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Uplink Reference Signal Based Handover with Mobile Relay Node Assisted User Clustering

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Abstract— In today’s cellular networks, an increasing number of connected devices onboard in fast-moving vehicles would require more efficient handover (HO) procedures. To this end, we investigate the utilization of mobile relay nodes (MRNs) in vehicles to facilitate efficient HO and HO-related power consumption reductions for all onboard user equipments (UEs). In particular, the potential gains in terms of HO rate, HO failure ratio (HOFR), ping-pong (PP) rate, and total power consumption are studied for different UE cluster sizes. To eliminate the measurement power-consuming procedure, uplink (UL) reference signals (RS) transmitted by UEs are exploited. Four different case scenarios are simulated utilizing both the DL and UL RS based HO procedure, with and without deploying MRNs on the buses traveling along the cell edges of surrounding macro BSs. Simulation results indicate that the UL RS based HO procedure can improve HO performance significantly because it reduces the air-interface signaling messages, namely the measurement report (MeasReport) transmission and reception. Also, in terms of power consumption, deploying MRNs is a more attractive solution with substantial power reduction for onboard UEs of higher cluster size.

Keywords— LTE, handover, Mobile relay node (MRN), uplink reference signal (UL RS), clustering, simulation, performance evaluation, power consumption.

I. INTRODUCTION

In the past, the primary use of cellular networks was just for voice and short message services. Today, this has been changed because of data transferring services such as online gaming, live video streaming and social application data (i.e. Facebook, Twitter), an increasing number of connected devices (i.e. laptop, tablets, smartphones, and portable devices), and on-board mobile devices. Multi-user Multiple-Input Multiple-Output (MU-MIMO) and massive MIMO (M-MIMO) have been developed for the 4G LTE and 5G NR standards respectively to cope with both an increasing number of connected devices and the capacity demands from their traffic. However, MIMO requires good knowledge of a user’s channel and in the case of high-speed mobile users, it further requires extensive pilot signaling to maintain accurate channel state information. In addition, MIMO technology implies a denser deployment of networks, typically realized by means of small cells. The introduction of denser networks has a great impact on the HO process of all fast-moving mobile users, and in particular all the onboard UEs, as the HO rate increases with speed [1]. A promising solution for the on-board fast-moving

passengers is the mobile relay node (MRN) that was introduced in 3GPP LTE R12 [2]. MRN provides a wireless backhaul connection via the base station (BS) by an outer antenna and thus reduce the power consumption of the UE, vehicular penetration loss, HO frequency and signaling overheads. The MRN architecture is designed such that only the MRN HO to the target cell instead of all passengers execute the individual HO procedure. The MRN maintains the connection with all UEs within a vehicle and provides UEs an unaware HO process.

Mobile relay node (MRN) is one of the cheaper options than existing solutions requiring dedicated macro base stations (BSs), for reliable communication, especially in urban areas. The basic idea is to deploy MRNs on public vehicles. As the vehicles move, the MRN moves with the UEs within the carriage. The MRN communicates with the donor eNB (DeNB) using the backhaul link and the UEs onboard communicate with the MRN through an indirect access link, as shown in Fig. 1. The outboard UEs communicate with the DeNBs through a direct access link. The relative position of the onboard UEs with respect to the MRN is stationary or at pedestrian speed, ensuring good channel conditions and thus high data rates for this link [3].

The Sounding Reference Signal (SRS) is a reference signal (RS) transmitted by the UE in the uplink (UL) direction that is used by the DeNB to estimate the quality of the UL channel. In the ultra-dense network, the network can track and locate the mobile user using UL RS based measurements. If UEs are moving together, they can jointly be tracked in a group using one UL RS with low resource consumption and high efficiency [4]. For UEs moving together (like in bus or car), a large number of HOs increases the signaling volume. A group HO procedure reduces signaling volume since the process is the same for all UEs in the group.

