X2-Based Handover Performance in LTE Ultra-Dense Networks using NS-3

Sherif Adeshina Busari, Shahid Mumtaz, Kazi Mohammed Saidul Huq and Jonathan Rodriguez
Instituto de Telecomunicações, Aveiro, Portugal
Email: [sherifbusari, smumtaz, kazi.saidul, jonathan]@av.it.pt

***Abstract*—Ultra-Dense Network (UDN) has emerged as a key enabler in enhancing the capacity of mobile networks in order to deliver super-speed connectivity and high data rates, provide seamless coverage and support diverse use cases whilst satisfying a wide range of other performance requirements, such as improved reliability, latency, energy and spectral efficiencies. However, the reduced cell size in UDNs poses serious challenges in the areas of inter-cell interference (ICI) coordination and mobility management (due to increased frequency of handovers and signaling overheads). In this study, we simulate scenarios using Network Simulator version 3 (NS-3) to study the impact of cell size on user throughput at the point of handover using pedestrian mobility (3 kmph) as case study. The simulation results show improved spectral (and energy) efficiency with small cells over macrocells but significantly shorter handover times, which translate to more frequent handovers. And since the Long Term Evolution (LTE) and next-generation cellular networks are required to support mobility without serious impact on connectivity and performance, we align with the decoupling of the user and control planes where the macro-layer manages control signals (e.g., handover signaling) while the small cell provides the users with high data rates. By allocating the small cells more bandwidth, preferably in the millimeter wave (mmWave) bands with abundant spectrum, this decoupled framework will guarantee better spectrum management to support the fifth-generation (5G) broadband services and applications.**

Keywords–UDN; mobility; handover; small cells; NS-3.

I. INTRODUCTION

Mobile networks have witnessed paradigm shifts in terms of deliverables, architectures and technologies through its evolution from the first-generation (1G) cellular systems announced in the early 1980's to the 5G networks expected to be deployed by 2020. Between 1G and 4G, mobile networks have moved from analogue to digital, voice-only to multimedia (voice and data), circuit-switched to packet-switched networks, and from 2.4 kbps throughput to a peak data rate of 100 Mbps (for highly mobile users) and up to 1 Gbps (for stationary and pedestrian users) [1], [2].

Alongside other performance metrics (data rate, capacity, coverage, latency, cost, spectral and energy efficiencies), mobility is an important feature in cellular systems as it enables users to freely roam across different cells in the network without serious impact on connectivity and performance [3]. While LTE systems standardized by the Third Generation Partnership Project (3GPP) have shown significant improvements in performance, the ever-growing demand for higher data rates and ubiquitous mobility required by new applications continues to pose serious challenges on legacy networks. With 4G networks reaching their theoretical limits, 5G networks are now building momentum to provide the networking solution for the new and smart digital era [4].

In the road towards 5G, the concept of UDN has been identified as the single most effective way to increase network capacity [5], among other enablers, such as massive multiple-input multiple-output (massive MIMO) antenna system, mmWave communication and device-to-device (D2D) communications [6]. Based on its potentials to significantly raise throughput, increase energy and spectral efficiencies, as well as enhance seamless coverage for cellular networks, pockets of dense deployment of low-power base stations (otherwise called small cells - microcell, femtocell, metrocell, picocells - with different levels of power, coverage and capabilities) are being witnessed in LTE systems, and hence the term LTE UDN [5].

The idea of small cells is to get users physically close to their serving base station (BS), thereby bringing down the inter-site distance (ISD) between two cells from 500-1000 m in macro BSs to 100-200 m for micro BSs (small cells) for typical urban deployment scenarios in the 2 GHz band. Hyper-densification of small cells is a promising solution in meeting the capacity, energy and spectral efficiencies expectations of next-generation cellular networks. However, despite the great anticipated benefits, the concept of UDN presents two principal challenges: mobility management and interference coordination. These challenges have drawn the attention of the research community in recent years [5], [7].

