be the key driver for extensive femtocell deployments in homes. This differs from the current situation where macro network coverage problem is the main reason for femtocell deployment. Coverage problems will not lead to a large-scale deployment of femtocells. Instead, for femtocells to be deployed even in regions where there is good QoS, mobile operators need to offer an incentive to entice their subscribers.

Considering that there is good QoS of macro networks such as in Finland, the most important factor for femtocell adoption is the development of new services and partnership with third party providers. Having new services that are appealing and create value for end-users will draw them to adopt femtocells. Strong WiFi presence in homes further suggests that new services offered via femtocells is needed. Mobile operators forming partnership with third party providers also foster service innovation. Therefore, it is critical that mobile operators use new services to boost consumer demand for femtocells. Femtocells would be the winner if current mobile traffic carried over WiFi networks is “onloaded” to them.

However, there is uncertainty about which technology will dominate the home networks in the future. It is likely that femtocells will augment WiFi and both eventually deployed in homes in which end-users deploying them to serve different purposes with respect to their individual needs. WiFi could be deployed to serve the need of internet access on various devices in homes while femtocells deployed for access to new services. If new services do drive femtocell adoption, based on current situation in Finland, mobile operators will benefit not only from revenue from these services but also be well positioned to handle future mobile data growth as more base stations are rapidly deployed in advance.

Three factors (interference mitigation and interoperability, femtocell management system, backhaul) are important to ensure good femtocell network operation. This is more evident when there is high uptake of femtocells. Having a large-scale deployment of femtocells means adding more network elements into the network. The network thus becomes denser. It also increases the network complexity and has to be managed in an efficient manner from both technical and business perspectives. Good femtocell network operation ensures good service quality delivered to femtocell subscribers which is essential for customer satisfaction. Having more network elements drives up cost and the benefits of the business model have to outweigh the cost. The cost issue of these network elements leads to the fifth factor which is FAAS deployment.

FAAS is better suited for a market that has mobile operators with vast differences in market share unlike in Finland. It offers an avenue for smaller mobile operators who want to offer femtocell services but are constrained by CAPEX. Therefore, the overall number of femtocell subscribers will increase as subscribers of smaller operators also have the opportunity to adopt femtocells.

However, FAAS could possibly cause a disruption for the telecommunication industry with non-mobile operators entering the femtocell business to compete with mobile operators. This implies that mobile operators either have to create a locked-in effect to keep their subscribers or partner with major service providers to enable a steady base of femtocell subscribers. This is more apparent for the major mobile operators who would want to protect their market positioning and maintain their market share.

Despite identifying the main factors that may drive femtocell adoption, bigger mobile operators are likely the ones to take the lead of rolling out femtocell services. They are probably not strongly limited by high CAPEX investments and would likely benefit from first mover advantage due to switching costs. Service providers probably would also prefer to partner with bigger mobile operators as there is a bigger potential femtocell subscriber base. A femtocell presence is better created when a bigger mobile operator is the first to successfully deploy femtocells rapidly in homes.

The issue of cost can be seen as a major element to build scale. Getting the cost lowered for femtocells makes it more attractive for potential femtocell subscribers. Lowering the cost of LTE modules enable more LTE-enabled devices to appear. Having lower LTE subscription fees will increase the number of LTE-enabled devices adopted by mobile subscribers which in turn will increase the chances of deployment for LTE femtocells. QoS over WiFi such as the usage of carrier grade WiFi could possibly threaten the role of femtocells. But, due to its high cost, it is currently used mostly in public places and offices. Lowering the cost in general could lead to new service applications which in turn could lead to more femtocell subscribers. Success of femtocells also depends on EOS and positive feedback which is better driven when there is a harmonised market.

It can be seen from this study that many other actors may also have to be involved when femtocells are rolled out. Therefore it brings about new business opportunities for mobile operators. This thus forms a business ecosystem. One mobile operator offering femtocells could lead to other mobile operators being keen to offer it as well to remain competitive which is likely for the case in Finland.