In previous works, a technique for self-optimization of the HO related parameters (offset and hysteresis) with dual MRNs is presented in [5]. The parameters are tuned based on the HO performance indicator and the velocity of the vehicle that affects the HO triggering decision. The results show that the proposed method can reduce the service interruption time and RLFs during the HO procedure. Another method to reduce the RLFs and increase the HO success rate is proposed in [6] where the author has prioritized the MRN HO over other UEs HO call. An analytical model for the MRN is proposed in [7] using a stochastic geometry approach. It is found that the penetration loss is the key factor to decide the data rate gain

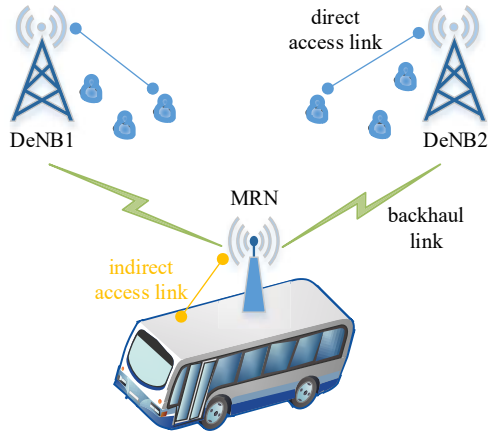


Fig. 1. MRN scenario.

into the system, i.e. high penetration loss brings high data rate gain to the onboard UEs when the bus with MRN is traveling along the cell edge. The work in [8] proposed a user-transparent mobility concept based on the transmission of UL RS (beacons) using Zadoff-Chu signature sequences for reliable detection at the eNB. The suitability of beacon resources, as well as the reliability of the proposed beacon design, has been validated to highlight its advantages over legacy HO mechanisms. The idea of joint tracking of groups of users utilizing the UL RS has been proposed in [4].

The main objectives of this work are to investigate the power consumption associated with HO signaling in an LTE network with MRN, to study the clustering aspects of MRN, and to define a power-efficient HO method based on UL RS. To this end, the first contribution of this study is an analysis of the HO performance in the presence of a MRN and the associated power consumption in LTE. The analysis is based on a scenario where clusters of UEs are traveling on buses along the cell edge of the macro BSs. The second contribution of this work is that it analyzes the impact of the onboard UEs cluster size on the HO performance and the associated power consumption. The last contribution provides a solution to the problem of high power consumption due to measurement report signaling during the HO procedure. We propose the UL RS based HO procedure to investigate the improvements in HO rate, HOFR, PP rate, and power consumption. We believe these studies contribute to determining the potential benefits of using MRN with UL RS based HO procedure. Please note that the performance of the MRN HO while taking into account the power consumption is overlooked in the literature.

The rest of the paper is organized as follows: Section II describes an overview of the MRN HO mechanism in LTE and the UL RS based MRN HO procedure. Section III discusses simulator modeling aspects. In Section IV, simulation results are presented, and finally, Section V provides a conclusion with future research directions.

II. OVERVIEW OF HANDOVER MECHANISM IN LTE MRN

There are four different MRN architecture alternatives (Alt.1 to Alt.4) discussed in 3GPP [2]. The MRN HO procedure based on architecture Alt 1 is shown in Fig. 2 in an LTE network [2]. The MRN can connect to the DeNB via the Un interface while the UEs can connect to the MRN via the Uu interface. The HO procedure in the architecture Alt 1 is more

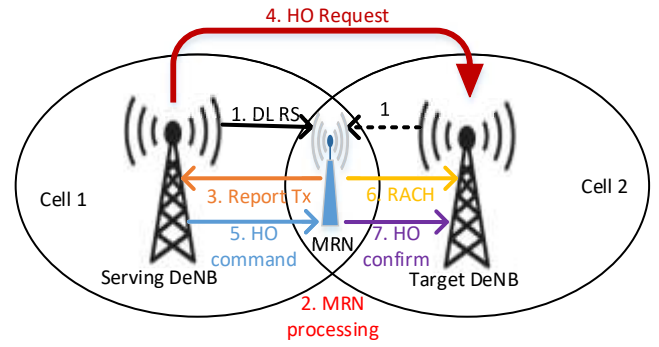


Fig. 2. MRN HO procedure (adapted from [2]) based on architecture Alt 1.

simplified and its latency analysis confirms better performance [9], which justifies our selection.

