Mobility Enhancement and Performance Evaluation for 5G Ultra Dense Networks

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Abstract—**Future wireless network will address the explosive increase demand of high-data-rate video services as well as massive-access machine type communication (MTC) requests, so that increasing number of small cells are conceived to be densely deployed in hot spots, resulting in an Ultra-dense Network (UDN). As a main issue for the future network, UDN is a step further towards a low-cost, self-configuring and self-optimizing network, while also leading to high-frequent measurement, intolerable handover failure (HOF), as well as huge power consumption in both the terminal and access network. Thus, mobility enhancement in ultra-dense scenario has become a critical problem for the next generation wireless systems. To solve this problem, the split of control plane and user plane (C/U) has become one of the most promising way, as it allows more flexibility and better service control schemes. Inspired by this, a set of macro assisted small cell enhancement schemes is proposed contributing to a novel Data-only Carrier (DoC) system in our previous work. In this paper, for improving the handover (HO) performance, new mobility-enhanced schemes are designed and analyzed in detail in DoC network, taking into consideration of mobility, flexibility and various typical handover scenarios. Simulations are conducted by a system-level platform to illustrate the fundamental relationship between key handover parameters and mobility performance. Numerical results show that the gain of system HOF rises by 53.6% via optimizing and reconfiguring the handover parameters in DoC network. In addition, the DoC network has an excellent performance gain in UDN with 82% HO improvement and 44.34% energy efficiency promotion compared with the current LTE network, which may be a promising mobility enhancement strategy for future 5G networks.**

I. Introduction

As the mobile devices grow rapidly over the past several years, the telecommunication industry has witnessed a boom in a wide range of applications and services. Data-oriented applications, such as video conference, streaming media and network game, have become part of people's life. Traffic requirements, predicted by Cisco, will grow at a compound annual growth rate (CAGR) of 61 percent from 2013 to 2018, reaching 15.9 exabytes per month by 2018 [1]. Meanwhile, more and more sensors are deployed in the city for better communication between human and devices, causing massive access requests as well as large quantity of MTC services. It is reported by IMS Research projects that global cellular module shipments for M2M applications will grow from nearly 33M in 2010 to over 118M in 2016 [2].

As a consequence, increasing number of low power nodes are placed in hot spots, such as business centric district (BCD) and residential area. The increasing number of small nodes bring cells closer and there is no more obvious boundary between them, enhancing capacity of per area by the space division multiplexing. Despite quite various advantages, ultra-dense small cell deployment also poses many challenges. Thus, with the introduction of Long Term Evolution (LTE) and LTE-Advanced, the Third Generation Partnership Project (3GPP) has started the standardization in system level about the migration towards heterogeneous network (HetNet), including interference cancelation, mobility enhancement technologies [3] and small cell enhancement schemes from both physical layer and higher layer aspects[4]. Particulary, handover performance, severely impacting the quality-of-service in HetNet, has become an open issue because of high-frequent measurement, intolerable handover failure (HOF), as well as huge power consumption in both the terminal and access network. Several researches have been carried out from different perspectives. In [5], mobility enhancement for small cell was discussed from the aspect of LTE-A and a scheme to reduce handover frequency was proposed based on the inter-site carrier aggregation technology. In [6], theoretical analysis of handover failure in HetNet with L3 filtering was developed under typical geometric model and the handover failure expression was derived as a function of L3 sampling periods. [7] proposed a cell-type adaptive handover algorithm in macro-femto HO scenario. Interference management was discussed in [8] where an optimal procedure to configure spectrum split was illustrated for higher throughput and lower HO failure.

Different from these works, we focus on the ultra-dense network where small cells are clustered and the interference between cells are hugely increased, and all types of intra and inter cell handover are all taken into consideration. Furthermore, mobility enhancement is based on the concept of new wireless architecture with control plane (C-plane) and user plane (U-plane) decoupled from each other. To our best knowledge, the parameters optimization and self-configuring under C/U split architecture, aiming at the mobility enhancement in ultra-dense scenario, have not been discussed yet.

In our previous work, based on the concept of C/U split, a macro-assisted small cell enhancement architecture was proposed to make the small cells "data-only" carriers, by making full use of macro eNB (MeNB) [9]. In this paper, a brief background of DoC system is introduced first and the basic concept of macro-assisted wireless system and the

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enhanced signallings and channels are discussed. After that, several redesigned key handover procedures are proposed in DoC system taking advantage of C/U seperation, taking into consideration of mobility, stability, energy efficiency and realizability. At last, the performance of DoC is analyzed and optimized in UDN scenario by optimizing several key parameters to achieve performance gain of handover improvement and energy efficiency promotion upon the traditional LTE system.

