HANDOVER OSCILLATION REDUCTION IN ULTRA-DENSE HETEROGENEOUS CELLULAR NETWORKS USING ENHANCED HANDOVER APPROACH

Baha Uddin Kazi
Department of Systems and Computer Engineering
Carleton University
1125 Colonel By Drive, Ottawa, ON, Canada
bahauddinkazi@sce.carleton.ca

Gabriel Wainer
Department of Systems and Computer Engineering
Carleton University
1125 Colonel By Drive, Ottawa, ON, Canada
gwainer@sce.carleton.ca

ABSTRACT

Ultra-dense heterogeneous networks (UDHetNets) are considered a promising architecture to achieve the goal of the next generation wireless cellular networks. However, in these dense networks, the number of handovers and handover oscillations can increase significantly. The enhanced handover for low and moderate speed UEs (EHoLM) algorithm presented here minimizes the number of handovers in the HetNets. We analyzed the handover oscillation and the performance of EHoLM in UDHetNets. The simulation results show that the EHoLM scheme also reduces the number of handovers and handover oscillations in the UDHetNets. The reduction of the number of handovers and the handover oscillations improve the user experience as well as the network performance. Moreover, we also present how we modeled and simulated the handover oscillation and EHoLM scheme in the UDHetNets using discrete-event system specification (DEVS).

Keywords: Cellular networks, ultra-dense networks, 5G networks, handover oscillation, DEVS.

1 INTRODUCTION

The next generation wireless cellular networks intends to overcome the challenges of existing wireless systems, such as the exponential growth of data traffic, coverage, lower latency, energy consumption, reliability, and cost. By mixing the different research done by academia and industry, the goal of the next generation networks (5G) is to provide a system capacity of 1000 times higher, 10 times the data rates, 25 times the average cell throughput, 5 times reduced latency, and 10 times longer battery life time. Also, we need to minimize the signaling overhead when compared to the current 4G networks (Peng, Li, Zhao, & Wang, 2015; Hossain, Rasti, Tabassum, & Abdelnasser, 2014; Agyapong, Mikio, Dirk, Wolfgang, & Anass, 2014; GSMA Intelligence, 2014; Agiwal, Abhishek, & Navrati, 2016).

In this context, network densification, such as the use of ultra-dense heterogeneous network (UDHetNet) is considered as a key enabler to achieve the goals of 5G cellular networks. World leading wireless system design and device manufacturing industries publicly stated that dense small cells are the foundation to achieve 1000× challenge in the 5G wireless cellular networks (Rakon, 2015; Qualcomm, 2014). In UDHetNets, small cells are added to the legacy macro cells, in order to get the access nodes as close as possible to the network users, as shown in figure 1(a). These small cells use lower transmit power, hence provide a small coverage area, and they can significantly improve the network capacity by spectrum reuse and improving the link efficiency by reducing the distance between the access nodes and the users.

However, these networks face new technical challenges such as mobility management and intercell interference. Since the coverage area of a cell is small, users equipment (UEs) experience frequent handover

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(HO), and handover oscillation. The 3rd generation partnership project (3GPP), telecommunications standardization body showed that the increase in the number of handovers in small cell networks compared to macro-only networks can be up to 120%-140%, depending on the UE speed (3GPP, 2013b). In UDHetNets, the number of handovers could be even higher, depending on the UE speed and density of the cells. Therefore, to realize the potential link efficiency and capacity benefits of dense small cells, we need adequate mobility management, and this has become a major technical challenge in the UDHetNets. The handover process is used to support the mobility of the UEs. The handover process makes UEs in active mode to be transferred from the serving cell to the neighboring cell with the strongest received power, and the user is not aware, as shown in figure 1 (b).

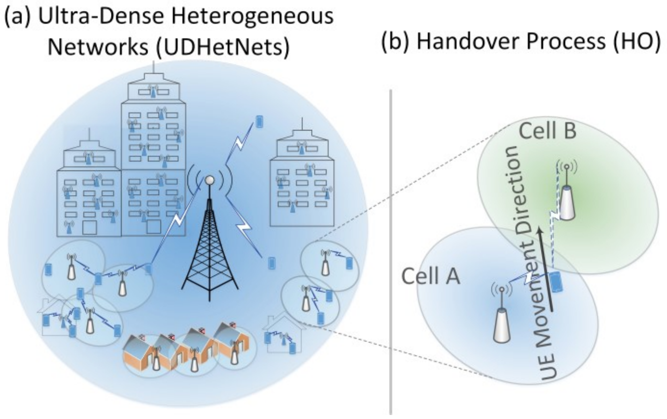


Figure 1: A simplified view of ultra-dense heterogeneous networks and handover process