The MRN performs the downlink (DL) RS measurements from both the serving DeNB (s-DeNB) and neighboring DeNBs, including the potential target DeNB (t-DeNB), which is the DeNB “taking over” the handovered MRN. The MRN carries out signal strength (SS) measurements over a set of specific RS sent by the serving DeNB as well as the neighboring DeNBs to compute the RS received power (RSRP) from each cell. These measurements are processed at MRN. After processing the measurements, if an “entry condition” is fulfilled, a measurement report (MeasReport) containing RSRP information and a candidate DeNB-list is transmitted by the MRN and received at the s-DeNB. The “A3 event” [10] is used as entry condition to assess if the RSRP of the t-DeNB is stronger than the RSRP of the s-DeNB plus a hysteresis margin (called A3 offset). To trigger the MeasReport, the entry condition has to be valid during a specified time defined by the time to trigger (TTT) parameter [10]. Based on the MeasReport, a HO request is issued from the s-DeNB to the t-DeNB. The t-DeNB then decides whether or not it can admit the MRN and feedbacks this information to the s-DeNB. Upon successful admission, the s-DeNB transmits the HO command (HOcmd) to the MRN with the necessary information to synchronize and carry out initial access to the t-DeNB. Upon successful reception of the HOcmd, the MRN accesses the t-DeNB, by means of a Random Access (RA) procedure via the RA Channel (RACH). With successful RA completion, the t-DeNB receives a HO confirmation (HOconf) message from the MRN. Each of these phases contributes towards the overall signaling cost and latency to execute the HO. Hence, enhancing and optimizing these phases will facilitate the improvement of quality of experience (QoE) of the user/device.

A. UL Reference Signal Based Handover Mechanism in LTE MRN

In UL RS based technique, MRN sends the UL RS which is received at several neighboring DeNBs, allowing the network to perform UL signal strength measurements as shown in Fig. 3. These measurements are processed in a central network controller to decide which DeNB shall serve a given MRN. Using this method, no measurement report is required to be transmitted from the MRN and received at the DeNB, thus it reduces the operational expenditures (OPEX) and environmental effects. The rest of the UL RS based MRN HO procedure remains the same as described for Fig. 2, starting from the HO request transmission.

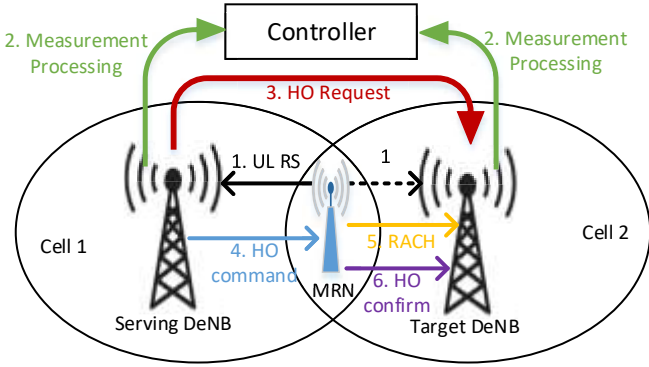


Fig. 3. UL RS based MRN HO procedure (adapted from [2][4]) based on architecture Alt 1.

III. SYSTEM MODEL

A MATLAB based LTE system-level simulator is used considering a hexagonal grid deployment of sixteen tri-sector eNBs with cell wrap-around feature to allow fair interference conditions across the scenario. A set of 100 UEs is randomly placed over the scenario. Three buses traveling on a specified path with fixed speed are deployed across the simulation scenario. Each bus contains a set of {4, 8, 12, 16} onboard UEs resulting a set of {12%, 24%, 36%, 48%} UEs onboard at a fixed speed and a specified direction. The buses follow a wrap-around trajectory over the specified road once hit the rightmost border of the simulated area. The remaining outboard UEs follow rectilinear motion at a fixed speed with initial random directions uniformly distributed between $[0^\circ, 360^\circ]$. The outboard UEs are randomly deployed outside the buses and all over the simulated area. A roof-top mounted MRN is installed on each bus. The users on the bus are getting cellular services from the MRN and the MRN is connected to a DeNB via a wireless backhaul as shown in Fig. 1. This wireless backhaul operates over the same bandwidth as the access link (i.e. in-band wireless backhaul is assumed). It is assumed that the buses are traveling along a road situated at the cell edge of the DeNBs across the simulated area. We motivate this by noting that DeNBs and MRN share the same access band and, therefore, MRN passing close to the DeNB may cause excessive interference and reduce the MRN cell coverage area. In addition, the UEs will experience poor radio link conditions at the cell edge. These UEs will then benefit from MRN following trajectory along DeNBs cell edges. The simulation setup is shown in Fig. 4. A thorough description of the simulator's modeling aspects and its features are covered in [1]. The main simulation assumptions are outlined in Table I.

