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Survey on Algorithms and Strategies for Mobility Enhancement under Heterogeneous Network (HetNet) Deployment Circumstances

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Abstract

Cell selection/reselection and handover (HO) are important mobility features and challenges of wireless cellular system. When network topology transforms from macro-only to heterogeneous network (HetNet) deployment, the imbalance of transmitted power and coverage area of different kinds of cells in HetNet introduce more challenges to those two important processes. In this paper, we investigate and elaborate some new algorithms and strategies to meet those challenges. On cell selection/reselection, there are two directions in associating more UEs with small cells, one is RSRP-based by introducing a empirical bias to expand small cells' coverage area, the other is fairness-based to maximize the system throughput and usage of resources. As to more important and difficult HO process, the proposed methods include optimizing the parameters of event A3, handling time to trigger(TTT), optimizing HO process and utilizing inter-cell interference coordination algorithm(ICIC) etc, to maximize the usage of capability of deployed small cell. The presented new algorithms and strategies promise specific performance improvement with introducing receivable time and computing complexity.

Keywords: *Heterogeneous network, HetNet, cell selection, cell reselection, handover, HO, small cell, HF*

1.Introduction

The main difference between homogeneous network and Heterogeneous network (HetNet) is that there are low power nodes (LPN) deployments throughout the macro cell layout[1]. Such LPNs include femto cells, pico cells and micro cells etc. Sometimes we call these LPNs small cells. In this paper, LPN and small cell are used interchangeably. One possible HetNet topology scheme is shown in Figure 1. There are many benefits by introducing small cells into macro cell layout. Firstly, small cells can effectively offload the traffic from some overloaded macro cell. Secondly, due to frequency reusing between macro cells and small cells, system capacity will increase remarkably. Thirdly, network coverage will be improved by deploying small cells in the cell edge where UE can access the network through small cells.

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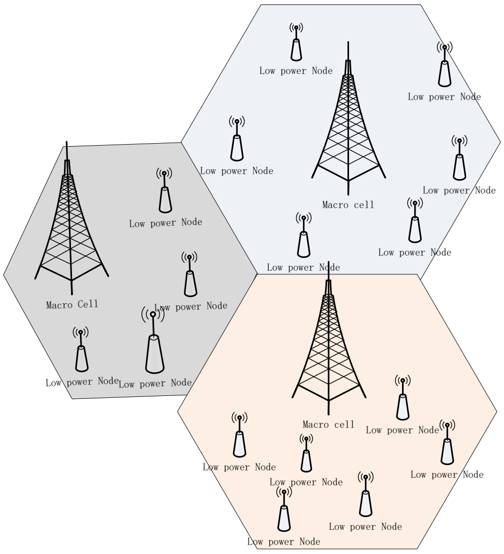

Figure 1. One Possible Hetnet Topology Scheme of Hetnet

However, although deployment of HetNet brings such advantages to the system, deployment of different types of cells in the same coverage area introduces some problems to the wireless communication network which impact mobile process including cell selection/reselection and handover (HO) process. First of all, the different transmitting power level between macro cells (about 46dBm) and small cells (about 20dBm) means that macro cell will shadow small cell, i.e., the user equipment (UE) of LTE-A does not discover the existence of small cell at all. Such small cell shadowed phenomena will decrease the whole data throughput and increase drop rate of UEs at the cell edge. Moreover, if deployed small cells can't be discovered and selected efficiently, the corresponding resources including device, frequency and power are a kind of waste to some extent. Lastly, due to the low power capability, the coverage radius of small cell is relatively small, which will result in problems to UEs' HO process, especially impacts high speed UEs. HO failure and PingPong HO are the main two problems of HO process in HetNet[2].

Operators would like to utilize these resources to the most degree. So there need some methods and ways to redirect UE to connect with small cell as many as possible. Scientists and practitioners have done many researches to resolve the above-mentioned problems. Meshkati et al[3] and Prasad et al.[4] have proposed some quick and effective small cell discovery algorithms. After discovering the small cell, UE can proceed to corresponding operation, such as cell selection/reselection, call process and HO process etc, according to channel and system condition.