In our previous work, we proposed the enhanced handover for low and moderate speed UEs scheme (EHoLM) in order to reduce the number of handovers in HetNets (Kazi & Gabriel, 2017a). In EHoLM, the control and data plane separation are used for the UEs who are in a coordinated multipoint (CoMP) transmission. Moreover, the handover criteria are not satisfied until a UE moves from a CoMP to a no CoMP region of a different eNB (evolved Node B) or base station instead of the conventional handover criteria (an A3 event). Here, we extend our previous work and present research results on handover oscillation in the context of UDHetNets. In order to study this phenomenon, we modeled the handover oscillation and we run multiple simulation scenarios. The simulation results show that the EHoLM handover method reduces the number of handover and handover oscillation in the dense heterogeneous networks. The number of handovers and handover oscillations are the two key performance parameters for handover process (3GPP, 2012). The reduction of handover and handover oscillation will eventually improve the user experience as well as the network performance.

The rest of the paper is organized as follows. We discuss the background and related works in section 2. In section 3, we briefly discuss the handover procedure according to the standardization process of the wireless cellular networks. The enhanced handover scheme (EHoLM) is presented in section 4 briefly. In section 5, we discussed how we modeled handover oscillation in ultra-dense HetNets. Simulation scenarios and results are presented in section 6. Finally, we conclude with the future advancements in the last section.

2 BACKGROUND AND RELATED WORKS

To improve the capacity and performance of wireless cellular networks, a number of technologies have been proposed, including massive multiple input multiple output (Massive-MIMO), millimeter-wave communication, multicell cooperation and ultra-dense heterogeneous networks (UDHetNets) (Jungnickel, et al., 2014; 3GPP, 2016a; Alsharif & Nordin, 2016). Among the various techniques, ultra-dense heterogeneous networks and multicell cooperation have been adapted as two key technologies to provide services the massive number of wireless users (Sun, Gao, Peng, Wang, & Song, 2013; Jungnickel, et al., 2014; Chen, Tianyu, Hsiao-Hwa, Zhiping, & Weixiao, 2017; Peng, Li, Zhao, & Wang, 2015). The

UDHetNets consist of macro-cells coexisting with dense low power cells such as pico-cells, femtocells and remote radio head (RRH). The RRHs are mounted outside the macro eNB (MeNB) and are connected via optical fiber. RRHs do not have a baseband unit (BBU), and the central macro eNB or BBU pool is in charge of the control as well as the baseband signal processing. The pico eNBs are low power nodes with the same backhaul and access features as the macro eNBs. The typical transmit power range of a Pico eNB (PeNB) is 23 to 30 dBm (Lopez-Perez, et al., 2011), as a result, the coverage area of the PeNB is also small. The home eNBs (HeNBs) are low power user-deployed access points. The typical transmit power of a HeNB is less than 23dBm and the coverage area is considered less than 50 meters (Lopez-Perez, et al., 2011). Figure 1(a) shows the overall architecture of ultra-dense heterogeneous cellular networks.

However, the deployment of these small cells can result in an increased interference and mobility (Ishii, Yoshihisa, & Hideaki, 2012a). Coordinated multipoint (CoMP) and dual connectivity are two promising technologies to overcome these challenges (Ishii, Yoshihisa, & Hideaki, 2012a; Jha, Kathiravetpillai, Rath, & Koc., 2014; 3GPP, 2015b; Chen, Tianyu, Hsiao-Hwa, Zhiping, & Weixiao, 2017).

Coordinated multipoint (CoMP) is an effective method to improve the user throughput by mitigating inter-cell interference (ICI), especially for cell edge users (3GPP, 2013a; Kazi, Etemad, Wainer, & Boudreau, 2016b; Chen, Tianyu, Hsiao-Hwa, Zhiping, & Weixiao, 2017). Before LTE-Advanced (LTE-A), each eNB served its own users' equipment (UEs). As a result, the UEs at the cell's edge could receive a lower signal quality from its serving eNB, and could have higher interference from the neighboring cells. In CoMP-enabled systems, the neighboring eNBs are grouped into a cooperating set. The eNBs of this set exchange information and process it jointly. The UEs in a CoMP cooperation set can receive signals simultaneously from one or more transmission points (Ding & Luo, 2013). In (Geirhofer & Gaal, 2012), the authors presented CoMP for HetNet scenarios, and studied CoMP schemes and the deployment architectures as well as their benefits and drawbacks. In (Kazi, Etemad, Wainer, & Boudreau, 2016b; Kazi, Etemad, Wainer, & Boudreau, 2016a), we presented a dynamic coordinator CoMP control architecture for reducing signaling overhead and feedback latency. The authors in (Chen, Tianyu, Hsiao-Hwa, Zhiping, & Weixiao, 2017) studied the performance of CoMP joint transmission in ultra-dense networks (UDNs). They also focused on how to improve the spectral efficiency in UDNs using CoMP. The 3GPP also included CoMP operation as a study item of release 14 for further enhancement on dense heterogeneous networks (3GPP, 2017).

