Signalling Cost Evaluation of Handover Management Schemes in LTE-Advanced Femtocell

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Abstract—Femtocell is a small access point using the wire broadband connections or wireless technologies to access the mobile operator's network for the UE (user equipment), which can provide better indoor coverage and satisfy the upcoming demand of high data rate for wireless communication system. Femtocell related handover cost reduction is one of the important targets in LTE-Advanced SON (Self-Organising Networks). In this paper, a handover optimization algorithm based on the UE's mobility state is proposed. An analytical model was presented for the handover signalling cost analysis. Numerical results are provided to compare the signalling cost of different handover management schemes. The comparison between the proposed algorithm and the traditional handover control algorithm shows that the algorithms proposed in this paper have a significant reduction in the signalling overhead.

I. INTRODUCTION

Nowadays standards for Universal Terrestrial Radio Access Network’s Evolution (i.e. Evolved UTRAN) has been done as Release 10, which aims at reducing delays, increasing user data rates, increasing cell-edge bit-rate and seamless mobility with deployed Home eNodeB (HeNB) [1]. Home eNodeB is a low power wireless access point which is deployed indoor to diverse the traffic load from the macrocell, while the indoor traffic is over 70% in the total traffic stream recently. Femtocell is low-power and low-cost; and it is more harmony to the environment due to the lower carbon emission. For mobile operator, femtocell reduces the OPEX because of the user’s self-installing and self-operation of femtocell. 3GPP has been carried out the research on Home eNodeB, and the applications of Home eNodeB may also introduce some challenges to the work related to LTE-Advanced.

A. Background

Femtocell can not only be used in UTRAN and IMS, which is known as Home NodeB or home base station, but also can be used in LTE E-UTRAN and LTE-Advanced E-UTRAN. Their commercial potential has been analyzed and a recent forecast by ABI Research predicts that the market for femtocell equipment will grow 95 percent per year, to more than $4 billion by 2012 [2]. The mass deployment of Home eNodeB and the mobility of UE between femtocell and LTE/LTE-A macrocell will create a large number of signalling, which will need the SON to solve. With the deployment of the Home eNodeB, the mobility between Home eNodeB and eNodeB is become more and more crucial in the LTE/LTE-A based networks. Mobility between one of the thousands of Home eNodeBs and an eNodeB will create a large number of handovers, moreover, the modifications of handover procedures for existing networks are needed, the optimization of handover procedure and algorithm will improve the performance of both the femtocell and LTE/LTE-A network [3].

B. Motivation

UEs with high velocities moving through the femtocell usually lead to performing some unnecessary handovers, where a outbound handover happens quickly after a inbound handover. These cause a decrease in the network performance, such as dropped call. Traditional handover methods cannot guarantee a good quality handover performance for the users under different moving speed in Home eNodeB and eNodeB mixed network. Traditional handover decision algorithms for users in mobile vehicles cannot meet current need, which usually leads to unnecessary handovers. In this paper, a handover optimization algorithm based on the UEs mobility state is proposed.

C. Related work

In [4], a simple and effective method has been proposed to perform access and handover management for femtocell systems. For closed access, femtocell and macrocell base stations exchange CSG membership list so that unnecessary handover signalling can be avoided. Procedures for femtocell hybrid access have also been proposed, with femtocell initiated handover with adaptive threshold based on QoS. No changes are required to the UEs. In [5], it proposed a mobility management scheme that move the mobility anchor for user plane from the S-GW to the HeNB GW and let the HeNB make the handover decision in HeNB-HeNB handover scenario. A call admission control optimization algorithm based on velocity and the real-timing attribute of the user’s service for femtocell network has been introduced in [3]. However, the algorithm involved the detection and the judgment of the real-timing attribute, which is complicated and not suitable for a cost-effective implementation. In [6], it proposed a handover
decision algorithm that combined the values of received signal strength from a serving macrocell and a target femtocell in the consideration of large asymmetry in their transmit powers in eNB-to-HeNB handover scenario.

D. Outline

In this paper, we consider a LTE/LTE-A based massive HeNB deployed network, which aim to decrease the large number of handover and signalling overhead. This paper proposes a simplified handover optimization algorithm based on the mobility state, the performance of handover signalling cost will be evaluated.

The rest of this paper is organized as follows: section II provides the HeNB-GW based HeNB network architecture. In section III, procedure for handovers from macrocell to femtocell is introduced. In section IV, a signalling analysis model is introduced and the handover optimizing algorithm based on the mobility state is evaluated in Section V. Finally, Section VI concludes the paper.

II. LTE FEMTOCELL SYSTEM ARCHITECTURE

The discussions for the LTE/LTE-A femtocell standards including the E-UTRAN femtocell architecture are undergoing in the Femto Forum, 3GPP and NGMN Alliance. There is a strong consensus to keep the architecture as flat as possible, following the principles of ‘all-IP’ networks adopted in the LTE standards. The debate is still going on as to whether there is a need for a signalling aggregation element or whether the evolved packet core (EPC) itself should be able to support femtocells directly [7]. The reference LTE femtocell architecture is shown in Fig. 1, which has a set of S1 interfaces to connect the HeNB to the EPC [1].