The remainder of this paper is organized as follows: In section II, we investigate the cell selection/reselection algorithms. Section III introduces HO algorithms and strategies used to improve the system performance and resource utilization of small cell. Section IV presents small cell addition and deletion strategies in Dual Connectivity (DC) scenarios to improve the cell edge and system throughput. In section V, we summarize the paper and present some concluding remarks.

2. Cell selection and Reselection Process

When UE is initiated or moves to a new cell during IDLE mode, it need to select or reselect suitable cell to camp on to process calling and data transmitting. So-called suitable cell is the cell that satisfies specific criteria for UE's need of communication. Conventional cell selection/reselection criterion is reference signal receiving power (RSRP-based) and reference signal receiving quality (RSRQ-based)[5]. Under HetNet deployment circumstances, the only RSRP-based and RSRQ-based method can't effectively distribute UEs to small cell[6]. Therefore, there needs other strategies to evenly distribute UEs among the cells, biased RSRP[7] and fairness-based methods are two relative new menthod[8].

2.1. RSRP-based Method

According to [5], the cell selections algorithm is:

$$S_{rxlev} = Q_{rxlevmeas} - \left(Q_{rxlevmin} + Q_{rxlevminoffset}\right) - P_{compensation} \quad (1)$$

$$S_{qual} = Q_{qualmeas} - \left(Q_{qualmin} + Q_{qualminoffset}\right) \quad (2)$$

Where S_{rxlev} and S_{qual} are cell selection RX level and quality value (dB) respectively, $Q_{rxlevmeas}$ is measured cell RX level value (RSRP), $Q_{qualmeas}$ is measured cell quality value (RSRQ), $Q_{rxlevmin}$ and $Q_{qualmin}$ are minimum required RX level (dBm)and quality level (dB) in the cell, $Q_{rxlevminoffset}$ and $Q_{qualminoffset}$ are offset to $Q_{rxlevmin}$ and $Q_{qualmin}$ in S_{rxlev} and S_{qual} evaluation. $P_{compensation} = max(P_{EMAX} - P_{PowerClass}, 0)\ (dB)$, P_{EMAX} and $P_{PowerClass}$ are maximum TX power level a UE may use and maximum RF output power of the UE (dBm) respectively.

UE only camps on cell that satisfy conditions where $S_{rxlev} > 0$ and $S_{qual} > 0$. In nature, such algorithm is *Max RSRP* strategy, namely, UE chooses the cell which DL receive power is the strongest as serving cell[7]:

$$Cell_{serving} = argmax_{\{i\}}\{RSRP_{meas}(i)\} \quad (3)$$

The *Max RSRP* strategy is useful and efficient when network are homogeneous cell deployments, e.g., cells are all similar transmitting powers as macro cells or small cells.

When LTE-A introduced HetNet concept, it introduced different types of cells including macro cell and small cell, where the difference of transmitting power maybe as large as 30dB. Moreover, although small cells such as metrocell, microcell and pico-cell etc are deployed by operators, operators have all the information about location and relevant parameters of those cells, femtocells are deployed by users themselves and at users' will, the operators can't control locations and powers of them. Under small cell deployment environment, if the traditional Max RSRP strategy is used, the small cells maybe not chosen for their low transmit power and don't meet the cell selection algorithm. We don't want to waste the scarce spectra and other resources by leaving deployed small cell long time unused. So we need to improve the conventional *Max RSRP* cell selection algorithm to direct more UE associating with small cell.

Intuitively, we can expand the *Max RSRP* strategy by introducing a bias[7], which is *Max RSRP+bias* algorithm, i.e., if DL RSRP received from a cell plus a bias is the strongest, it's chose as serving cell:

$$Cell_{serving} = argmax_{\{i\}}\{RSRP_{meas}(i) + Bias\} \quad (4)$$

Where *bias* is offset for cell selection, 0 for macro cell, an empiric value greater than 0 for small cell. The *Max RSRP+bias* strategy sounds well and it can solve the small cell not chosen problem due to low DL RSRP to some extent[7, 9], which can effectively expand the small cell's coverage and offload from macro cell and increase the usage of resources of small cell.