Another promising technology to increase the user throughput, as well as to achieve mobility enhancement, is called dual connectivity (Ishii, Yoshihisa, & Hideaki, 2012a; Jha, Kathiravetpillai, Rath, & Koc., 2014; 3GPP, 2013b). In dual connectivity, the UEs can connect with two or more eNBs simultaneously using the control plane and user plane separately.

The (3GPP, 2013b) report suggested three deployment scenarios for studying dense HetNets. In scenario 1, macro and small cells have the same carrier frequency. In scenario 2, macro and small cells have the different carrier frequency. Finally, in scenario 3, all are small cells with one or multiple carrier frequencies. In all the three scenarios, the eNBs are connected via a non-ideal backhaul. In (Ishii, Yoshihisa, & Hideaki, 2012b; Jha, Kathiravetpillai, Rath, & Koc., 2014), the authors showed how dual connectivity could achieve mobility enhancement. They only considered the scenario 2 above.

In (Lopez-Perez, Güvenc, & Chu., 2012), the authors presented a review of the handover process, and they identified technical challenges for mobility management in HetNets. In (3GPP, 2013b; 3GPP, 2016a) different deployment scenarios and challenges of small cell enhancements in HetNets were presented. In (3GPP, 2016d; 3GPP, 2015a), 3GPP discussed details of the handover process in the LTE and LTE-A networks. An advanced handover scheme that could reduce the number of handovers and its oscillations in UDHetNets could improve performance for 5G wireless cellular networks.

We used the CD++ toolkit that implements discrete-event system specification (DEVS) and Cell-DEVS formalisms (Wainer, 2009; Zeigler, Praehofer, & Kim, 2000). DEVS provides a number of advantages for modeling and simulation (M&S). A real-world dynamic system modeled in DEVS is described as a formal model that is described as the composition of atomic (behavioral) models and coupled (structural) models.

The hierarchical and modular nature of DEVS allows the description of multiple levels of abstraction and enhances the reusability of a model. Furthermore, according to the level of accuracy, DEVS reduces the computational time by reducing the number of calculation. Finally, the same model could be extended with different DEVS-based simulators, allowing for portability and interoperability at a high level of abstraction (Inostrosa-Psijas, Wainer, Gil-Costa, & Marin, 2014).

3 HANDOVER PROCESS IN WIRELESS CELLULAR NETWORKS

According to the 3GPP specifications, in LTE-A cellular networks, UE-assisted network-controlled handovers are performed as follows (3GPP, 2016d). The UE processes the measurement report (MR) and sends it to the serving eNB, which takes the decision to move from one cell to another cell based on the received MR. The handover is performed mainly via the radio resource control layer (RRC) between a UE and the eNB in the control-plane. The handover process can be divided into 3 states (3GPP, 2012). In state 1, UE checks the handover criteria (A3 event) and process the measurement report (MR). State 2: after the handover criteria are satisfied but before the handover command is successfully received by the UE. In this state UE waits for TTT expire, send the measurement report and wait for receiving handover command. State 3 starts after the HO command is received by the UE and before the UE reconnect to the new eNB successfully. Figure 2 shows the details of the handover process with different states of UEs (3GPP, 2016d; Kazi, Gabriel, & Victor, 2017b).