The SRS based module has been modeled as per 3GPP standards described in [11][12] and integrated with the system-level simulator. The SRS resources can be distributed in the time, frequency, and code domain as shown in Fig. 5. At each beacon occasion, a part of the system bandwidth is used for SRS. A beacon occasion occurs at a given SRS periodicity. The SRS periodicity is defined as the tendency of SRS transmission/reception to recur at specified intervals. Each Zadoff-Chu sequence is transmitted in a limited bandwidth (B_{SEQ}), which determines the number (N_{SRSRB}) of SRS resource blocks (RBs) that can be transmitted in each beacon occasion. A number of orthogonal sequences (M_{SEQ}) can be sent in parallel in the same resource block. These

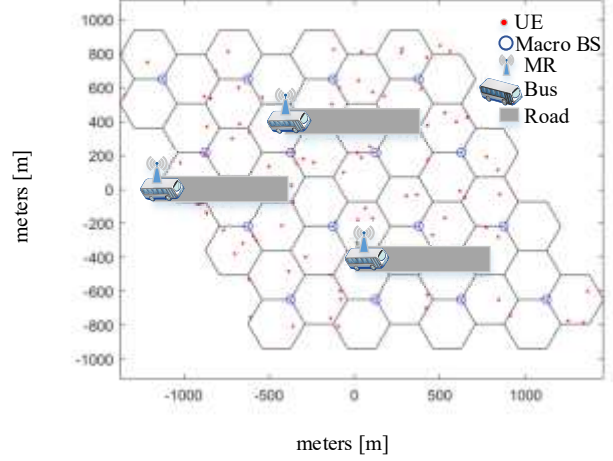


Fig. 4. The considered simulation scenario, with the buses following a wrap-around trajectory over the specified road once hit the rightmost border.

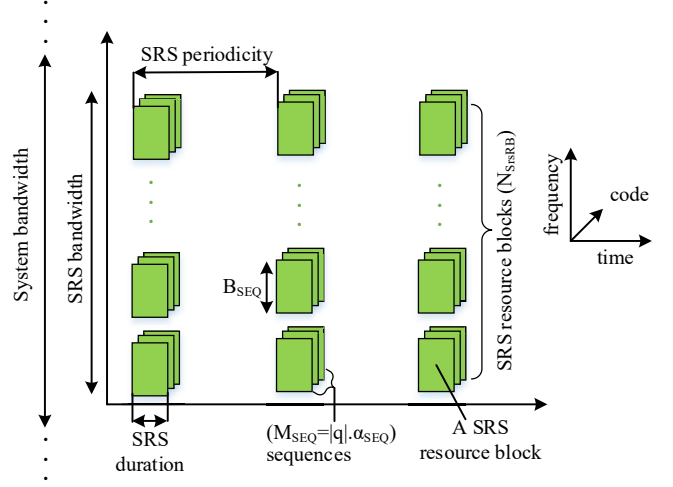


Fig. 5. SRS resource dimensioning [8].

sequences are generated from (α_{SEQ}) cyclic shifts of each root sequence and $(|q|)$ different root sequences. The SRS resources can be dimensioned by selecting these parameters appropriately. The SRS parameters used in the system-level simulator are explained in Table I.