6.2 Recommendations

The results of this study demonstrate that there is great contribution for various groups of people and stakeholders. In academia, researchers could focus on creating new algorithms for dynamically accessing spectrum. Furthermore, developing new green technologies to enable energy saving. Engineers could focus on developing new products with better energy-efficient systems to reduce cost. Electronics with better computation power and features would also be of interest. For the business people, it gives an idea about pricing strategies to support mobile traffic growth. Application developers could focus on creating the killer application to drive the demand for femtocells through new services. It is useful for device manufacturers as they should consider embedding more devices with cellular technologies to bring new 'smart' products to the market. Femtocell manufacturers could think about integrating cellular technologies with WiFi. It has significance for mobile operators as it grants an understanding of which factors are more important than others and where to focus their resources on. Mobile operators and service providers could identify business opportunities to exploit which brings in new revenue streams. There are also issues that regulation bodies could ponder about such as releasing and allocation of spectrums for femtocells to maximise spectrum efficiency.

6.3 Limitations

Since the approach of systems thinking has been conducted, the major drawback is the lack of focus on details. As the systems had been analysed from a broader view, assumptions to a certain degree is needed. This further shows that there is always a possibility that these assumptions can be better formulated by the use of quantitative research.

The methods developed in this study can only be useful guidelines and not the full solution for business and policy decision making. High level issues such as the future health of the economy were not considered. In addition, there are random processes which can impact the systems. This means that there will always be some form of risk. Therefore the methods developed in this study are only useful pointers but not the full solution.

6.4 Future Work

Some of the findings from this study could lead to identification of possible future research topics. The various mobile offloading solutions could be more elaborately modelled to exclusively include different segments (e.g., public locations, geographical areas, population densities). This could lead to exploration of new business models and actors of wireless provisioning for these segments.

Quantitative formulation could be used to investigate many of the forces that have been presented regarding femtocell adoption. It could be interesting to examine the degree each of these forces will have on femtocell adoption by the use of quantitative methods.

Examining the effects of regulations and standards to understand how these will affect market dynamics could be another area for future studies. This is more related to spectrum allocation and licensing. This study could also trigger mobile operators to look more closely into developing new business models. This includes development of various business models for femtocells such as pricing strategies for subscribers. A possible method is the use of game theory. The study on FAAS could be further expanded as Smallcell-as-a-Service to examine its impact on the market.

Overall, combining the approach of this qualitative research with methods driven by hard data such as statistical analysis can be another avenue for further investigation. The rise of big data grants the increase of focus on detailed complexity. However it is necessary to have a balance between both approaches while emphasising the importance of each approach as well.

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Appendix

Interview questions

Introduction

When is your company going to face capacity problems or you are already facing this issue?

Deployment

What factors will lead you to launch small cell service/offloading service in homes?

What kind offloading/small cell deployments will you consider?

- How will deployment of femtocells compare to future macro network expansion?
- Which geographical locations are most suitable?

Business Opportunities

What will cause the success and failure of a femtocell business?

- Why is the uptake of femtocells not high? What causes this and what can counter the threats?
- What incentives to offer?
- What are the technical challenges of a large-scale deployment?

What kind of business opportunities and threats do you see by mobile offloading?

- Will you choose to offload via femtocells or WiFi? Why?
    - How do you see WiFi and femtocells working alongside each other?
    - What caused WiFi's success? What lessons can be learnt for femtocells?
    - WiFi and femtocells as substitutes or complementary now and in future (are they competing standards)?

- In which situations will you deploy open/closed femtocell networks?

- Deploying femtocells can be used as a platform for "Femtocell-as-a-Service". How do you think this as a game changer in the femtocell business?
    - What do you feel about multi-operator solutions (network sharing) and outsourcing?
    - What do you feel about the leasing of a femtocell network?