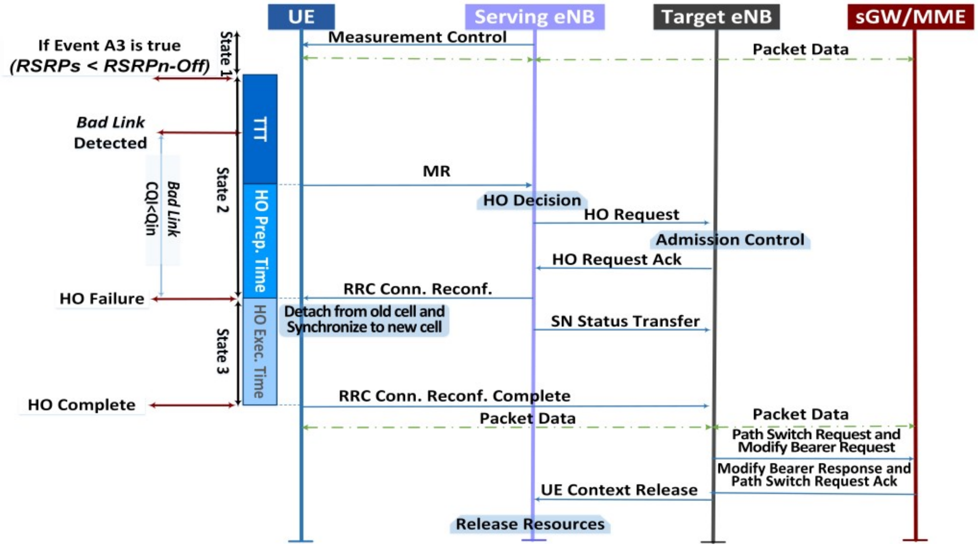


Figure 2: Simplified handover process for LTE and LTE-A cellular networks

Every 40 ms, the UE calculates the reference signal received power (RSRP) and computes the linear average over 5 successive RSRP samples. To accomplish this, the following formula is used (3GPP, 2016c; Vasudeva, Simsek, López-Pérez, & Guvenc, 2015; Lopez-Perez, Güvenc, & Chu., 2012):

$$M(n) = \frac{1}{5}\sum_{k=0}^{4} RSRP_{l1}\,(5n-k) \qquad (1)$$

Where,

$RSRP_{l1}$: RSRP sample measured every 40 ms

n: discrete time index of the RSRP sample

k: delay index of the filter

Therefore, the handover measurement period for an UE in layer three (L3) is 200ms. Once the RSRP of the serving cell ($RSRP_s$) plus the A3 offset or hysteresis margin is lower than the filtered RSRP of one of the neighbouring cells ($RSRP_n$), the UE starts the time to trigger (TTT) timer (Lopez-Perez, Güvenc, & Chu., 2012; Kuang, Jakob, Zarah, Heinz, & Joachim, 2015):

$$\text{Event A3: } RSRP_s + Off < RSRP_n \tag{2}$$

If the A3 event condition presented in equation 2 is true throughout the TTT, the UE sends the measurement report to the serving eNB (eNB_s) once the TTT expires. This MR kicks off the handover preparation phase, as shown in figure 2. The serving eNB issues a handover request message to the target eNB (eNB_t). This handover request carries out admission control procedure for the UE in the target eNB. After the admission control, eNB_t sends a handover request Ack message to the eNB_s. When the eNB_s receives the handover request Ack, data forwarding from eNB_s to eNB_t starts and the eNB_s sends a handover command (RRC Conn. Reconf) to the UE. The handover execution phase (state 3) starts with this handover command. The UE then synchronizes with the eNB_t and sends a handover complete (RRC Conn. Reconf complete) message to the eNB_t. As a result, intra eNB handover process of the UE is complete, and the eNB_t becomes its eNB_s. After completing the reconnection to eNB_t (new eNB_s) data transmission to the UE starts. The new eNB_s sends a path switch request to the serving gateway to inform the core network that it is the new eNB_s for the UE. The serving gateway or the network sends a modify bearer response message to the new eNB_s and switched the downlink data path from the previous eNB_s to new eNB_s. Finally, new eNB_s sends UE context release message to the old eNB_s, based on the message old eNB_s release the allocated resources for the UE.

4 ENHANCED HANDOVER SCHEME

In CoMP enabled networks, if a conventional handover process is used, some handover might occur though the UE is still in CoMP transmission and served by the same CoMP cooperating set. That is, the serving eNB still serves the UE with other cooperating eNBs, but the UE is handed over to another eNB in the CoMP set. This is an unnecessary handover, which eventually degrades performance. Considering this, the EHoLM algorithm exploits CoMP and the dual connectivity provided for control plane and data plane separation for UEs. In this approach, the handover criteria will not be satisfied until a UE moves from a CoMP to no-CoMP region in a different eNB, or to a different CoMP set without the current eNB_s (instead of doing it as in equation 2). The EHoLM scheme is shown in figure 3.