The major contributions of this paper are summarized as follows:

1. We focus on the redesign of the future 5G network towards a macro-assisted data-only carrier system, aiming at resolving the problems about massive access requirements, high frequent handover probability, huge-interference and low-probability of small cell sleeping;

2. Based on a system-level platform, a detailed evaluation about key parameters in handover triggering are analyzed and the relationship to system performance in UDN network is derived;

3. Furthermore, due to the handover performance of various types of HO in this DoC system, e.g., macro-macro HO and macro-small cell HO, the mobility enhancement strategy is proposed to further improve the mobility performance by optimizing the system parameters;

4. We take current LTE system as the basis for comparison and the simulations illustrate that DoC system can achieve much lower HOF rate and higher energy efficiency. Thus our work may be recommended as a candidate for mobility enhancement scheme in future 5G networks.

The rest of the paper is organized as follows. In Section II, a system architecture of macro-assisted DoC system is introduced and the basic concept of C/U split is illustrated briefly. The novel handover procedures in DoC network of both intra and inter macro cell are proposed in detail in Section III. In Section IV, a system-level platform is built with key parameters summarized in a table, and the whole system is analyzed carefully to study the relationship between key handover parameters and system performance under some simulation assumptions in typical UDN scenario. Furthermore, the system is enhanced by the reconfiguration of the system to achieve better handover performance. The comparison between DoC and LTE network is given. Finally, conclusions are summarized In Section V.

II. Data-only Carrier System

In our previous work [9], the DoC system is formulated by making full use of macro cell based on the split of control and user plane. The system architecture is illustrated in Figure 1. Numerous small cells with high frequency carriers (e.g. 3.5GHz) are placed on the coverage of one macro cell with low frequency (e.g. 2GHz). As more and more small cells are deployed densely in some typical hot pots in UDN scenario, small cell clusters are formed in hot spots.

A. C/U Split DoC Architecture

In C/U split architecture, the small cells are deployed to provide high throughput capacity in hot spot area, and the macro cell maintains the "always-on" coverage. Thus a typical UE in the small cell cluster field, named as SUE, could receive high-data rate from small cells in the U-plane, while keeping the Radio Resource Control (RRC) connection with the MeNB from C-Plane. Other UEs beyond the coverage of small cells (MUEs) have to keep both RRC control signalling links and data transmission links with the MeNB.

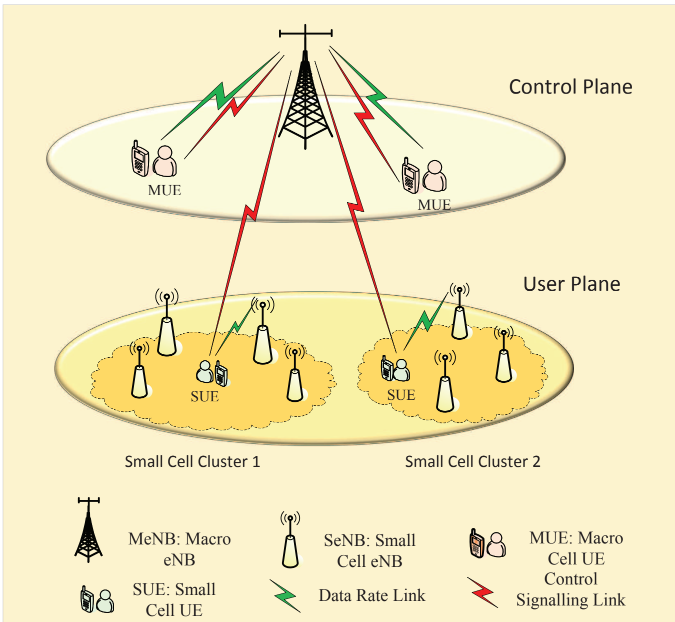


Fig. 1. Control and User Plane Split in DoC System.