Spectrum/Network management

Which spectrums do you see femtocells using now and in the future?

- Using higher frequencies (eg 3.5 GHz) for homes to prevent macro-femto interference?
- What are your views from use of cognitive radio and television white spaces?
- If the backhaul is wireless, which frequencies should be considered as most suitable and why?

Do you have Self-Organising Networks and how will it support future femtocell deployments?

Marketing and Services

How will you market (differentiate) a femtocell service to potential customers if they are satisfied with WiFi?

- If customers are paying for coverage, why will they want to pay for more coverage?

How important are new services offered have to the success of deploying femtocells in homes?

- What kind of new services will you offer?

Cost, Price, Revenue

How is the cost of femtocells different from WiFi?

What kind of pricing/billing mechanism are you going to use?

Which market segments do you think will bring in the most revenue for a femtocell services?

- Which customer segments will most likely be targeted to be early adopters?

Device Availability

WiFi has been integrated in consumer electronics, what factors will lead to LTE being also integrated?

- How will LTE device availability affect uptake of femtocells?

Conclusion

What are the key drivers in your opinion that will drive a femtocell business?

Technical Architecture (Block Diagrams)

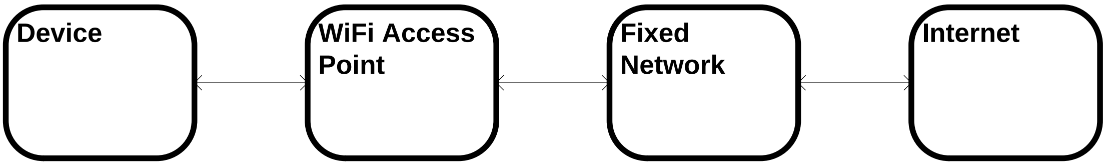

Fig. 45. Block diagram of WiFi architecture

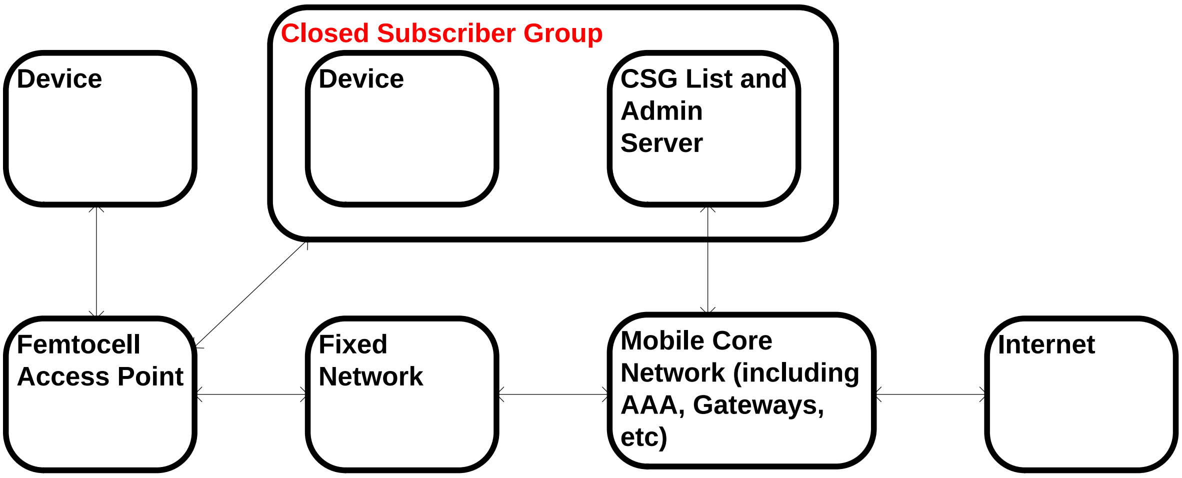

Fig. 46. Block diagram of femtocell architecture

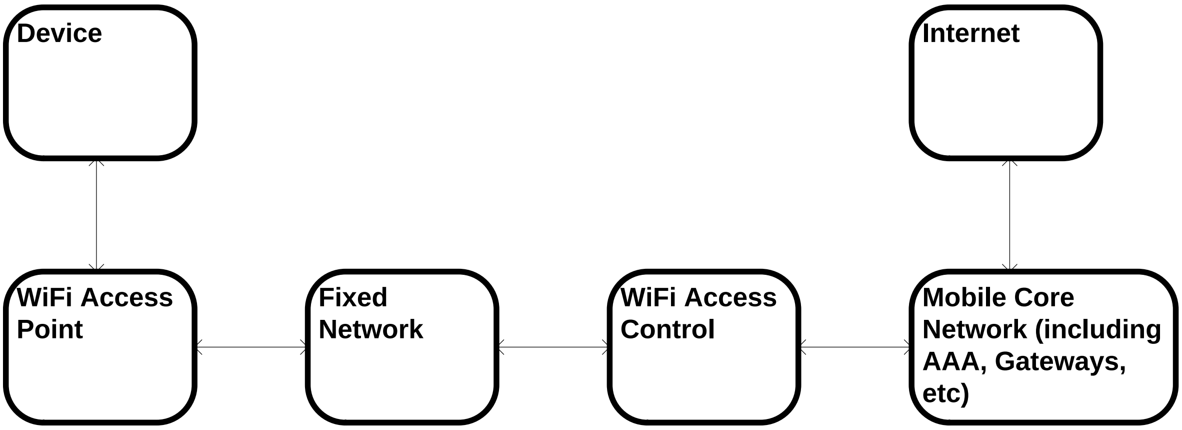

Fig. 47. Block diagram of WiFi-cellular integration architecture