IV. SIMULATION RESULTS

In this section, we provide a simulation evaluation of the HO performance and the total power consumption (including UE and eNB), with/without deploying a MRN. Both the DL and UL RS based HO procedures are evaluated to have a fair comparison. Mainly, the potential benefits of using MRN with UL RS based HO procedure are shown, considering the HO performance and power consumption metrics. We also show the impact of varying onboard UEs cluster size on the HO performance metrics and the associated power consumption. A set of {12%, 24%, 36%, 48%} UEs are traveling on the buses positioned across the scenario and the remaining outboard UEs are moving outside the bus, all over the scenario. Four following case scenarios are simulated,

- Case 1:** DL RS based HO without MRN deployment.
- Case 2:** DL RS based HO with MRN deployment.
- Case 3:** UL RS based HO without MRN deployment.
- Case 4:** UL RS based HO with MRN deployment.

Table I Simulation parameters and assumptions.

Feature	Implementation
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Network topology	A hexagonal grid of 16x3=48 cells
Inter-site distance	500 m
System Bandwidth	$B_{sys} = 5$ MHz (paired FDD), carrier frequency $f_c = 2.1$ GHz
eNB DL power	43 dBm
MRN and UE power	23 dBm
Antenna patterns	3D model specified in [13], Table A.2.1.1.2-2
Channel model	6 tap model, Typical Urban (TU)
Shadowing	Log-normal shadowing: Mean 0 dB, Standard deviation: 8dB
Propagation model	$L = 130.5 + 36.7 \log_{10}(R)$, R in km, for eNB $L = 140.7 + 36.7 \log_{10}(R)$, R in km, for MRN [13]
UE and Bus speed	{30} km/h
RLF detection by L1 of UE	T310=1s, N310=1, N311=1 as specified in [14] $Q_{in} = -4.8$ dB; $Q_{out} = -7.2$ dB as specified in [15]
HO parameters	TTT= {64} ms, A3 offset = {3} dB.
SRS periodicity	{40ms} [12] Table 8.2-1
Number of transmission combs (K_{TC})	2 (in LTE only 2 combs allowed) [11]
Cyclic shift	{0, 1, 2, ..., 7} for $K_{TC}=2$ [11]
Bandwidth	7, choices {0, 1, 2, ..., 7} [11]
Configuration (C_{SRS})	
Bandwidth (B_{SRS}) in PRBs	12
SRS frequency hopping bandwidth	0, choices {0, 1, 2, 3} [11]
SRS configuration index (I_{SRS})	Range=0 to 636, [12]
SRS duration	0.5ms (1 slot)
Root sequence q	(u,v) where u= sequence group number= {0,1,...29} and v= base sequence number within the sequence group = {0,1} [11]

The cases without MRN deployment on the buses mean that all UEs including both onboard and outboard will execute their individual HO procedure with macro DeNB. The cases with MRN deployment mean that only MRNs and outboard UEs perform the HO procedure to the t-DeNBs and target eNBs respectively. On-board UEs perform no individual HO procedure.

In short, the HO rate is measured in the total number of triggered HO events divided by the simulation time. The HO failure ratio (HOFR) is defined as the total number of HO failure events divided by the total number of triggered HO events. The ping pong (PP) rate is defined as the total number of ping pong events divided by the simulation time [16]. The impact of varying the cluster size of onboard UEs on the HO rate is shown in Fig. 6. For Case 1, a gradual increase in HO rate is observed as the percentage of UEs onboard increases. The reason behind this is the increasing number of group HOs when there are no MRNs installed on the rooftop of the buses. The number of HO cases reduces when we use the MRNs on the buses (Case 2). In this case, only the MRNs execute HO to the t-DeNB instead of all UEs in a cluster execute the individual HO procedure, leading to an overall reduction in the HO rate. Comparing Case 3 with Case 1, a significant drop in the HO rate can be noticed. This is because no measurement report transmission/reception is required in case of UL RS based mobility (see Fig. 3), thus the HO procedure completes before the UE loses its connection to the s-DeNB. This reduces HOFR (see Fig. 7) resulting in a reduced HO rate. More interestingly, the HO rate of 12% UEs onboard condition remains consistent for Case 2 and Case 3. We can argue that for a less number of UEs onboard, we can get the same HO rate performance without deploying the MRN by using the UL RS based HO procedure (Case 3). Case 4 has the lowest HO