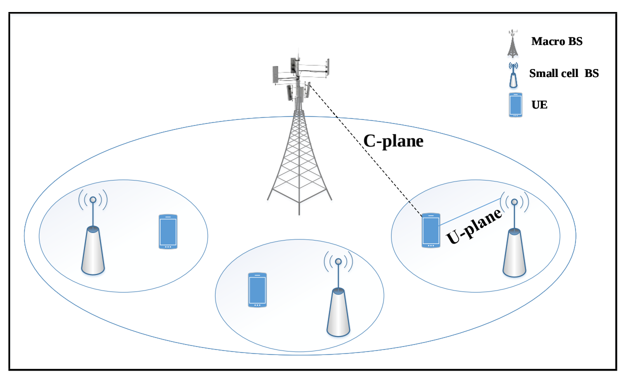

Figure 1. Decoupling of control and user plane in UDN.

Increased ICI resulting from reduced cell size in UDNs is controlled using advanced ICI management and cancellation techniques, while separation architecture (i.e., decoupling of the user plane from the control plane, as illustrated in Figure 1) is being proposed and investigated for mobility management [8]. The topology is such that the macro-layer handles the more efficient control plane functions, such as mobility management, synchronization and resource allocation etc., while the small cells handle the high-capacity and spectrally-efficient data plane services [2]. This framework will allow more bandwidth to be allocated to the small cells for high data rate user experience. The high-power macro BSs, with much wider coverage, will provide control signaling which has low rate requirements, thereby leading to better spectrum management for next-generation cellular networks.

In this study, we simulate two scenarios to investigate the impact of cell size on user throughput during X2-based handover processes. The first set explores the mobility of a User Equipment (UE) between two macrocells with ISD of 500-1000 m while the second set studies the behavior of small cells with ISD of 100-200 m, which are typical values for urban macrocell and microcell deployment, respectively [5], [7]. The goal is to investigate the decoupled/separation architecture being proposed in literature for user mobility management in UDN deployment for future mobile systems.

The remainder of this paper is organized as follows: Section II gives an overview of related literature; Section III details the simulation procedures. Results and analyses are presented in Section IV and Section V provides the conclusions and direction for future work.

II. Literature Review

Handover algorithms play an important role in LTE networks as they impact on the performance of the systems. Studies have been conducted to investigate the effect of handover on signaling overhead, user throughput, outage probability, cell capacity, load balancing, interference management and energy efficiency, among others, using different scenarios, set-ups and simulators [3], [9]. In this work, we investigate the impact of cell size on user data rate and spectral efficiency at the point of handover. In this section, we present a brief overview on handover in LTE networks and the tool (NS-3) used for the study.

A. Overview of NS-3

NS-3 is an open source, discrete-event network simulator which provides a platform for conducting simulation experiments with packet data networks. It is built as a system of software libraries that work together, with user programs written in either the C++ and/or Python programming languages. For the purpose of education and research, NS-3 serves as a tool to model and study the behavior of networks or systems in a highly controlled, reproducible environment which may be difficult or impossible with real systems [10], [11]. Compared to NS-2, NS-3 has better core architectural features which enable the simulation of realistic packets and development of complex simulation models [12].

B. Evolved Packet System (EPS)

According to 3GPP, EPS is divided into two different functional parts: Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) representing the RAN and the core network, respectively. These are also known as LTE and System Architecture Evolution (SAE), respectively [13]. The EPS system architecture is illustrated in Figure 2.

In NS-3, the EPS system is modeled by the LTE-EPC Network SimulAtor (LENA) model shown in Figure 3, comprising of the UE, evolved NodeB (eNodeB), combined serving gateway (SGW) and packet data network gateway (PGW) and their respective interfaces, mobility management entity (MME) and others. The eNodeBs are responsible for all radio functionalities of the user and control planes, the SGW/PGW serves as router between the user and the network while the MME (in conjunction with the eNodeBs) manages all mobility functionalities [11], [9], [14].