![Fig. 1. Overall E-UTRAN architecture with deployed HeNB GW.](image)

The overall E-UTRAN architecture with deployed HeNB GW is showed in Fig. 1, which is standardized in release 9 [1]. Here we choose the E-UTRAN femtocell system architecture based on HeNB GateWay.

III. HANDOVER PROCEDURE

Because the femtocell involved network architecture different from traditional LTE network architecture, the handover procedure between LTE-Advanced macrocell and femtocell should be revised. Here we present the handover procedure based on the E-UTRAN architecture as illustrated in Fig. 1.

The Fig. 2 below shows the handover procedure from macrocell to femtocell (Intra-MME/Serving Gateway) [1][3].

IV. SIGNALLING ANALYSIS MODEL

There are three scenarios in HeNB related handover: from femtocell to macrocell, from macrocell to femtocell and from femtocell to femtocell, in this paper, we only consider the handover between femtocell and macrocell. In our model, we assume that handover will occur if a connecting-state UE moves cross the border of the serving femtocell or macrocell without considering other conditions.

The coexistence of femtocell and macrocell leads to extra signalling overhead for handover support. The superfluous signalling overhead declines the overall QoS of the system performance. The QoS parameter chosen in this paper for the performance analysis of mobility is signaling cost. Firstly, an outline of the handover optimization algorithm is presented in sub-section A.

A. A Low-complexity Handover Optimization Algorithm

The high speed macrocell users usually do not want to handover to the femtocell while the low speed may be want to handover to the femtocell; the traditional handover algorithm let the high speed macrocell users handover to the femtocell, which may introduce two times unnecessary handovers for the user, so we develop a simple but effective low-complexity handover algorithm to optimize the system performance. The
detailed pseudo code of handover algorithm is described as follows:

**Algorithm 1 Low-complexity Handover Optimization Algorithm.**

1: Mobility state Initialization;
2: if RSRP_Target>RSRP_Source+Hysteresis then
3: if Mobility state>Threshold_H then
4: Connect to macrocell;
5: else
6: Handover to femtocell;
7: end if
8: else
9: Return.
10: end if

B. Analysis Model

This section will present a simple model that evaluates the signalling overhead of the handover optimization algorithm based on the work in [8][9]. The mobility patterns of an UE influence the number of handover in a handover scenario, thus it can determine the average signaling cost of each handover scenario. There are some crucial assumptions of the mobility model list as follows:

- Only femtocell and macrocell are in the LTE/LTE-Advanced service area.
- The hexagon cell shape simplify into the circular shape with the radius of R (macrocell) and r (femtocell).
- The special velocity environment changes described here include the following scenes, to simplify the complexity of the calculation, we assume that there are two mobility state of the UE, low mobility state: slow walk, stationary while the high mobility state: drive a car, for example.
- If the UE cross the boundary of the cell (macrocell, femtocell) in LTE/LTE-Advanced connection state, handover request will be sent to the target eNodeB/home eNodeB.

Let $\alpha$ denotes the proportion of the high mobility users while $1-\alpha$ means the proportion of the low mobility users. A big value of $\alpha$ means the high proportion of high mobility users while low $\alpha$ represents a high proportion of low mobility users. Two scenarios are considered in handover between macrocell and Femtocell. Scenario 1: an UE in active state moves into and ends the active state in a femtocell whose session initializes in the macrocell; scenario 2: an UE in active state moves across the femtocell, whose session initializes in the neighbor macrocell, and finally moves out of the femtocell, showed in Fig. 3. The probability of the handover happens between the macrocell and femtocell is the sum probability of scenario 1 $P_{s1}$ and scenario 2 $P_{s2}$:

$$P_h = P_{s1} + P_{s2}$$ (1)

Let $T_{S1}^{C}$ denotes the UE’s camp time in the femtocell in scenario 1, that is, the time from an active UE moves into the femtocell until the time it stops in the femtocell. $T_{S2}^{F}$ is denoted as the UE’s camp time in the femtocell in scenario 2, which is an active UE who initializes the session out of the femtocell comes into the femtocell to the time it leaves the femtocell; while $T_{H}^{M}$ and $T_{H}^{F}$ are the session holding time in scenario 1 and scenario 2 respectively. $f_{FL}$ is denoted as the probability distribution function (pdf) of low mobility users’ camp time in femtocell with the pdf $K/t$ ($K$ is the standardization factor, $t$ is the camp time of the low speed user in the femtocell), while $f_{FH}$ is denoted as the pdf of high mobility users’ camp time $T_{FH}$.