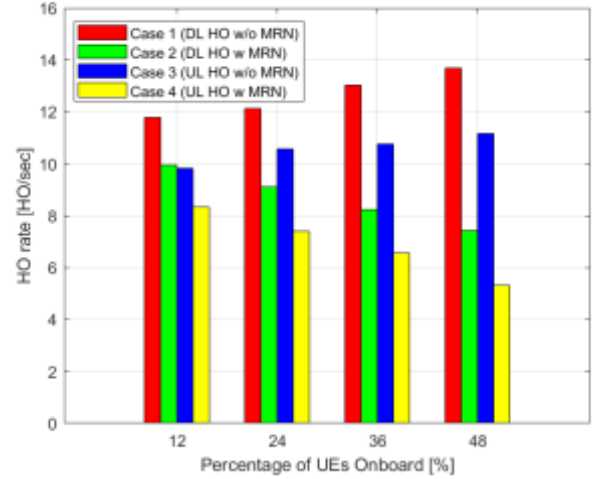


Fig. 6. Impact of varying the cluster size of onboard UEs HO rate.

rate because we are using both the MRN and the power-efficient HO procedure at the same time. We found that the HO rate of 48% UEs onboard case is reduced to almost three times and for 36% UEs onboard case to half when comparing Case 1 and Case 4. We argue that deploying the MRNs with UL RS based HO procedure for the case of higher number of UEs onboard reduces the number of HOs almost three times in comparison with Case 1.

The impact of varying the cluster size of onboard UEs on the HOFR is shown in Fig. 7. A similar trend of the graph for Case 1 and Case 2 can be observed as noticed in Fig. 6, i.e. deploying the MRNs reduces the HOFR that is expected. It is also clear from the graph that a high percentage of UEs onboard leads to a higher reduction in HOFR for Case 2. More interestingly, significant improvements in terms of HOFR can be seen for Case 3 and Case 4. This is because no measurement report transmission/reception is required for the UL RS based HO procedure and the HO process completes early (i.e. before the UE loses its connection with the s-DeNB), reducing the number of HO failure cases. This also justifies the trends of high improvements in HO rates in Fig. 6. Also, Case 4 has slightly lower HOFR in comparison to Case 3 which is attributed to the deployment of the MRNs for this case.

Similarly, the impact of varying the cluster size of onboard UEs on the PP rate is shown in Fig. 8. A ping pong event is the occurrence of a HO between a s-DeNB and a t-DeNB, followed by another HO to the original s-DeNB, all this happening under a predefined time. In the simulation scenario, the cluster of UEs onboard follows a specified path at the cell edge of the macro BS. We can see a high PP rate for the cases where we do not have the MRNs (i.e. Case 1 and Case 3) as compared to the cases where we use the MRNs (i.e. Case 2 and Case 4). This is because the MRN not only improves the radio link conditions of the UEs onboard but it also improves the PP rate as only the MRN handover to the t-DeNB (not the UEs onboard). The lowest PP rate is spotted for Case 4, 48% UEs onboard event, almost three times lower than Case 1.

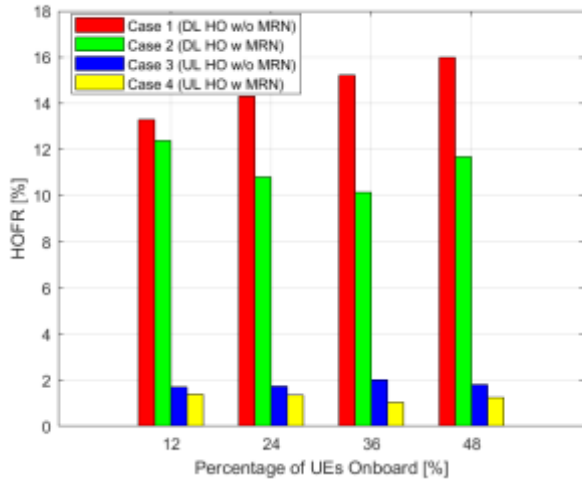


Fig. 7. Impact of varying the cluster size of onboard UEs on HO failure ratio.