But there is a new problem introduced by the choice of *bias*. Firstly, now the value of *bias* is decided by simulation or chosen by empirical experience of practitioners, it's difficult to decided whether the chosen value is optimal or not for specific small cell. Secondly, the cell range expansion (CRE) of small cell indeed results in offloading from the macro cell, but the offload performance, i.e. the UE number and traffic etc associating with small cell, is difficult to justify and predict. Therefore, there need more efficient strategies or methods to balance the number of UE and traffic distribution among macro cells and small cells.

2.2 Fairness-based Method

Except traditional RSRP (RSRQ)-based cell selection/reselection algorithms, recently fairness-based scheduling methods including max-min and proportional fair[7, 10, 11] are introduced into cell selection/reselection algorithm. In their inspiring work[11], Fallgren M. integrates Max-min algorithm into joint cell selection and power allocation. And Chen et al. [10] focus their research on proportional fair scheduling algorithm, which is

$$\sum_{i\in I}\frac{R_i^{(s)}-R_i^{(P)}}{R_i^{(P)}} \le 0 \tag{5}$$

where I is the user set and $R_i^{(P)}$and $R_i^{(s)}$are the average rates of user i allocated by scheduler P and S respectively. Scheduler P is proportional fairness if it satisfies eq. (5).

According to Shannon's theory [12],

$$R = B\, log_2(1+\frac{RSRP_{serving}}{N_0+\sum_i RSRP_{ni}}) \tag{6}$$

where B is the allocated bandwidth, $RSRP_{serving}$ is the received serving cell DL RSRP, $RSRP_{ni}$ is the received DL RSRP of the *i*th neighbor cell, $\sum_i RSRP_{ni}$ is the sum of all the received neighbor DL signal, N_0 is background noise.

Assume R_i is the long-term or average throughput achieved by user *i*, the optimization goals[8] can be set as $\sum_i log\, R_i$. Taking spectrum efficiency in to account, the fairness objective function is adapted to be used in cell selection algorithm with the site's throughput achieving maximum at the same time [7] . In [7], the authors give two different algorithms according to the number of pico cells, one is optimal optimized fairness which is suitable for there is small number of small cells in or around a macro cell. The objective function of optimal optimized fairness is defined as:

$$U(k_1,k_2 \dots k_m) = \prod_{i=1}^{m}\prod_{j=1}^{k_i} r_{ij} / \prod_{i=1}^{m} k_i^{k_i} \tag{7}$$

$$U_{max}(k_1,k_2 \dots k_m) = max\{U(k_1,k_2 \dots k_m) | \sum k_i = n\} \tag{8}$$

Where k_i is the number of UEs associated with cell i, r_{ij} is instant downlink data rate from cell i to UE j referring to eq. (6), n is the total number of UEs in site and m is the total number of cells in site.

The other is Greedy optimized fairness which is a heuristic algorithm and more suitable for a larger number of small cell in or around a macro cell. The utility function is:

$$CellID_{serving}(j) = arg\ max_{\{i\}} \left\{ \frac{r_{ij}.k_i^{k_i}}{(r_{ij}+1)^{k_i}} \right\} \quad (9)$$

From the work of the simulation result expressed in [7, 10, 11], the introduction of utility function into the cell selection and reselection procedure can improve the whole site throughput and spectrum efficiency comparing with the only the dependence of the strongest received DL signal, for example, the simulation result show there is about 20% spectrum efficiency gain for cell edge and about two fold UEs associating to small cells [7].

3. Handover Process

When UEs are in IDLE mode, cell selection/reselection process is used to decide which cell to camp on. When UEs are in Connection state, connecting problems resulting from UEs' roaming are handled by HO process. In wireless cellular system, the handover (HO) process allows a UE to transfer an ongoing call or data session from one channel connecting to the core network (CN) to another channel, which is a most important feature to keep ongoing calls or data sessions from interruption with UEs' moving out a source cell's coverage area.