In traditional LTE system, the UE will suffer from quite a long delay to get access to the best candidate base station after serval times of inter-frequency measurements [4], due to the huge interference between signallings in UDN network. In contrast, in this typical scenario in Figure 1, the separation of control and data plane are realized in DoC system and small cells are designed towards "data-only" carriers, with the assistance of macro cell. In this way, on the one hand, the interference between the small cells can be suppressed by the removal of all the overhead of public system information and cell-level control signallings from small cells, e.g., Cell-specific Reference Signal (CRS), Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS). On the other hand, more useful data traffic can be transmitted utilizing the resource blocks. As a result, the DoC network can achieve faster access connection and higher spectrum efficiency (SE).

B. Signalling Enhancement

In LTE system, UE performs inter-frequency measurements on small cells periodically. However, in DoC system, all the small cells are informed to listen to the uplink UE sounding reference signal (SRS) by MeNB and then deliver the listening reports back to MeNB through Xn interface. In this way, the best candidate BS is selected by MeNB taking consideration of the listening reports, containing signal to interference plus noise ratio (SINR) SINR of SRS, BS resources and UE mobility information, which can be an optimal strategy in BS

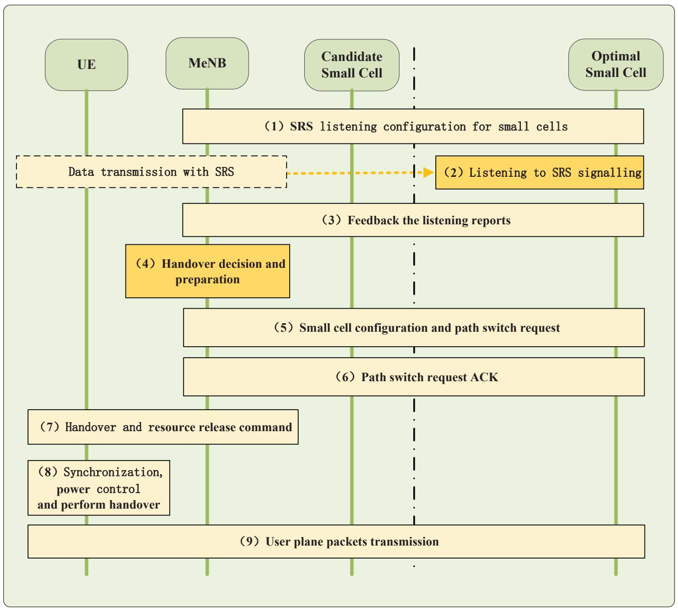


Fig. 2. Intra Macro Cell Handover Procedure.

selection compared with traditional LTE system. In addition, it achieves a UE-centric system and most of the small cells are set to sleep until being informed by MeNB, making the network more flexible and energy efficient. The number of SRS can be enhanced by space division multiplexing between different small cell clusters to fulfill the demand of high traffic from both video services and MTC requirements.

III. Handover Technical Design and Enhancement

Benefits from the C/U split configuration, in this section, the key mobility procedures in DoC system are designed and proposed in UDN network in both intra-macro and inter-macro handover scenario, to achieve better performance of mobility, stability, energy efficiency and realizability.

A. *Handover Triggering Procedure*

During the handover procedure, the Reference Signal Receiving Power (RSRP) from the serving base station $RSRP_S$ and that from the targeting base station $RSRP_T$ are calculated. If the A3 entering condition, as expressed in the following,

$$RSRP_T > RSRP_S + H_{yst} \tag{1}$$

is satisfied, the Radio Link Failure (RLF) monitoring will be carried out based on L1 processing every 10ms, where $Hyst$ is the A3 offset. Handover (HO) between two neighboring cells is executed when the criteria of HO is met during time-to-trigger (TTT) time period. Thus A3 $Hyst$ and TTT are two key parameters to be optimized. In this paper, we evaluate HO performances by adapting various A3 $Hyst$ and TTT values.

B. *Intra MeNB Handover*

The key procedure of intra MeNB handover is illustrated in Figure 2. In the preparing phase, before the handover procedures, the UE must already have a RRC-connection with macro base station in C-plane and a data transmission base station in U-plane, which could be either Macro cell or small cell. Based on the UE moving direction, moving speed, and the resource in MeNB, the MeNB will either provide service to UE by itself or inform the cluster of small cells in the roughly area of waking up into listening mode (1). After getting the detailed information about the SRS in both time domain and frequency domain, the small cells could listen to SRS signalling from UE to MeNB in (2). The cluster of small cells then transmit the reports through Xn interface (3), so that the macro would conduct handover decision procedure (4) based on the triggering strategy. Thereafter, the MeNB needs to prepare the target optimal small cell for UE context information in (5), including the moving speed, moving direction and service requesting information, and switches the data transmission path from source BS to targeting BS. Later the ACK containing necessary parameters is sent back to MeNB (6), containing the power and resources information. Thus, the MeNB triggers handover command to UE, containing the uplink synchronization, power configuration and resources block information of the optimal small cell (7). Based on these information, UE may finally adjust its synchronous clock, transmission power and other relative information (8), to make a new packet transmission in user plane with the optimal selected small cell (9).