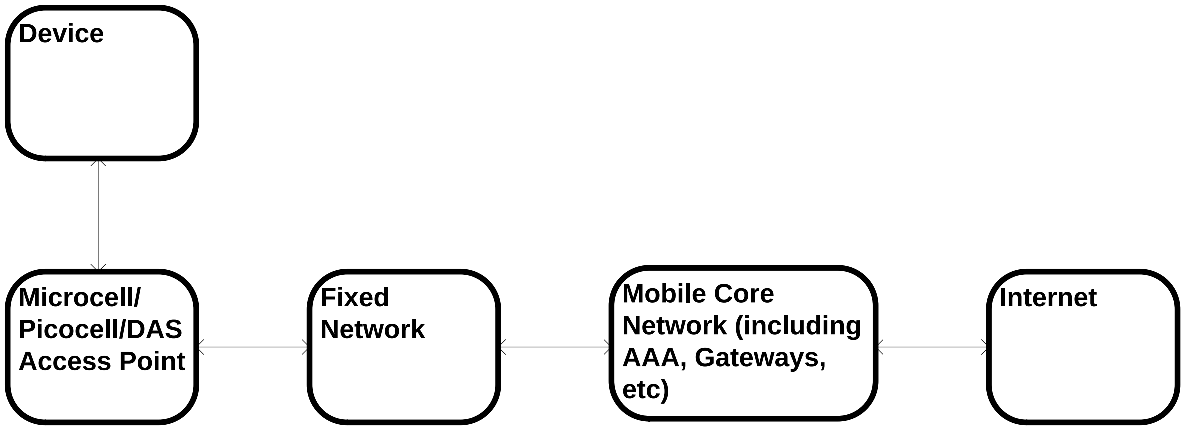

Fig. 48. Block diagram of microcell/picocell/DAS architecture

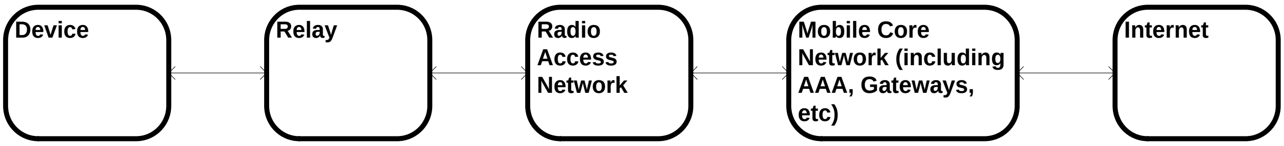

Fig. 49. Block diagram of relay architecture

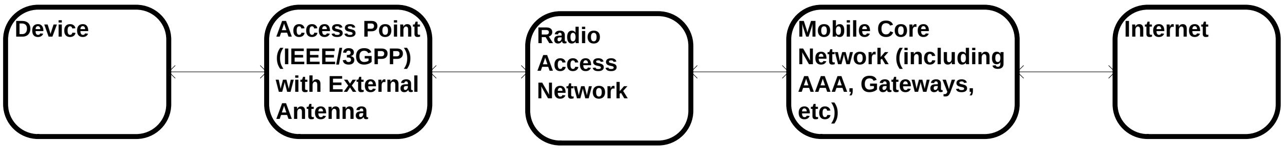

Fig. 50. Block diagram of fixed receivers architecture

Other VNCs

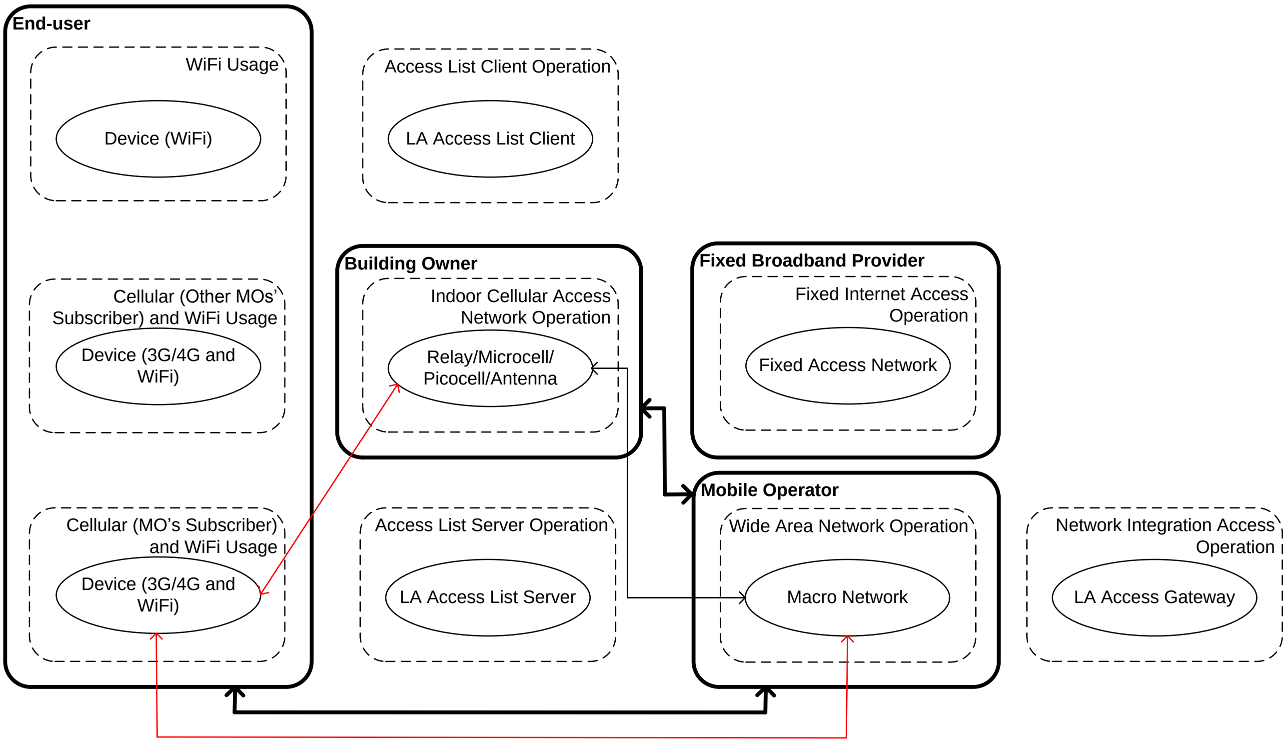

Fig. 51. Relay/Microcell/Picocell/Fixed receivers (3GPP) access VNC (scenarios 7, 8, 9, 10, 11)

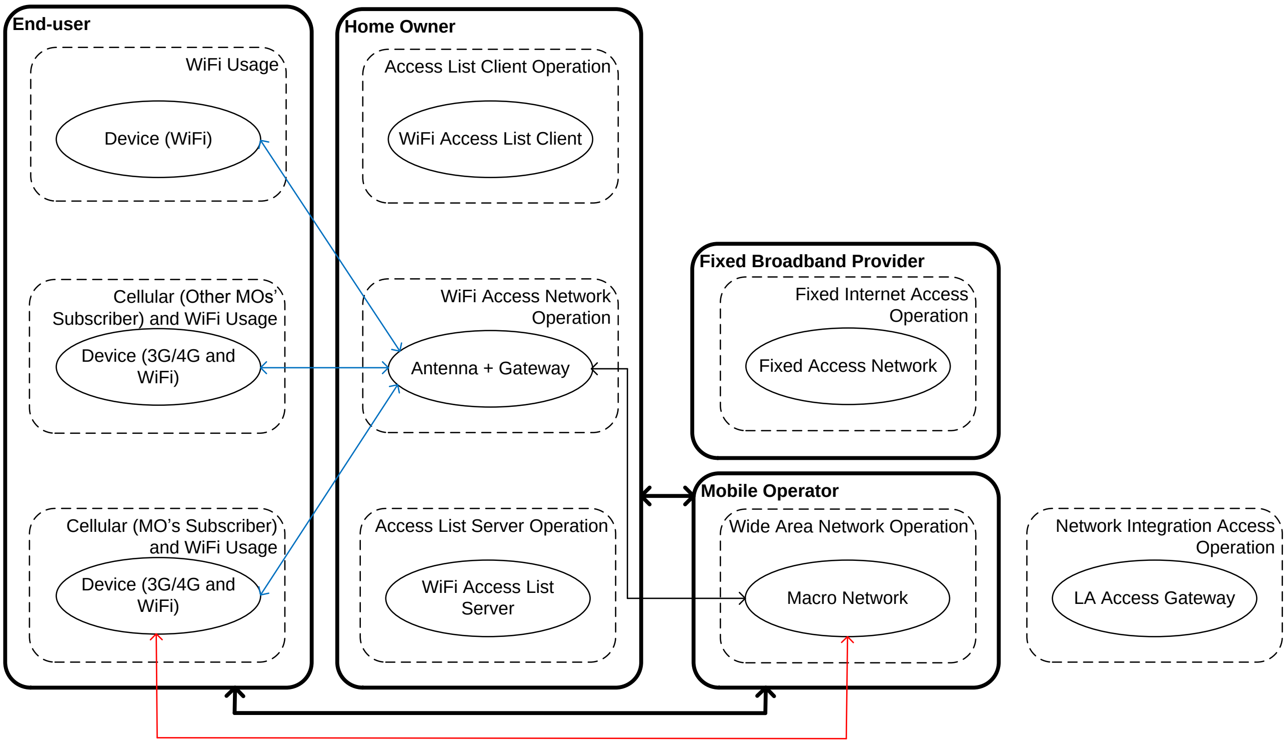

Fig. 52. Fixed receivers (IEEE) access VNC (scenario 11)