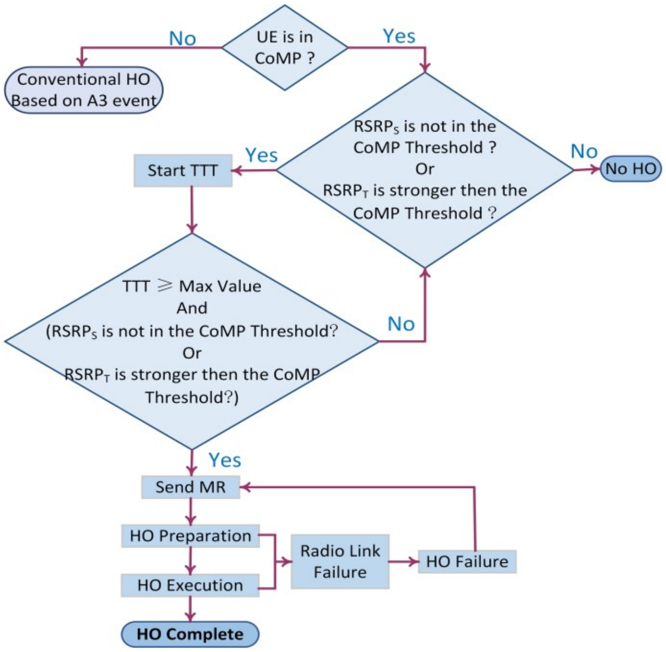


Figure 3: The EHoLM handover scheme

5 MODELING HANDOVER OSCILLATION

The handover is a process that consumes radio resources, which are limited; therefore, it is important to minimize the number of handover oscillations. If a UE handed over from cell *u* to cell *v* and then another handover back from cell *v* to cell *u* within the minimum time-of-stay (MTS) we have a handover oscillation. The time-of-stay (TS) in cell *v* is the duration of time from when the UE successfully complete the handover to cell *v* to when the UE successfully sends the handover complete message to cell *u*. We considered MTS ≤ 1 seconds for simulation (Kuang, Jakob, Zarah, Heinz, & Joachim, 2015; 3GPP, 2012). Moreover, if a UE stays in a cell is less than the MTS, the handover also is considered as unnecessary (3GPP, 2012). Therefore, reducing the handover oscillation is an important metric in handover performance evolution. Figure 4 shows how we modeled the handover oscillation in the left and how we count their number in the right. To count the handover oscillation, we follow the 3GPP specification as discussed in (3GPP, 2012; 3GPP, 2013b; 3GPP, 2016a).

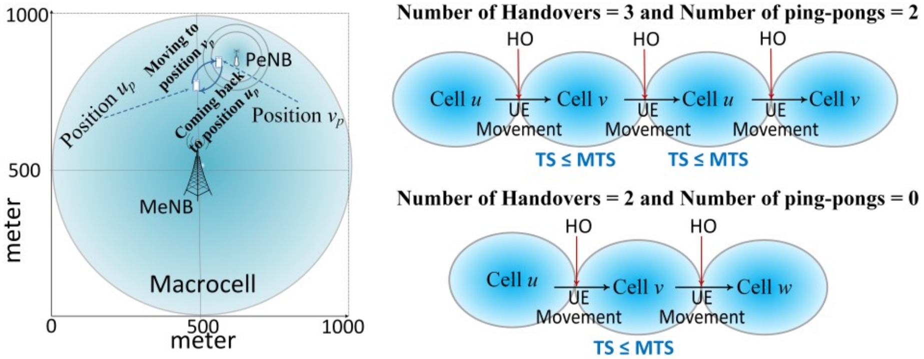


Figure 4: Handover oscillation modeling

In this study, we focus on handover oscillation in the UDHetNets. In the simulation scenarios, the minimum distance between macro eNB (MeNB) and pico eNB (PeNB) is considered 100 meters and the minimum distance between PeNB and PeNB is considered 50 meters. The UEs are randomly placed closer to the border of macro cells and pico cells (point u_p). The UEs then move straight in a random direction with an angle to the point v_p of cell *v*, which is also closer to the border of the cells. The UEs move back and forth continuously between initial position and final position until the simulation ends.

We used DEVS to model the process described in Figure 4. Each MeNB, PeNB, and UE in the networks are defined as DEVS coupled models composed of two atomic models (*Buff* and *Proc*). Figure 5 shows a code snippet of *UEProc* and *UEBuff* DEVS atomic models developed in the CD++ toolkit.