It should be noted that the handover procedure in DoC is based on the uplink SRS listening strategy. The main difference of the handover strategy between DoC and LTE system can be summarized as follows:

- The listening strategy in DoC architecture help to make a UE-centric network, which eliminates the huge signalling interference, shorten the time delay for UE to get access to the target base station and save lots of power of UE, especially in UDN networks.
- The handover decision procedure can be triggered taking into consideration of the RSRP reports from small cells, the loading condition of eNB and the context information of UE, which is more easy to be realized under the centralized control of MeNB, particularly in C-RAN network.
- The small cells are selectively informed by MeNB, thus most of the cluster of UEs can have relatively long period time to get asleep under low traffic scenario, resulting in better EE of the system.
- The SRS signalling is originally transmitted by UE on both RRC and data link, so that the listening strategy is easy to be implemented without any change of SRS transmission scheme.

Though the UE in DoC system experience shorter time to select the optimal base station, the delay on Xn interface between MeNB and SeNB should be noted. Therefore, the most suitable scenario to apply DoC system should be configured with optical backhaul which is nearly ideal in the aspects of capacity and delay. Still, even if the backhaul is non-ideal, taking 5ms of delay on Xn for example, the access delay in DoC network is approximately 50ms. The delay in DoC

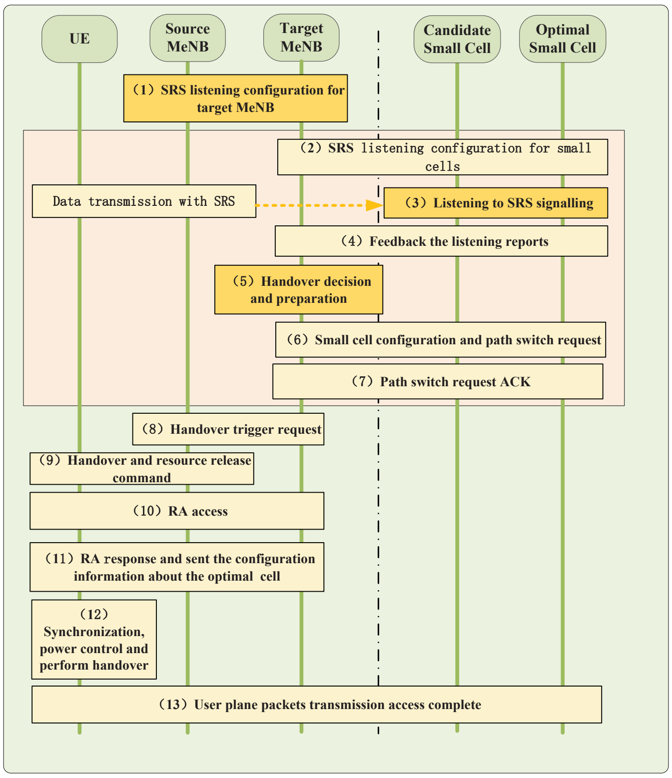


Fig. 3. Inter Macro Cell Handover Procedure.

network is still shorter than that of nearly several hundred milliseconds in LTE system.

C. Inter MeNB Handover

In the case of inter MeNB handover, UE also experiences two stages of handover, namely small cell selection and handover execution, shown in Figure 3. At first, the SRS from UE is listened by source MeNB. Then source MeNB will configure the target MeNB with the details about SRS from UE based on the moving trajectory in (1). Then the steps (2) $\sim$ (7) in inter MeNB handover is just the same as the steps (1) $\sim$ (6) in intra MeNB procedure. After step (7), the optimal small cell has been selected and then the target MeNB sends handover triggering request to source MeNB in step (8), together with the non-competitive preambles of UE. In step (9) the source MeNB command the UE to perform the handover to target MeNB, and reconfigure the UE with uplink synchronization, power configuration, non-contention random access preamble of target MeNB. Then the UE can get random access to the target MeNB first to set up the new RRC-connection in C-plane and get the configuration parameters and non-contention preamble for optimal small cell stored in in target MeNB (10) $\sim$ (11). In the end, the terminal can get synchronization to the optimal small cell and adjust its power to perform U-plane packets transmission (12) $\sim$ (13).