In HetNet deployment, small cells are generally deployed in hotspots and cells edge to offload and/or improve coverage, which bring great impacts to HO process, such as resulting in increase of handover failure (HF) rates and/or Ping-Pong (PP) rates due to power difference between macro cells and small cells. For example, in a scenario depicted in Figure 2, a UE is moving to the edge of the macro cell, when it arrives a location between the macro and small cells, where the reference signal receiving power (RSRP) of macro cell has too weak to maintain its high data rate or high Quality of Service (QoS) and geographically it is more near the small cell. But due to the low power property of the small cell, the RSRP of small cell doesn't satisfy the entering condition of event A3, .i.e., $Mn+Ofn+Ocn-Hys<Mp+Ofp+Ocp+Off$ [13].So the UE will have to continue its connection with the macro cell until the RSRP of small cell meet the entering condition of event A3. Under such circumstance, the UE locating between macro cell and small cell may experience poor connecting QoS or even call drop.

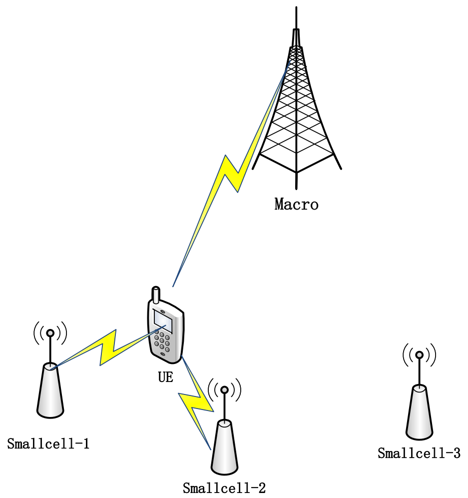

Figure 2. UE Locating Near the Small Cell But Doesn't Satisfied the A3 Entering Condition

When small cell are introduced to macro-only wireless cellular system, changes of network topology and cells' types bring more challenges to HO process, which call for adjusting of HO parameters and/or HO procedures to meet the new setting, eg. M. Z Chowdhury et al[14] elaborated HO call flow for femto-to-macro cell, macro cell-to-femtocell and femtocell-to-femtocell repectively.

Event A3 is the basic criterion for discussing HO process[13]. To improve the performance of HO, part of work is to adjust parameters in event A3. 36.839[2] defines mobility enhancements in HetNet, Which defines criteria for occurrence decision of HF and PP. Moreover, the definition of HF rates and PP rates and other performance metrics, simulation scenario and simulation parameters are given in 36.839 as well. Therefore, to optimize the usage of small cells is to jointly optimize parameters and procedures of HO by combining event A3 and settings in 36.839 effectively.

In nature, event A3 is a RSRP-based criterion. So intuitively, a bias to RSRP-based methods can be introduced to expand the coverage of small cell, i.e. cell range expansion (CRE). D. López-Pérez et al[9] propose a mobility based inter-cell interference coordination algorithm(MB-ICIC), which combines HO parameter optimization with ICIC to reduce the HF and/or PP rates for high-mobility UEs, i.e. some subframes are reserved for specific macro cell or picocell exclusively in order to avoid co-channel interference. In[9], the impact of CRE to coverage of macro cells and small cells is elaborated as well. Figure 3 illustrates the coordinated resources.

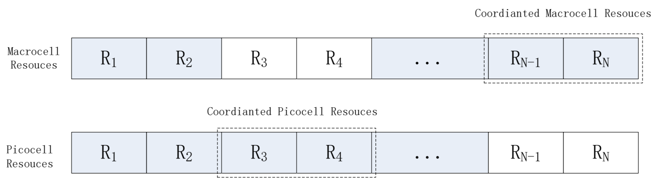

Figure 3. Interference Coordination at Macrocell and Pico Cell

According to 36.839, time to trigger (TTT) plays an important role in HO procedure. The impacts of different TTT setting to HF rates and PP rates are evaluated in [9, 15, 16]. Chuan M et al [17] investigated the inter-tier HO among a three-tier HetNet of macro cells, relays and picocells. After analyzing target tiers, dwell probability and HO probability, they proposed a handover algorithm consisting of three schemes for inter-tier handover in three-tier macrocell, relay and femtocell HetNet. However, Gh. Zhou et al [18] proposed network-controlled handover (NCH) mechanism after examining the shortcoming of traditional HO trigger mechanism. In the proposed NCH mechanism, a "triggered periodic" event A3 with small offset and short TTT was configured by eNB, which is initiated after RSRP received satisfying the entering condition of event A3. When SINR monitored is below the defined threshold, HO preparation is triggered for the strongest target cell in the last measurement report. Figure 4 shows the tradition HO trigger mechanism in LTE, and Figure 5 illustrates the NCH trigger mechanism.