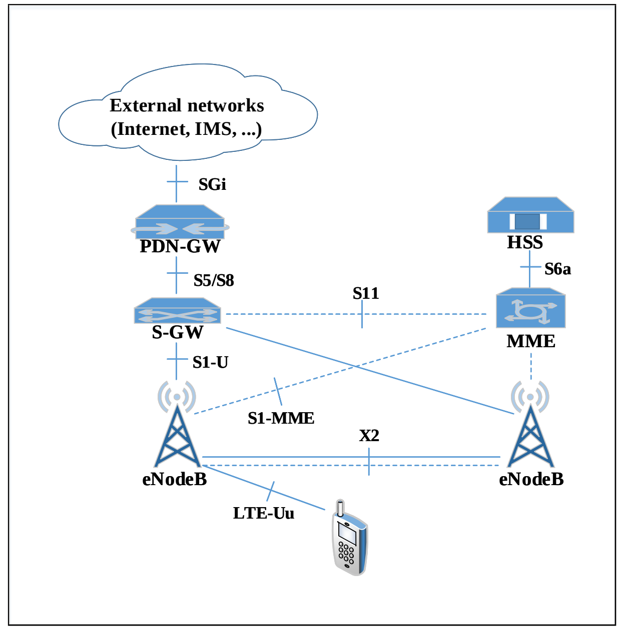

Figure 2. EPS Network Architecture.

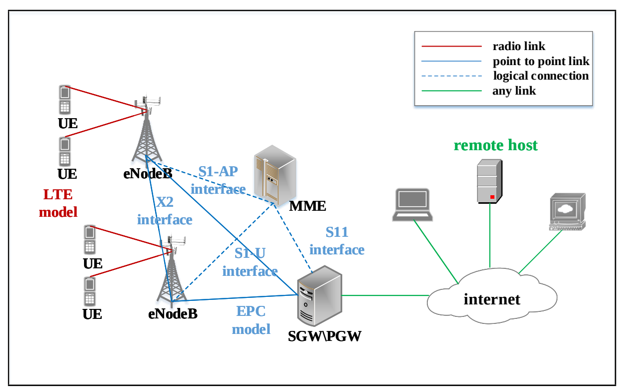

Figure 3. Overview of NS-3 LENA Model.

In EPS, handover decision and implementation are solely undertaken by the eNodeBs. And in contrast with the third-generation (3G) Universal Mobile Telecommunications System (UMTS), handover in LTE is hard handover (i.e.,) the UE has to be first disconnected from the serving eNodeB before being attached to the target/neighbor eNodeB with better signal strength [13].

C. Mobility Management in LTE

LTE networks have simplified architecture, improved user mobility support and higher data rate capability than earlier generations of cellular systems [15]. As users move between the coverage areas of the eNodeBs, they get, process and report measurements about their serving and neighbor eNodeBs [16]. According to 3GPP LTE, UE measurement reports are the key input for X2-based handover processes [3], which are accomplished in four phases: downlink handover measurements, processing of downlink measurements, uplink reporting and handover decision and execution [16].

Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) measured in dBm and dB, respectively, are two types of handover triggering quantities measured by the UE which are reported to the serving eNodeB [11]. As the UEs move away from the serving eNodeB and towards the neighbor eNodeB, the quality of the signal from the serving eNodeB degrades and that of the neighbor eNodeB improves, thus necessitating a handover from the former to the latter. Depending on the handover algorithm, the required condition(s) set out by 3GPP, as presented in Table I, would have to be satisfied in order to trigger the handover process.

TABLE I. LIST OF EVENT-BASED TRIGGERING CRITERIA.

Event	*Triggering Condition*
A1	Serving cell becomes better than threshold.
A2	Serving cell becomes worse than threshold.
A3	Neighbor cell becomes offset dB better than serving cell.
A4	Neighbor cell becomes better than threshold.
A5	Serving cell becomes worse than threshold 1 and neighbor cell becomes better than threshold 2.

In LTE, there are two types of handover: S1-based handover involving eNodeBs and the MME, and X2-based handover which is entirely handled by the eNodeBs. And according to 3GPP specifications, the X2 interface is a point-to-point interface which inter-connects two eNodeBs and over which X2-based handover is implemented. Handover in LTE is a UE-assisted (i.e., UE provides input to the network in form of measurement reports) and network-controlled process (i.e., dependent on the source and target/neighbor eNodeBs for triggering and execution) [15].