The mainly difference between intra MeNB and inter MeNB handover procedures can be concluded as:

- Handover between different cells are started by the triggering form the source MeNB, and the SRS configuration needs to be sent to candidate target MeNB. This procedure can be removed under intra-eNB handover scenario as UE is always keeping RRC connection with MeNB to help MeNB get SRS information easily.
- In inter MeNB handover scenario, not only the U-plane packet transmission path, but also the C-plane RRC connection is re-configured.
- DoC system achieves better flexibility than the traditional LTE one by selecting the optimal small cell by the MeNB-centric decision. If necessary, the U-plane can be configured as dual-connection and the data flows can be routed and aggregated from several small cells to one UE to achieve better peak data rate.

TABLE I
MAIN PARAMETERS OF EVALUATION ASSUMPTIONS

Items	Macro Cell	Small Cell
Carrier Frequency/Bandwidth	2.0GHz/10MHz	3.5GHz/10MHz
BS Total TX Power	46dBm	30dBm
BS Number	19	760
Antenna Height	25m	10m
UE Antenna Height	1.5m	
Antenna Patten	4 × 4SM	
UE Speed	3km, 10km, 18km, 30km	
Time To Trigger	10ms, 160ms, 320ms, 480ms	
A3 Offset	-1dB, 1dB, 3dB	
T310	1s	
Qin	-6dB	
Qout	-8dB	
Cell Selection Criteria	RSRP	Macro Assisted

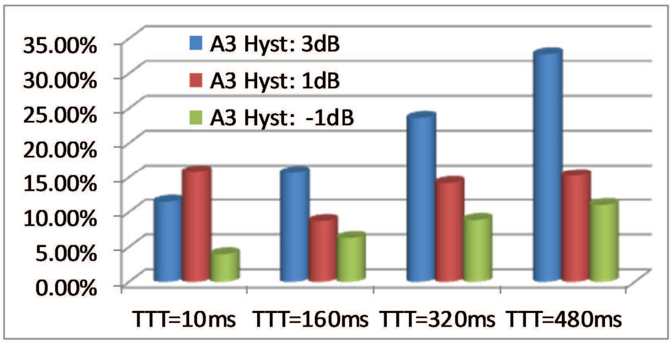
IV. PERFORMANCE EVALUATION

In the previous section, new schemes in handover procedures in UDN network are proposed based on the concept of C/U split. In this section, numerous simulations are conducted to show the handover performance in DoC network.

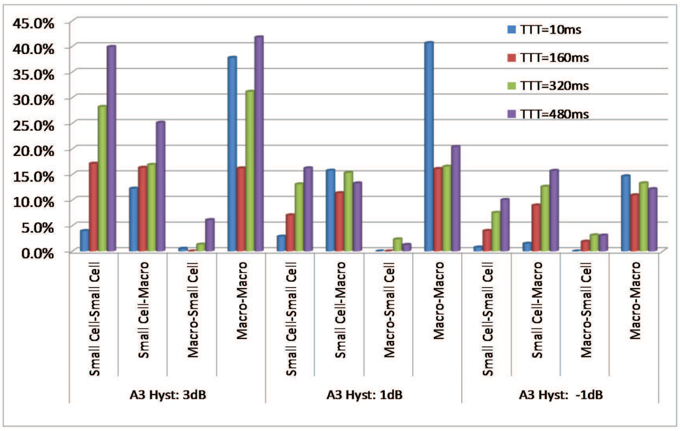
A. Simulation Models and Assumptions

A combination of OPNET-based system-level and Matlab-based link-level simulator is built as the simulation platform to evaluate the performance of the system. Main parameters are set according to 3GPP TR 36.839 [3] and TR 36.872 [4] summarized in Table I.