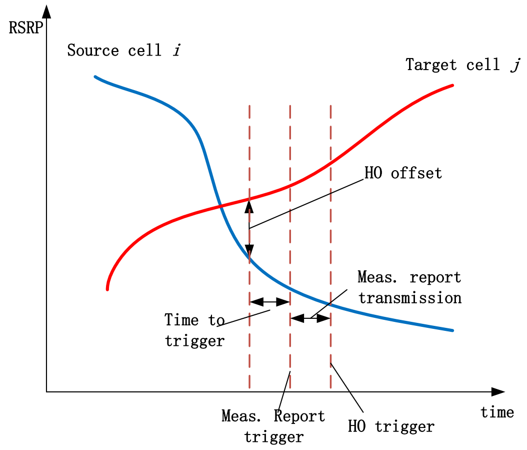

Figure 3. Traditional Handover Trigger Mechanism in LTE

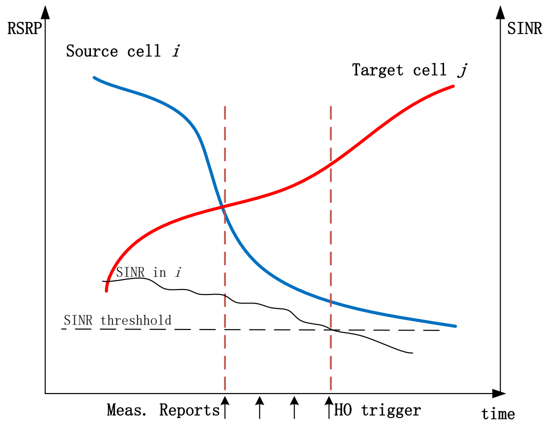

Figure 4. New Handover Trigger Mechanism In LTE[18]

4. Small Cell Addition and Deletion in DC Scenario

Traditionally speaking, any UE connect with basestations through one pair of carrier frequencies, which are down link carrier and up link carrier individually. With the ever-increasing development of economy, users desire higher data rate. So there need more and more bandwidths to meet users requirement. In order to create much more usable bandwidth and increase users' bitrate, scientists and practitioners from wireless industries wonder whether more than one carrier frequencies can be aggregated to produce much wide bandwidth or not. So Carrier Aggregation (CA) was introduced into LTE-Advanced [19]. CA means that there are at least two frequencies aggregated to carry users' traffic, where anyone of the carrier frequencies is referred as component carrier.

In HetNet deployment, there exist many low power nodes (LPN) or small cells (LPN and small cell are exchangeable in this paper) within the coverage of a macro eNB. So in HetNet, the concept of CA is extended to different eNBs, in which the component carriers come from different eNBs. The extended CA is referred as Dual Connectivity (DC). Moreover, researchers propose to split the control and data into different carriers as to increase the data rate and utilize the available spectrum as the same time, as showed in Figure 5.