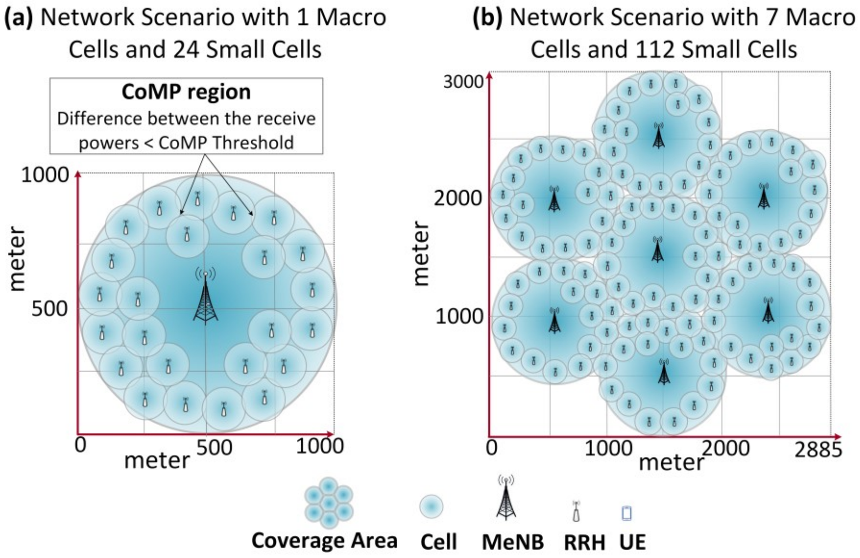
```
UEProc::UEProc( const std::string &name ) : Atomic( name ),
In( addInputPort( "In" )), Out( addOutputPort( "Out" )),
    Out( addOutputPort( "X2Out" )), Req( addOutputPort( "Req" ))
 {  ...   }
Model &UEProc::externalFunction( const ExternalMessage &msg ) { ... }
Model &UEProc::outputFunction( const InternalMessage &msg ) {  ... }
Model &UEProc::internalFunction( const InternalMessage & ) { ... }


UEBuff:: UEBuff( const string &name ): Atomic(name),
    In(addInputPort("In")), Req(addInputPort("Req")),
    X2in(addInputPort("X2in")), Out(addOutputPort("Out")),
    { ... }
Model &UEBuff::externalFunction( const ExternalMessage &msg ){...}
Model &UEBuff::internalFunction( const InternalMessage & ) { ... }
Model &UEBuff::outputFunction( const InternalMessage &msg ){ ... }
```

Figure 5: Sample code snippet for the UE processor and UE buffer atomic models in CD++ toolkit

UE processor *(UEProc)* calculates the RSRP based on the received power and generate the MR. According to the handover criteria, *UEProc* triggers the MR to the serving MeNB *Buff* or PeNB *Buff* through the output port (Out). Once the eNB receives a message, the eNB *Buff* pushes it in a queue. The message is popped out from the queue and forwarded to the eNB processor (*eNBProc)* to process when a request is received from its processor. The *eNBProc* takes the HO decision based on the received MR from the UE and sends the HO request to the eNB_t through the output port (X2Out) as all the MeNBs and PeNBs are connected by X2 link. The number of MeNBs, PeNBs, and UEs could be different according to the simulation scenarios. Finally, all the MeNBs, PeNBs and UEs together composed the top-level coupled model, which is the network coverage area.

6 SIMULATION SCENARIOS AND RESULTS

To study the handover oscillation and the EHoLM handover procedure in the context of dense HetNets, we considered the scenarios suggested in (3GPP, 2017; 3GPP, 2013b; 3GPP, 2012; 3GPP, 2013c). Figure 6 shows the simplified network architectures of the simulation scenarios we used. The network scenario in figure 6(a) has 1 macro cell and 24 Pico cells separated by the minimum ISD as mentioned in the table 1. Figure 6(b) shows a dense HetNet with 7 macro cells and each macro cells has 16 small cells. UEs are connect to the eNBs based on the strongest received power.



(a) Network Scenario with 1 Macro Cells and 24 Small Cells

(b) Network Scenario with 7 Macro Cells and 112 Small Cells

Figure 6: Simplified simulation scenarios with MeNB and PeNB placement

We ran a series of simulations on both EHoLM and the conventional handover model, based on the initial conditions summarized in table 1. These simulation parameters have been chosen based on the 3GPP specifications and other related works (3GPP, 2013a; Kazi, Etemad, Wainer, & Boudreau, 2016a; Zhang & Zhou, 2012; 3GPP, 2016b; 3GPP, 2013b). In our case, cells are considered macro and pico cells in an urban area.

The simulation results were obtained and analyzed conducting a number of simulation runs for each simulation scenario so that the margin of error is based on a 95% confidence interval. Some of the collected simulation results are presented below.

Table 1: Initial assumptions for the simulation

Parameters	Macrocell	Picocell
Number of eNBs	1 and 7	24, 112
Transmit power	43 dBm	30dBm
Carrier Frequency	2000 MHz	3500 MHz
Path loss model	$128.1 + 37.6\log_{10}(d)$	$147 + 36.7\log_{10}(d)$
Antenna gain	12 dBi	05 dBi
Number of UEs	100, 200	
UE speed (km)	3, 5, 10 and 30	
MeNB to PeNB distance	ISD > 100 m	
PeNB to PeNB distance	ISD > 50 m	
RSRP sample	Every 40 ms	
TTT	160 ms	
A3 offset	3 dB	
CoMP threshold	6 dB	
Handover preparation time	50 ms	