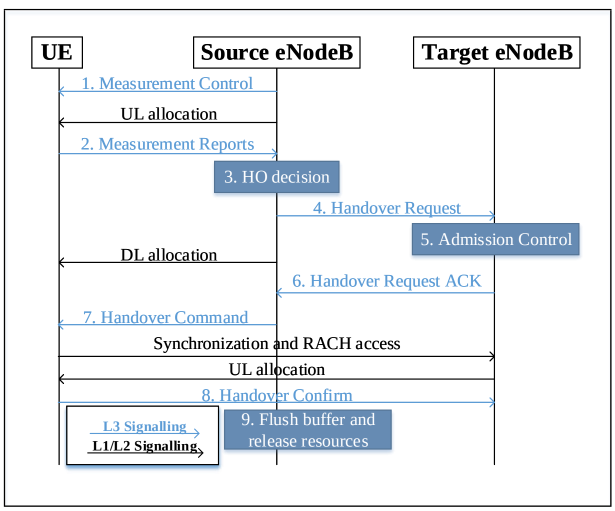

Figure 4. Handover signaling procedure.

In the LENA model, test suites are provided to evaluate three types of X2-based handover algorithms: A2-A4-RSRQ, A3-RSRP and no-op handover algorithms [14]. The no-op algorithm is a special algorithm which disables automatic handover trigger in order to allow manual handover, while the other two are automatic and based on UE measurement reports satisfying the respective conditions set out in Table I, based on 3GPP specifications [3], [11], [14].

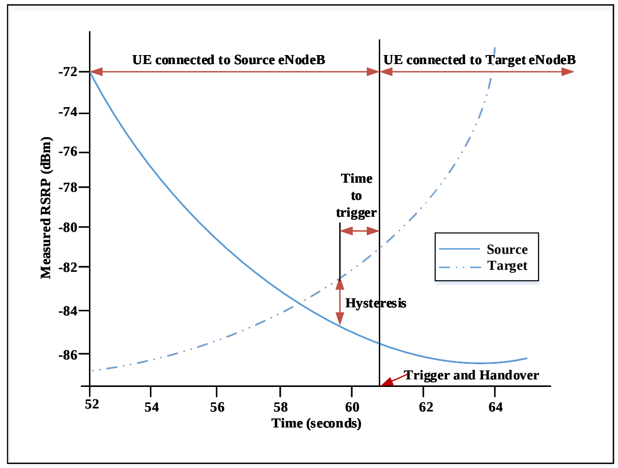

Figure 5. Typical measurement curves for handover scenario.

For the A2-A4-RSRQ algorithm, the threshold and offset parameters respectively represent the RSRQ values and the difference in RSRQ between the serving and target cells that must be surpassed before handover would happen. For the A3-RSRP, the hysteresis value represents the difference in RSRP between the serving and target cells that must be maintained for an amount of time called Time-to-Trigger (TTT) before handover could be triggered [3], [17]. Typical handover signaling and measurement curves indicating the triggering parameters are shown in Figures 4 and 5, respectively.

III. SIMULATION PROCEDURES

In this section, we describe the test scenarios and present the simulation parameters and tools.

A. *Test Scenarios and Simulation Parameters*

In order to evaluate the effect of cell size on user throughput in LTE UDN during handover scenarios, the implemented cellular network topology is shown in Figure 6. The scenario was simulated using a modified lena-x2-handover-measures.cc script available in the LTE module of NS-3, to implement the A2-A4-RSRQ X2-based handover algorithm.

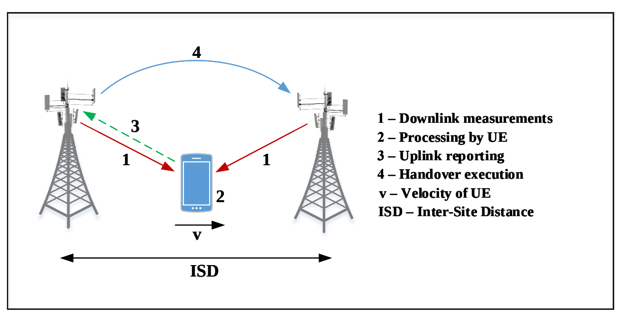

Figure 6. Simulation Network Topology.

For the scenario, a UE moves at a constant speed of 3 kmph (typical pedestrian speed according to 3GPP) between the serving and target eNodeBs separated at an ISD of 500-1000 m apart (typical urban macrocellular deployment). Then, the cell size was reduced to ISD of 100-200 m (for UDN/small cell/microcellular deployment).

TABLE II. HANDOVER SIMULATION PARAMETERS.