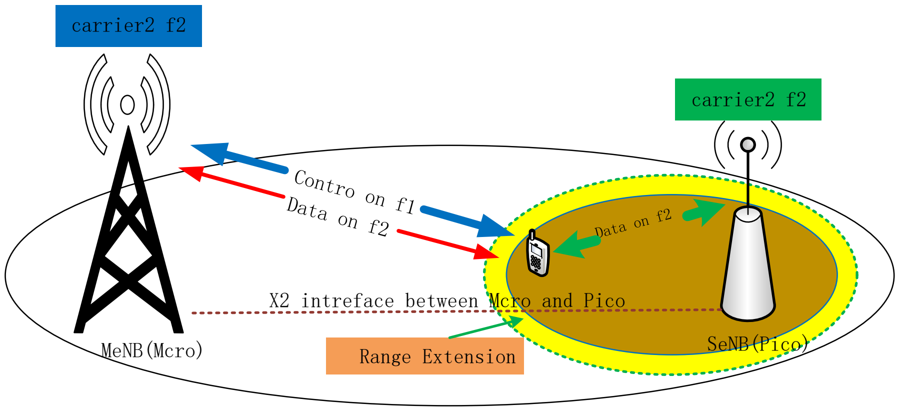

Figure 5. A Typical Deployment Scenario of Dual Connectivity.

With the split between user plane and control plane in DC scenario [20], there emerges the possibility of the small cell addition and deletion autonomous controlled by UE [21]. And when a UE travels in the coverage area of the macro and small cells, it may experience many small cells during one session, as showed in Figure 6. In such a scenario, if traditional HO process and cell selection algorithms are used, the delay introduced by frequent measurement, transferring and decision will be too much for such a small coverage area of small cell. Therefore, a new autonomous UE controlled cell change, addition and deletion algorithm is proposed to mitigate the delay and to promote the performance of UEs and the overall performance of the system.

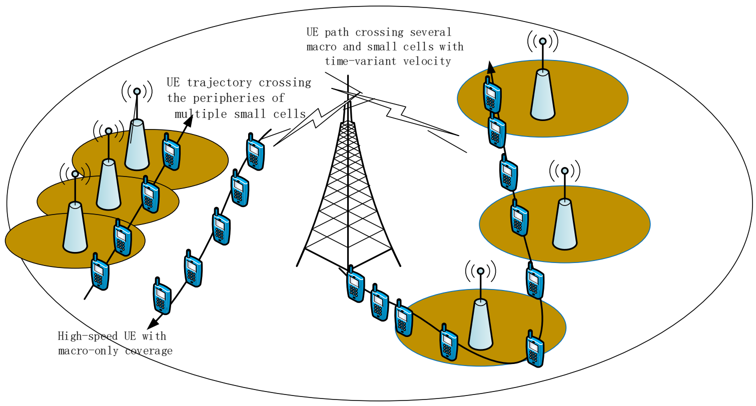

Figure 6. A Deployment Scenario of Dual Connectivity.

To realize the UE controlled autonomous small cell addition and deletion, a new event A6 need to be introduced to decide whether a UE needs to change its serving small cells or not. When the RSRP or RSRQ of neighbor cell becomes offset better than serving cell, event A6 is activated. The enter and leave condition of A6 is as following.

Enter condition: $Mn + Ocn - Hys > Ms + Ocs + Off$

Leave condition: $Mn + Ocn + Hys < Ms + Ocs + Off$

In order to help UEs autonomously perform addition or deletion of serving small cells, the serving macro cell need to do some configuration for this UE. These configuration includes measurement setting, access control algorithm, decision strategies etc. according to UE's roaming and access context information. After configuration, when a UE enter a small cell which can be used as a split user plane from a session of the macro cell, it can activate the event A6. Once the RSRP or RSRQ of pre-configured small cells meet the triggered condition, the UE in DC state will initiate the request message to the object small cell to ask access permission. The request message must contain the necessary information to help the destination make decision, including X2 context of the source serving small cell, context of UE S1 EPC signaling, destination small cell ID, key of KeNB, RRC context etc.. After receiving the access request, destination small cell will execute access control process to prepare for UE's access according to received EAB QoS. UE and related small cells need to exchange several signaling like the abovementioned before the addition process is finished. All the interaction and signaling exchange is between the UE and the destination small cell without the involvement of the macro cell which is traditional play an important role during the HO process. The signaling process of addition of UE in DC state is shown in Figure 7.