Figure 7 shows a comparison between the conventional and EHoLM scheme with respect to the frequency of handover as a function of the speed of UEs. In this case, we considered one macrocell with 24 picocells as shown in figure 6(a) and 100 UEs with different speed (3km/h, 5km/h, 10km/h and 30km/h). We first define the initial position and final position of the UEs. The UEs move back and forth continuously between initial position and final position until the simulation ends as we discussed in section 5. We considered same carrier frequency (SCF) of 2000 MHz for both macro eNB and pico eNB, and different carrier frequencies (DCF) of 2000MHz for the macro eNB and 3500MHz for the pico eNB. Figure 7 shows that in all cases EHoLM scheme reduces the number of handovers significantly.

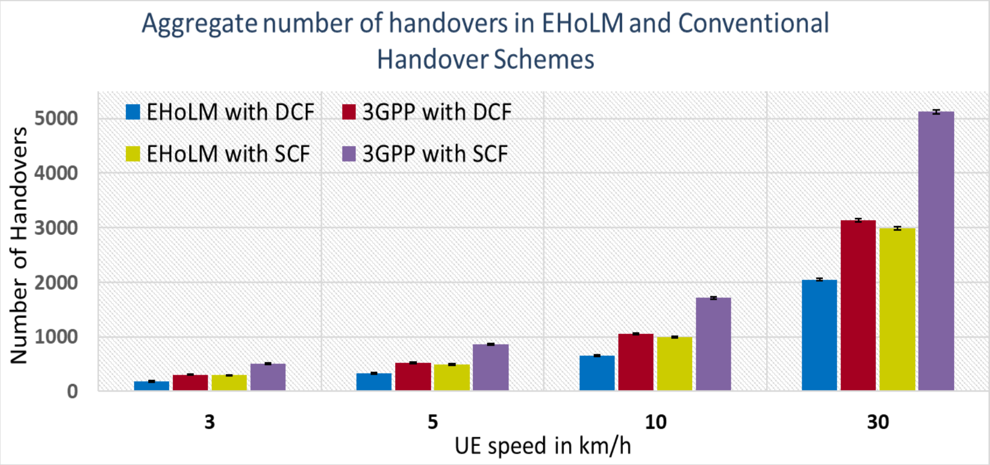


Figure 7: Number of handovers in EHoLM and Conventional handover schemes with respect to the UE speed and carrier frequencies

Figure 8 shows a comparison between the conventional and EHoLM scheme with respect to the number of handover oscillations as a function of UE speed. The simulation scenario uses 1 macro cell, 24 Pico cells as shown in figure 6(a) and 100 UEs. UEs are randomly distributed closer to the cell edge area of macro eNBs and pico eNBs. The speed of the UEs is considered 3, 5, 10 and 30km/h. In 8(a), both the conventional and EHoLM handover procedures use the same carrier frequency of 2000 MHz for both macro and pico eNBs. In 8(b), both the conventional approach and EHoLM scheme use different carrier frequencies of 2000 and 3500 MHz for macro and pico eNBs respectively. According to the figure, in case of different carrier frequencies for MeNBs and PeNBs, EHoLM reduces the number of handover oscillations more than same carrier frequencies for MeNBs and PeNBs compared to conventional handover process. However, in both of the cases with different UE speed, the EHoLM handover procedure reduces the number of handover oscillations significantly.

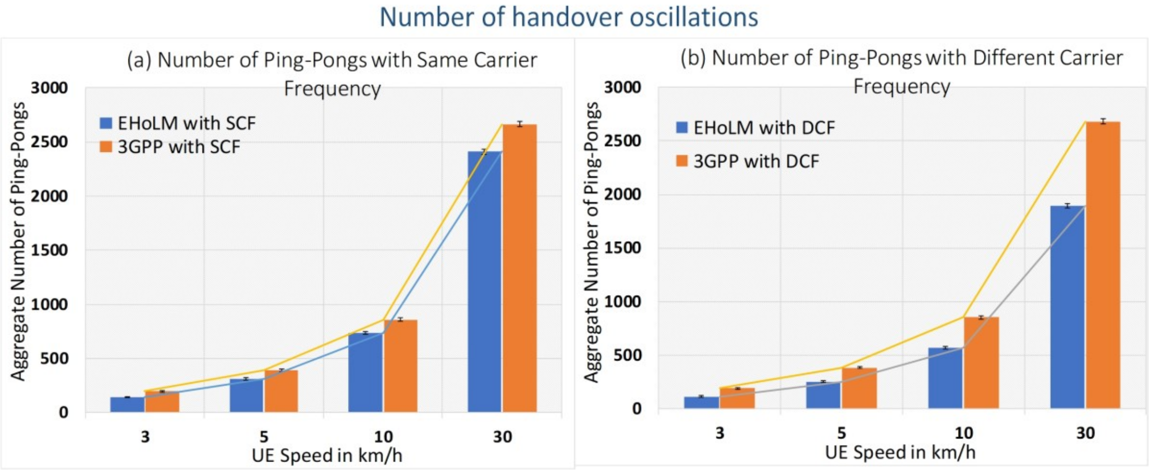


Figure 8: Number of handovers oscillations in EHoLM and Conventional handover schemes with respect to the UE speed and carrier frequencies