Parameters	*Microcell*	*Macrocell*
ISD (m)	100, 150, 200	500, 750, 1000
eNodeB Tx Power (dBm)	44	46
eNodeB Antenna Height (m)	10	15
eNodeB Noise Figure (dB)	5	
UE Tx Power (dBm)	24	
UE Noise Figure (dB)	9	
UE Antenna Height (m)	1.5	
UE Speed (kmph)	3	
UE mobility	straight line at constant speed	
Thermal Noise (dBm/Hz)	-174	
Frequency Band (MHz)	2100	
Downlink Freq. (MHz)	2120	
Uplink Freq. (MHz)	1930	
DL EARFCN	100	
UL EARFCN	18100	
System Bandwidth (MHz)	5 (25 RBs)	
Number of Users	1	
Antenna Mode	SISO	
Antenna Pattern	Omnidirectional	
Antenna Gain (dBi)	0	
Duplexing Mode	FDD	
Tx Time Interval (ms)	1	
Path Loss Model	COST-231	
Serving Cell Threshold	30	
Neighbor cell offset	1	
Hysteresis (dB)	3 dB	
Time-to-Trigger (ms)	256	
HO Triggering event	A2-A4	

In particular, the parameter that were varied was the ISD, using the different configurations set out in Table II with respect to the UE and eNodeBs (macrocell and microcell), which are broadly in line with ITU-R case study in [7].

B. Tools and Softwares

The simulation was carried out using ns-3.24 version installed on Ubuntu 12.04 LTS operating system via VMware Workstation 12 Player installed on a 4 GB RAM, core i3 HP laptop computer. The Network Animator (NetAnim) software was used for the animation display while the graphs of the simulation results were plotted using MATLAB.

IV. RESULTS AND ANALYSES

In the following subsections, we present the results and analyses of the simulations.

A. Animation of Network Topology

A sample snapshot of the topology obtained from NetAnim is shown in Figure 7. Node 0 is the SGW/PGW, node 1 is the remote host, node 2 is the serving eNodeB, node 3 is the target eNodeB while node 4 represents the UE. It also illustrates the time of the handover, thereby serving as a tool to monitor that the scripts executed as designed.

B. Simulation Results

From the RSRP/RSRQ traces obtained from the simulations, the downlink RSRP and SINR values obtained at the points of handover for both the serving and target cells are presented in Tables III and IV, for the microcell and macrocell, respectively.

Based on the downlink Signal to Interference and Noise Ratio (SINR) values presented in Tables III and IV, the

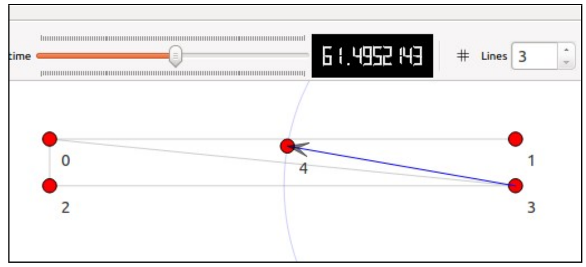

Figure 7. Handover illustration with NetAnim.

downlink spectral efficiencies (η) and data rates (R_d) are obtained using (1) and (2), respectively [14], [18].

$$\eta = \log_2(1 + \frac{\gamma}{\Gamma}) \tag{1}$$

$$R_d\ (Mbps) = \eta\ (bps/Hz) \times\ Bandwidth\ (MHz) \tag{2}$$

$$\Gamma = \frac{-\ln(5 \times BER)}{1.5} \tag{3}$$

γ is the SINR and Γ is a coefficient (known as SINR gap) which is computed using (3) to account for the difference between the theoretical and model performance of the Modulation and Coding Scheme (MCS), depending on the target Bit Error Rate (BER) [14]. For the simulations, $BER = 5 \times 10^{-5}$ and $Bandwidth = 5\ MHz$.

TABLE III. RSRP AT HANDOVER FOR MICROCELL DEPLOYMENT.

ISD (m)	*RSRP (dBm)*		*SINR (Linear)*	
	Serving Cell	*Target Cell*	*Serving Cell*	*Target Cell*
100	-83.97	-83.72	8443830	8947470
150	-87.39	-87.21	3844440	4005080
200	-89.85	-89.70	2182600	2256910

TABLE IV. RSRP AT HANDOVER FOR MACROCELL DEPLOYMENT.