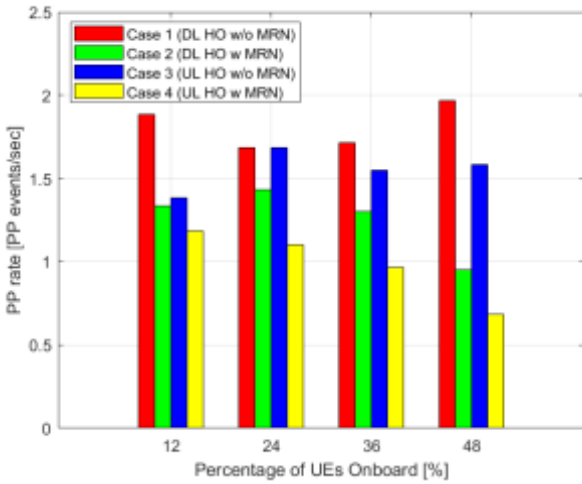


Fig. 8. Impact of varying the cluster size of onboard UEs on PP rate.

The UE and eNB transmitted power consumption due to the transmission of the HO related signaling is calculated using our previous work covered in [17]. Similarly, the received power of both the UE and eNB during the reception of the HO related signaling messages is determined using our work described in [18]. The total power consumption is the addition of both transmitted and received power consumption at the UE or eNB side. The impact of a varying onboard UEs cluster size on the total average supply power consumption is presented in Fig. 9. Specifically, we focus on the HO signaling over the air interface in both UE/MRN (UL) and eNB (DL) transmissions, namely: the HOcmd transmission from the eNB side, labeled as (5) in Fig. 2, and the MeasReport, the RACH, and the HOconf transmission from UE/MRN side, labeled as (3), (6), and (7) respectively. It is to be noted that only the DL RS based HO procedure cases (i.e. Case 1 and Case 2) have the power consumption due to MeasReport transmission/reception. This is because when we utilize the UL RS based HO procedure (i.e. Case 3 and Case 4), no measurement report transmission/reception is required, which reduces the overall power consumption. Also, the power consumption due to HOcmd signaling is higher than the other signaling messages because of the higher number of

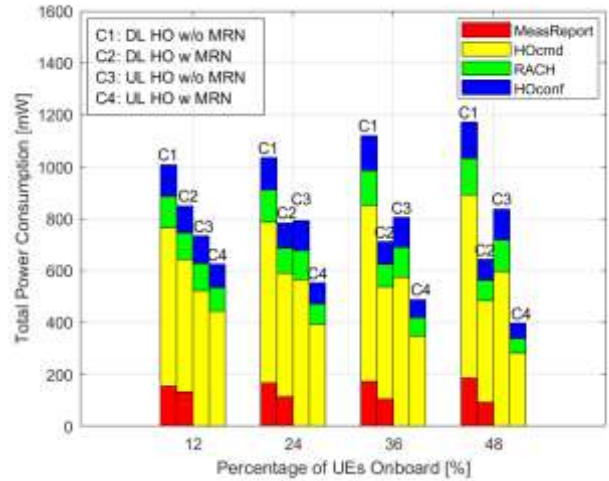


Fig. 9. Impact of varying the cluster size of onboard UEs on the total average supply power consumption.

resources consumed (double than the other signaling messages) for the transmission/reception of this specific signaling [18]. More interestingly, the power consumption of 24% UEs onboard case remains consistent for Case 2 and Case 3. For this specific case, we can get the same power consumption performance without deploying the MRN by only utilizing the UL RS based HO procedure (Case 3). The power consumption with UL RS based HO procedure cases (Case 3 and Case 4) reduce significantly in comparison to DL RS based HO procedure cases (Case 1 and Case 2) respectively. The reduction in power consumption is because of the reduced number of HO rate (see Fig. 6), HOFR (see Fig. 7), PP rate (see Fig. 8), and no requirement of MeasReport transmission/reception. We also note that increasing the UEs onboard cluster size reduces the total power consumption significantly for Case 4 in comparison to other cases (a roughly 780 mW power saving in comparison to Case 1, for 48% UEs onboard case).