As we mainly focus on the mobility analysis for small cell enhancement in the future 5G networks, the ultra-dense network 3GPP TR 36.872 [4] is set as the default scenario. The layout of the scenario in OPNET platform is configured of 19 hexagonal macro cells with 3 sectors where 4 small cell clusters randomly placed in each cell. The radiuses of the cell and the clusters are 288m and 50m respectively. The distance between clusters center and MeNB is at least 105m and the cluster centers should be configured further than doubled cluster radius. Furthermore, 10 small cells are deployed in each cluster, which makes for total 40 small cells in each cell. Terminals are configured into two categories, MUE and SUE. MUEs are randomly placed within the coverage of each MeNB, and the number for MUE is 12 in each cell. 12 SUEs are deployed around the area with the radius of 70m from

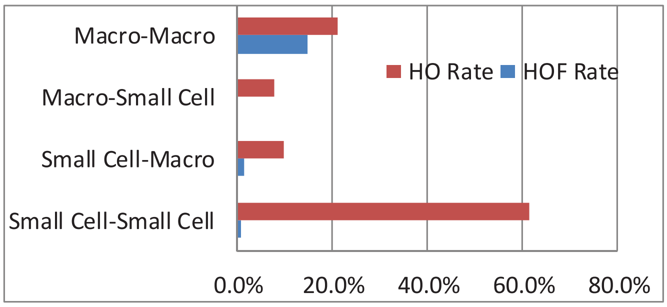


a) HOF in DoC system under different configuration of A3 Hyst and TTT parameters

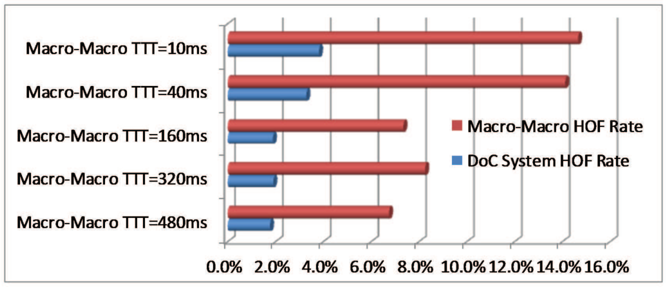


b) Proportion of HOF among different handover types

Fig. 4. Mobility Analysis under different configuration of HO parameters.



a) HO and HOF proportion of different handover types under the suboptimal mobility configuration



b) Proportion of Macro-Macro HOF and DoC system HOF under different macro-macro TTT configuration

Fig. 5. Mobility Enhancement of DoC system by the reconfiguration of the Macro-Macro parameter.

cluster center in each cluster, resulting in 48 SUE in each cell.

The pathloss models, applied with 3D distance between eNB and UE, are set according to ITU UMa and ITU UMi in 3GPP 36.814. The shadowing models of MeNB and SeNB are resulting from ITU UMa 36.819 and 3GPP TR 36.814 respectively.

The base station power consumption model is formulated as the following liner model according to EARTH Project [10]:

$$P_{in} = N_{TRX} \frac{\frac{P_{out}}{\eta_{PA}(1-\sigma_{feed})} + P_{RF} + P_{BB}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{cool})} \tag{2}$$

where P_{out} is the transmission power which is related to the traffic load, σ_{feed} is the feeder efficiency and η_{PA} is the efficiency of the power amplifier. The static part includes the radio frequency power P_{RF} and baseband pooling power P_{BB}. Other efficiency parameters affects the system as well, such as DC-AC efficiency σ_{DC}, grid supply efficiency σ_{MS} and air conditioner efficiency σ_{cool} .

B. Handover Performance Analysis

In this subsection, the handover performance is analyzed in detail in DoC system. The speed of UE is set as 30km/h. The relationship between different configuration of key handover parameters and the system performance is illustrated in Figure 4. The handover failure rate (HOF) general increases with the growth of time-to-trigger (TTT) because it is much harder to handover to the best station and cause stage 2 RLF in Figure 4 a). In addition, the lower A3 offset is, the lower HOF it archives, due to faster selection and decision decreased the stage 2 RLF. When the TTT is quite small (10ms), it is too easy to perform handover. As A3 offset grows gradually, the handover will experience more RLF stage 2, defined in [3], at first and then decrease due to less cell re-selection. When the TTT is relatively large (>100ms), the A3 offset does not affect the trend that much because the TTT has helped to prevent frequent handover. The more detailed proportion of HOF among different handover types is shown in Figure 4 (b). It is clear that the macro-macro handover causes most of the handover failure in DoC system. Higher TTT and A3 cause greater HOF especially among small cells. In this way, a set of suboptimal configuration for DoC system is selected with A3 offset -1dB and TTT 10ms. Under this suboptimal configuration, the HOF in DoC system is 3.82%.