ISD (m)	*RSRP (dBm)*		*SINR (Linear)*	
	Serving Cell	*Target Cell*	*Serving Cell*	*Target Cell*
500	-95.78	-95.70	556841	566974
750	-99.27	-99.21	249220	252683
1000	-101.76	-101.71	140483	142320

TABLE V. HANDOVER TIME FOR MICROCELL AND MACROCELL DEPLOYMENT.

Microcell		Macrocell	
ISD (m)	*Time (s)*	*ISD (m)*	*Time (s)*
100	60.90	500	301.38
150	90.94	750	451.58
200	121.02	1000	601.98

The handover time for both scenarios is shown in Table V. It shows the time the serving cell executes handover to the target cell, having satisfied both the hysteresis and TTT conditions. The results showing the impact of ISD on the achievable spectral efficiencies and data rates, at the point of handover, are shown in Figures 8-11, for the microcell and macrocell, respectively.

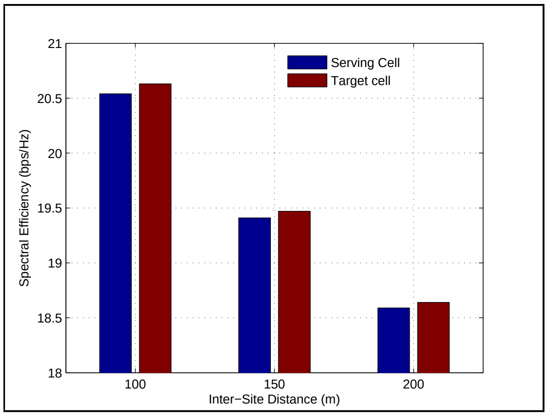

Figure 8. Spectral efficiency for microcell deployment scenarios.

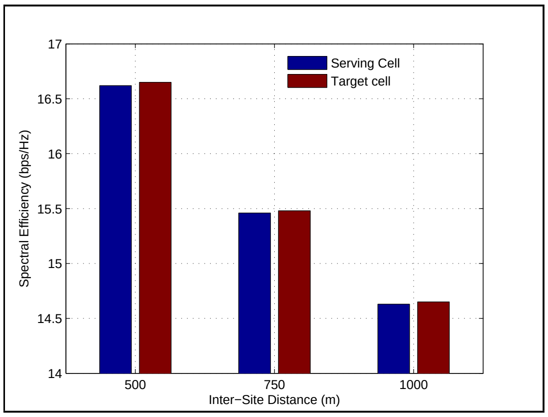

Figure 9. Spectral efficiency for macrocell deployment scenarios.

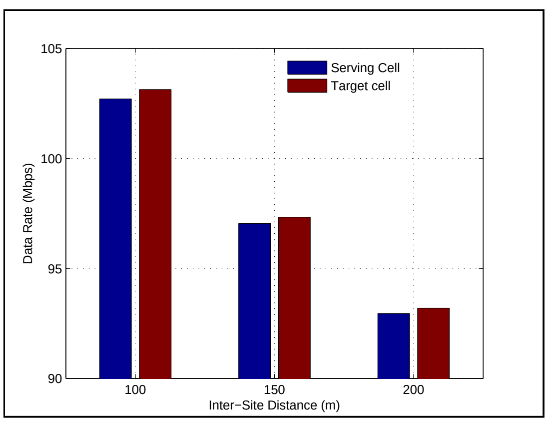

Figure 10. Data rate for microcell deployment scenarios.

In the following subsection, we present the analysis and discussion of the simulation results.

C. Analyses and Discussion

At handover, from the simulations results presented in Tables III-V and plots shown in Figures 8-11,

1) the RSRP values, spectral efficiencies and data rates for the serving cells are lower than those of the target cells for all the scenarios, thus justifying the need for handover. Without handover, the serving cell signal and performance would continue to degrade thereby leading to low quality of experience (QoE) for the end users.
2) the RSRP values, spectral efficiencies and data rates for the microcell deployment are better than those of the macrocell deployment for all scenarios. In each case, the performance improves as the ISD reduces, with the best results achieved at ISD of 100 m.
3) the performance of the microcell scenarios were better than those of the macrocells, despite the higher transmit power of the macrocells. This implies that the small cells have better energy efficiencies.
4) the handover times for the microcells were significantly shorter than those of the macrocell scenarios. This implies an increase in the number of handovers in the small cells.
5) the difference in performance between the serving and target cells at the point of handover were higher in the small cell deployments than those of the macrocells. This shows that the macrocells are more stable in handling control signaling than small cells. With small cells handling handover, the hysteresis and TTT values would be achieved much faster, thereby resulting in increased frequency of handover.