Fig. 10 shows the impact of varying the cluster size of onboard UEs on the DL/UL RS transmission and measurement average supply power consumption. The DL RS are transmitted from the DeNB side and received at the UE for measurement processing. Similarly, the UL RS are transmitted from the UE/MRN and received at the DeNB within the UL RS beacon range and then the central network controller process these measurements to decide which DeNB will serve a given UE/MRN. The power consumption in Fig. 10 is the sum of DL/UL RS transmission and measurement power consumption. The power consumption for Case 1 remained consistent because all UEs carry out individual DL RS measurements every 50 ms in the simulations. A gradual decrease in the DL RS power consumption is seen with increasing UEs onboard cluster size, for Case 2. This is because of our assumption that when a cluster of UEs is traveling on a bus with MRN, only MRN executes the DL RS measurement from the neighboring DeNBs. The frequency of UE measurement can be reduced when a UE is onboard to save energy [3]. Increasing the cluster size leads to a higher reduction in power consumption. Similarly, the power consumption for Case 3 remained consistent and almost half of the Case 1 because all UEs perform individual UL RS transmission every 40 ms (SRS periodicity) in the

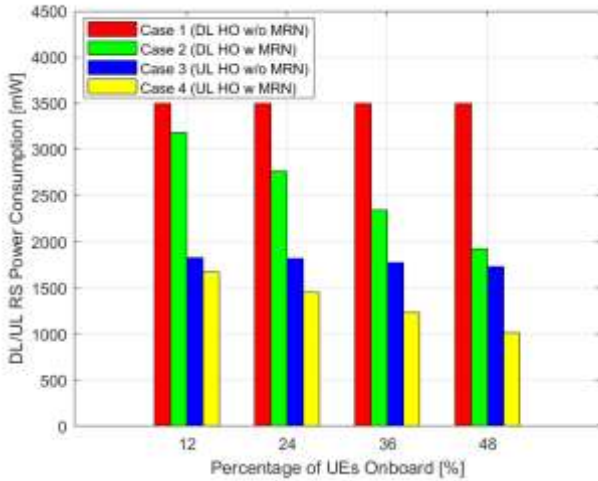


Fig. 10. Impact of varying the cluster size of onboard UEs on the DL/UL RS transmission and measurement average supply power consumption.

simulations. A gradual decrease in the UL RS power consumption is seen for Case 4 with increasing UEs onboard cluster size because of the assumption that only the MRN sends the UL RS to the neighboring DeNBs. Overall, the graph shows that the UL RS based HO method can reduce the total RS power consumption by almost half of the DL RS based HO procedure (comparing Case 1 with Case 3 and Case 2 with Case 4).

V. CONCLUSIONS

In this paper, a simulation analysis is presented to see the improvements in terms of HO performance and the power consumption when MRNs are installed at the roof-top of buses traveling along the cell-edges of the DeNBs and UL RS based HO procedure is used. We found that MRN is beneficial for a higher number of UEs belonging to the bus. If the number of UEs onboard is less (i.e. 8 UEs per bus), we can use UL RS based HO procedure without MRNs instead of DL RS based HO procedure with MRNs to get almost the same performance. In this way, we can reduce the cost of deploying the MRNs as well as the OPEX. High improvements in terms of HO rates, HOFR, PP rates, and power consumption are observed for the case scenarios where UL RS based HO procedure is utilized. Such improvements come because of no measurement report transmission and reception over the air-interface thus the HO procedure complete before the UE loses its connection to the s-DeNB. We found that increasing the UEs onboard cluster size reduces the total power consumption significantly for Case 4 (UL RS based HO procedure with MRN) in comparison to other cases. Also, the UL RS based HO method can reduce the total RS power consumption by almost half of the DL RS based HO procedure. So, the

proposed UL RS based HO procedure is power-efficient and it is beneficial since it reduces the OPEX and the environmental effects. In the future, we will propose a UE specific SRS periodicity selection procedure (e.g. as a function of speed) to further reduce the power consumption.

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