C. Mobility Enhancement Evaluation

In this subsection, the mobility enhancement scheme is illustrated by Figure 5 a). The speed of UE is also configured as 30km/h. It shows that under the previous suboptimal configuration, small cell-small cell handover and the macro-macro handover occupy more than 60% and one-fifth of the whole handovers respectively. However, the HOF between MeNB still rises to 14.66% under the suboptimal configuration (TTT: 10ms; A3 offset: -1dB). That is to say, the handover between macros are not suitable to the parameter configuration, due to macro-macro handover will need relatively long time to

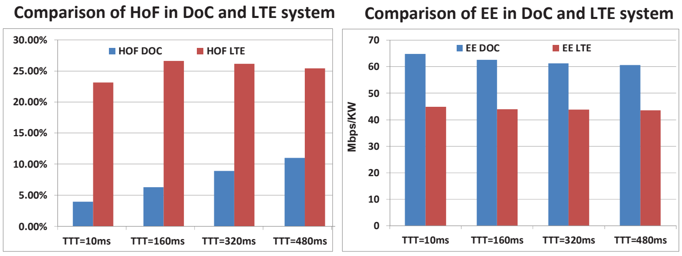


Fig. 6. Performance comparison between DoC system and LTE system. (a) Handover failure rate comparison; (b) Energy efficiency comparison per cell.

transfer the path and execute handover command. If the TTT is too short, it may cause stage 3 RLF from the target eNB, defined in [3], and experience HOF during the HO procedure.

Inspired by the previous evaluation, the macro-macro TTT parameters is studied individually to achieve better performance in DoC system and realize the mobility enhancement in UDN network, shown in Figure 5 b). When the TTT macro-macro rises to 480ms, keeping TTT for other handover types remaining 10ms, the macro-macro HOF decrease to 6.75%. In this way, by reconfiguration of macro-macro handover parameters, the system mobility HOF has decreased from 3.82% to 1.77%, with a huge gain of 53.6%.

D. Comparison between DoC and LTE

The performance of DoC and LTE system are compared in detail with various configuration of handover parameters in this subsection. Under the typical moving speed of 30km/h, the UE in DoC system always achieve better HO performance with lower HOF and higher EE, illustrated in Figure 6. The raise of TTT in LTE does not make much difference because UE has to experience several hundreds milliseconds delay already in UDN network. Traditional handover scheme for LTE user are no longer suitable at all. While in DoC system, the small cells are configured into pure data carrier which contribute to interference cancelation. It can be concluded that DoC system achieves more than 82% handover HOF gain and 44.34% EE gain upon the LTE system in ultra-dense network. This is because the network listening strategy in DoC system also help to build a UE-centric network so that faster access rate can be realized. In addition, more resource blocks of public signallings and channels are saved for useful data transmission, helping to improving the throughput of the network. Thus the energy efficiency will also benefit from it and the small cells will have more flexibility to realize on-off strategy on demand, without providing always-on downlink discovery signallings. The performance gain will be greater as the denser of the small cells in future 5G networks.

V. Conclusion and Future Work

HetNet deployment is one of the key enabler to enhance the capacity of wireless networks for LTE-Advanced networks. Ultra-dense deployment of small cells in HetNet has to face the challenges from the aspects of mobility enhancement because UE in traditional LTE system under UDN scenario suffers from severe signalling interference between small cells, intolerable delay to access and high energy consumption to perform measurement. Thus, based on the concept of C/U split, in this paper, several handover procedures are designed and proposed to evaluate the performance of DoC system in our previous work. The fundamental relationship between key handover parameters and system performance are illustrated and the mobility enhancement strategy is given to optimize the mobility parameter configuration for DoC network. Numerical results show that the DoC network has better mobility performance in UDN with much lower handover failure and higher energy efficiency than the current LTE network.

In the future, the mobility study in UDN network also face several important challenges to the improvement of the system. On the one hand, UEs from one small cell cluster could aggregate the reports and send to MeNB as a group by a local “cluster node” to further reduce the burden on Xn interface. The strategy to select the best local small cell “cluster node” should be discussed, taking into consideration of both ideal and non-ideal backhaul situation. On the other hand, some special but practical scenarios should be studied, e.g, UE coming in and out of a building in Home-eNB clustered scenario or the fast mobility scenario under high-speed railway scenario.

Acknowledgment

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