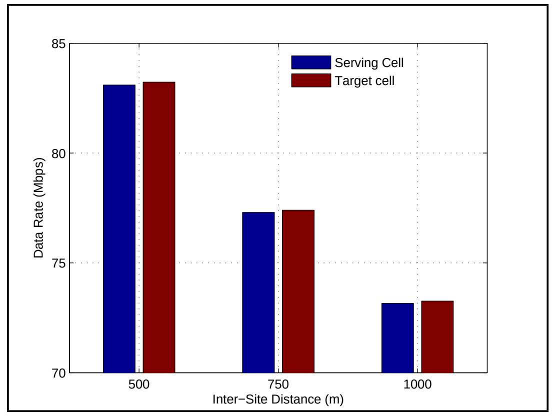

Figure 11. Data rate for macrocell deployment scenarios.

Quantitatively, as can be deduced from Table V, the required handover time for macrocells is 5x that of small cells for typical deployment scenarios with ISD of 500 m and 100 m (and 10x for 1000 m and 100 m) for macrocell and small cell, respectively. Very short handover times will result in increased frequency of handover and significantly high measurement overheads, thereby leading to poor spectrum management, which is undesirable for next-generation mobile networks, starting with 5G.

It should however be noted that the scenario considered in the simulation is a single-user, single-input single-output (SISO) system which did not consider the effects of interference from multiple users nor implemented enhancements such as carrier aggregation and advanced MIMO techniques, all of which will impact on the obtained results. Also, other simplifying assumptions have been used in the development of LTE/LENA modules in NS-3, and the interested reader is referred to [14] for the details.

V. Conclusions and Future Work

Densification of small cells has the potential to deliver increased network capacity based on increased cell density and high spatial and frequency reuse, enhanced spectral efficiency based on improved average SINR (with tighter interference control) and improved energy efficiency based on reduced transmission power and lower path loss resulting from smaller cell radii or distance between the small cells and the UEs.

On the other hand, however, UDN presents serious challenges in terms of mobility support, interference management and cost. In the context of mobility, it poses a severe problem due to high frequency of handovers (due to shorter handover time), increased signaling and high measurement overheads that would be incurred if the control signals are from spatially-close small cells. Results from this simulation campaign buttress these outcomes.

The trend and direction for future work in realizing the gains of densification of small cells, therefore, is to decouple the control and user planes such that mobility management (handover and other control signaling) is handled by the macrocell layer where very high data rate is not required, while the data plane functionalities are handled by the closest small cell in order to support the high data rate demands of next-generation services and applications. This framework is an area of growing research interest for 5G and beyond-5G (B5G) systems.

Acknowledgment

This work is part of the Wireless Networks and Protocols course of the MAP-Tele Doctoral Program. Sherif A. Busari would therefore like to thank Profs. Manuel Ricardo, Adriano Moreira and Rui Aguiar for providing guidance and feedbacks, and to acknowledge his PhD grant funded by the Fundação para a Ciência e a Tecnologia (FCT-Portugal) with reference number PD/BD/113823/2015. Also, the research leading to these results received funding from the European Commission H2020 programme under grant agreement no. 671705 (SPEED-5G project).

References

[1] A. Gupta and R. K. Jha, "A Survey of 5G Network: Architecture and Emerging Technologies," IEEE Access, vol. 3, 2015, pp. 1206–1232.

[2] F. B. Saghezchi *et al.*, Drivers for 5G: The 'Pervasive Connected World'. John Wiley & Sons Ltd., UK, 2015, chapter 1, pp. 1–27, in Rodriguez J. (Ed.), Fundamentals of 5G Mobile Networks.

[3] B. Herman, N. Baldo, M. Miozzo, M. Requena, and J. Ferragut, "Extensions to LTE Mobility Functions for ns-3," in Proceedings of the 2014 Workshop on ns-3 (WNS3 '14), May 7, 2014, Atlanta, Georgia, USA. ACM, 2014, pp. 1–8.