Figure 9 shows the percentage of UEs participate in the handover or handover oscillation in the conventional and EHoLM scheme. In this case, we use the same network and the same set of UEs for both conventional and EHoLM scheme. According to the figure, 12% of the UEs do not require to participate in the handover oscillation in EHoLM scheme. This is a significant improvement over convensional approach.

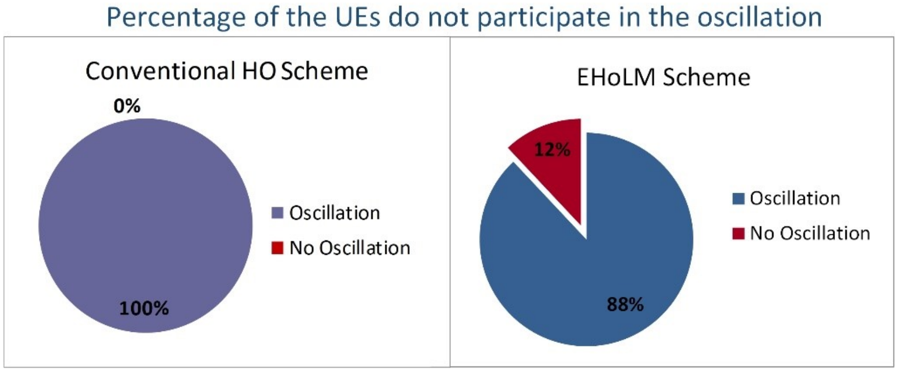


Figure 9: Percentage of UEs do not participate in the handover oscillation

7 CONCLUSION

The main goal of this research was to analyze the handover oscillation and the EHoLM scheme, to observe how the scheme performs with handover oscillation in the ultra-dense heterogeneous networks. We modeled the handover oscillation in the dense heterogeneous scenarios using DEVS and tested the EHoLM approach in different scenarios as mentioned in the previous sections of the paper. The simulation results showed that this approach reduces the number of handovers and handover oscillation compared to the conventional handover approach. The reduction of the number of handovers and handover oscillation reduce the control overhead within the networks, which eventually will improve the users' experience as well as network performance. Therefore, EHoLM has the potential to improve the overall performance of wireless cellular systems. A possibility to expand this work is to examine how it affects the power consumption of the UEs and the networks since the power consumption of a device also depends on the message transmission. As the EHoLM handover process reduces control messages transmission within the networks, it might have potential in the energy efficiency, which is one of the goal of the next generation wireless cellular networks.

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AUTHOR BIOGRAPHIES

BAHA UDDIN KAZI is a Ph.D. candidate in the Department of Systems and Computer Engineering at Carleton University. He received his MASc in Computer Networks from Ryerson University. He has reported his work in about 15 peer-reviewed publications, including journals, research monograph and conference papers. He is serving as a member of the technical committee of several international conferences. His research interests focus on performance engineering, modeling and simulation, wireless cellular networks and network protocols. His email address is bahauddinkazi@sce.carleton.ca.

GABRIEL A. WAINER, FSCS, SMIEEE, is Professor and Associate Chair for Graduate Studies, Department of Systems and Computer Engineering (Carleton University). He held visiting positions at the University of Arizona; LSIS (CNRS), Université Paul Cézanne, University of Nice, INRIA Sophia-Antipolis, Université Bordeaux (France); UCM, UPC (Spain), and others. He is the author of three books and over 350 research articles; he helped organizing over 100 conferences, being one of the founders of the Symposium on Theory of Modeling and Simulation, SIMUTools and SimAUD. Prof. Wainer is Special Issues Editor of SIMULATION, member of the Editorial Board of IEEE/AIP CISE, Wireless Networks (Elsevier), and others. He received the IBM Eclipse Innovation Award, the First Bernard P. Zeigler DEVS Modeling and Simulation Award, the SCS Outstanding Professional Award (2011), the SCS Distinguished Professional Award (2013), the SCS Distinguished Service Award (2015) and various Best Paper awards. He is a Fellow of SCS. Email: gwainer@sce.carleton.ca