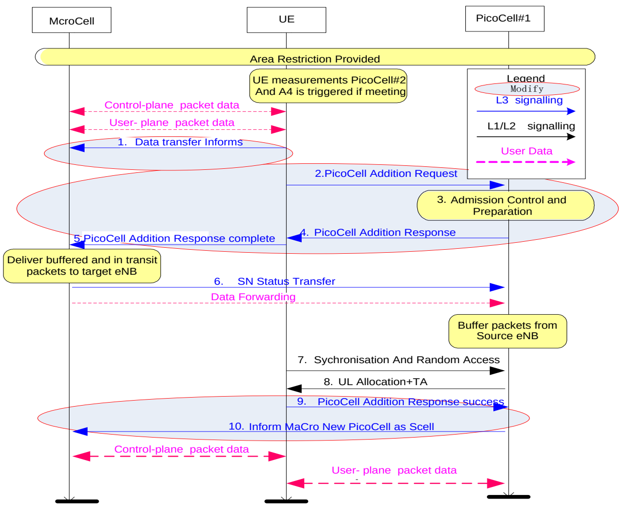

Figure 7. Addition of Serving Small Cell

When UE move to the edge of the serving small cell, it has to measure the RSRP or RSRQ to decide when to execute HO process. If RSRP or RSRQ of a UE in DC state meet the leave condition of A6, it will exchange some message between the serving small cell and macro cell to complete the deletion operation, as showed in Figure 7. Because there may not exist suitable small cell for UE, the macro cell needs to take over the user plane itself. Therefore, there are two situations. One is when UE delete the serving small cell and the macro cell will fulfill the data carrier of the user plane, the other is when UE delete the serving small sell and addition another small cell. The detail of serving cell deletion is illustrated in Figure 8

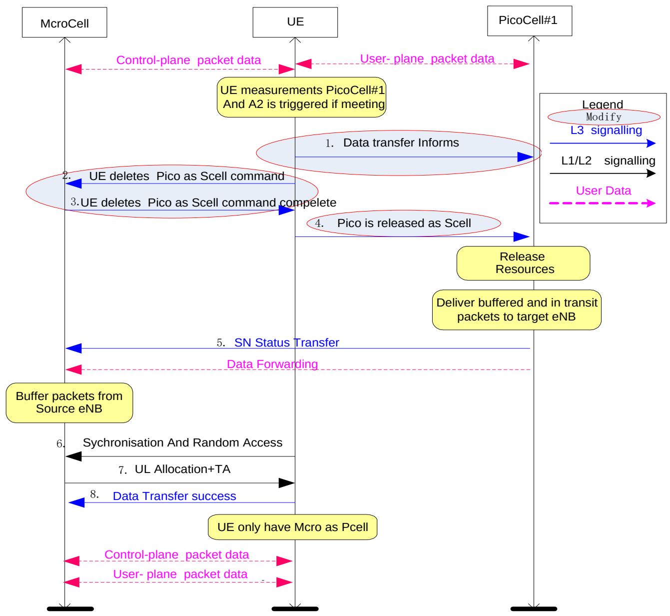

Figure 8. Deletion of Serving Small Cell

5. Conclusion and Future Work

The transformation from macro-only to HetNet deployment puts forward new challenges that demand many more innovations to take advantage of the full potential of deployed small cells. Among those, mobility management about cell selection/reselection when UEs are in idle mode and HO processing when UEs are in RRC-connected mode is high on the list to secure traffic offloading and small cell associating rates. This paper presents some new ideas about mobility management after integrating small cells into the existing macro-only network on cell selection/reselection and HO respectively after extensive investigation. These presented innovations promise to associating as many UEs as possible with small cell without compromising related performance such HF rates, PP rates and call drop rates etc.. As DC is introduced into LTE-A, there emerge some new ideas as to HO processing between two small cells or between small cell and macro cells. In the paper, one new idea, i.e. UE autonomous addition and deletion serving small cells is illustrated.

Although there are many innovations on algorithms and/or procedures on mobility management in HetNet, there still need more works on mobility enhancements as of HetNet deployments. About cell selection/reselection, the research objective maybe optimize selecting parameters to direct more UEs into small cells' service without introducing time and computing complexity. As to HO process, emphasis may be put on inventing more effective algorithms or finding optimal procedures to reduce HO responding time, to optimize HO parameters and to validate HO performance etc., by taking UEs' moving speed and small cells' coverage area into account.

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