[4] Z. S. Bojkovic, M. R. Bakmaz, and B. M. Bakmaz, "Research challenges for 5G cellular architecture," in Proceedings of the 12^{th} International Conference on Telecommunication in Modern Satellite, Cable and Broadcasting Services (TELSIKS), 14–17 Oct., 2015, Serbia. IEEE, pp. 215–222.

[5] S. Vahid, R. Tafazolli, and M. Filo, Small Cells for 5G Mobile Networks. John Wiley & Sons Ltd., UK, 2015, chapter 3, pp. 63–104, in Rodriguez J. (Ed.), Fundamentals of 5G Mobile Networks.

[6] Q. C. Li, H. Niu, A. T. Papathanassiou, and G. Wu, "5G Network Capacity: Key Elements and Technologies," IEEE Vehicular Technology Magazine, vol. 9, no. 1, 2014, pp. 71–78.

[7] "Guidelines for Evaluation of Radio Interface Technologies for IMT-Advanced, Report ITU-R M.2135-1," Tech. Rep., 2009, https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2135-1-2009-PDF-E.pdf [retrieved: 2017-03-23].

[8] H. A. U. Mustafa, M. A. Imran, M. Z. Shakir, A. Imran, and R. Tafazolli, "Separation Framework: An Enabler for Cooperative and D2D Communication for Future 5G Networks," IEEE Communications Surveys & Tutorials, vol. 18, no. 1, 2016, pp. 419–445.

[9] N. Baldo, M. Requena-Esteso, M. Miozzo, and R. Kwan, "An Open Source Model for the Simulation of LTE Handover Scenarios and Algorithms in Ns-3," in Proceedings of the 16^{th} ACM International Conference on Modeling, Analysis & Simulation of Wireless and Mobile Systems (MSWiM '13), Barcelona, Spain. ACM, 2013, pp. 289–298.

[10] NS-3 Tutorial, Release ns-3.24, 2016, http://www.nsnam.org/documentation [retrieved: 2017-03-23].

[11] M. Assyadzily, A. Suhartomo, and A. Silitonga, "Evaluation of X2-handover performance based on RSRP measurement with Friis path loss using network simulator version 3 (NS-3)," in Proceedings of the 2^{nd} International Conference on Information and Communication Technology (ICoICT), 28–30 May, 2014. IEEE, 2014, pp. 436–441.

[12] G. Carneiro, P. Fortuna, and M. Ricardo, "FlowMonitor: A Network Monitoring Framework for the Network Simulator 3 (NS-3)," in Proceedings of the 4^{th} International ICST Conference on Performance Evaluation Methodologies & Tools,20–22 Oct., 200 9, Pisa, Italy. ACM, 2009, pp. 1–10.

[13] A. Helenius, "Performance of handover in Long Term Evolution," Master's thesis, Aalto University, Finland, 2011, http://lib.tkk.fi/Dipl/2012/urn100708.pdf [retrieved: 2017-03-23].

[14] The LENA ns-3 LTE Module Documentation, Release v8, 2014, http://networks.cttc.es/wp-content/uploads/sites/2/2014/01/lena-lte-module-doc.pdf [retrieved: 2017-03-23].

[15] B. Herman, D. Petrov, J. Puttonen, and J. Kurjenniemi, "A3-Based Measurement and Handover Model for NS-3 LTE," in Proceedings of the 3^{rd} International Conference on Mobile Services, resources and Users (MOBILITY 2013). IARIA, 2013, pp. 20–23.

[16] M. Anas, F. D. Calabrese, P. E. Ostling, K. I. Pedersen, and P. E. Mogensen, "Performance Analysis of Handover Measurements and Layer 3 Filtering for Utran LTE," in Proceedings of the 18^{th} International Symposium on Personal, Indoor and Mobile Radio Communications, Sept., 2007. IEEE, pp. 1–5.

[17] K. Dimou *et al.*, "Handover within 3GPP LTE: Design Principles and Performance," in 70^{th} Vehicular Technology Conference Fall (VTC 2009-Fall), Sept. 2009. IEEE, pp. 1–5.

[18] G. Piro, N. Baldo, and M. Miozzo, "An LTE Module for the Ns-3 Network Simulator," in Proceedings of the 4^{th} International Conference on Simulation Tools and Techniques, (SIMUTools '11), 2011. ACM, pp. 415–422.