$T_{MH}$ is denoted as the high mobility users’ macrocell camp time with the pdf $f_{MH}$, which is assumed exponentially distributed with mean $1/\mu$, $\alpha$ and $\mu$ are the radius of the femtocell and macrocell, respectively. With the assumption of the user has a constant speed (example: $v$ m/s) in the femtocell and macrocell, that is:

$$v = T_{FH}/r = T_{MH}/R$$

We can obtain that

$$T_{FH} = (r/R)T_{MH}$$ (2)

Therefore, we can get the following equation from the equation (2)[9].

$$f_{FH} = (r/R)f_{MH}$$ (3)

Let $T_f$ denotes the camp time of both high mobility users and low mobility users in femtocell with the pdf $f_f(t)$, that is:

$$T_f(t) = \alpha T_{FH}(t) + (1-\alpha)T_{FL}(t)$$

$$f_f(t) = \alpha f_{FH}(t) + (1-\alpha)f_{FL}(t) = \alpha(r/R)f_{MH}(t) + (1-\alpha)f_{FL}(t)$$ (4)
For users in scenario 1, the pdf of $T_{C_{S1}}$, $f_{S1}(t)$, can be obtained based on the excess life theorem [10],

$$f_{F}(T_{C_{S1}}) = \frac{1 - F_{F}(T_{C_{S1}})}{\mu_f}$$  \hspace{1cm} (5)

$\mu_f$ is the mean of the $F_{S1}(T_{C_{S1}})$, which is the CDF(cumulative distribution function). While for the scenario 2, the pdf of the $T_{S2}$, $f_{S2}(t)$, is equal to the $f_{F}(t)$. The probability of the handover in scenario 1 and scenario 2 is express as[9]:

$$P_{S1} = \frac{P(T_H > T_{C_{S1}})}{\mu_f} = \int_{0}^{\infty} (1 - F_{T_H}(x))f_{S1}(x) \, dx = \alpha P_{H}^{S1} + (1 - \alpha)P_{L}^{S1}$$  \hspace{1cm} (6)

Where $i=12$, $F_{T_H}(x)$ is the CDF of $T_H(i=1, 2)$, and $T_H$ follows the exponentially distributed with the mean of $1/\zeta$. $P_{H}^{S1}$ and $P_{L}^{S1}$ are the probability of high speed users and low speed users in scenario i ($i=1,2$), respectively.

Finally the closed-form expression of $P_{S1}$ and $P_{S2}$ can be derived as follows[9], where, $U$ is the upper limitation of the femtocell users’ camp time:

$$P_{S1} = \alpha \frac{R\mu}{r\zeta + R\mu} + (1 - \alpha) e^{-\zeta} + KEi(-\zeta) \frac{1}{\zeta(K(U - 1))}$$  \hspace{1cm} (7)

$$P_{S2} = \alpha \frac{R\mu}{r\zeta + R\mu} + (1 - \alpha)KEi(-\zeta)$$  \hspace{1cm} (8)

where

$$Ei(x) = \int_{-x}^{\infty} \frac{1}{y^x} \, dy$$

The handover signalling can be divided into transmitting signalling and processing signalling. The signalling cost in the Home eNodeB related handover are list as follows: $T^{H_{eNB}}_{UE}$ is denoted as the transmitting signalling between UE and (Home) eNodeB, $T^{H_{HeNB}GW}_{H_{eNB}GW}$ is denoted as the transmitting signalling between Home eNodeB gateway and Home eNodeB, $T^{H_{eNB}GW}_{MME}$ is denoted as the transmitting signalling between Home eNodeB gateway and MME/S-GW, $P_{H_{eNB}}$ is denoted as the signalling processing cost at eNodeB, $P_{UE}$ is denoted as the signalling processing cost at UE, which contains the detached time in the handover, $P_{H_{eNB}GW}$ is denoted as the signalling processing cost at Home eNodeB Gateway, $P_{MME}$ is denoted as the signalling processing cost at MME.

Signalling cost of the HeNB related handover in each scenario is derived as follows:

$$C = P(\sum T_{j}^{i} + \sum P_{k})$$  \hspace{1cm} (9)

Where $P$ is the probability of the handover in a scenario, here $P = P_{h}$, $(\sum T_{j}^{i} + \sum P_{k})$ is the signalling cost in the scenario.

V. PERFORMANCE EVALUATION

In order to verify the performance of the algorithms presented in this paper, we compare the algorithm proposed this paper with traditional handover scheme in aspect of system signalling overhead in different scenarios based on the signalling analysis model presented in section IV.

As discussed in [11], the cost parameter has no unit but can be defined to be proportional to the delay required to send or process a signalling message. Other measurements for the cost parameters are possible. Here we use the parameters in table presented in [5] as follows:

<table>
<thead>
<tr>
<th>Parameter Values For Signalling Cost Evaluation</th>
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<tbody>
<tr>
<td>Parameters</td>
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<td>Value</td>
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Table I

Fig. 4 shows the signalling overhead versus the proportion of the mobility users with the $R$ set as 100r, the mean of the high mobility users’ macrocell camp time $1/\mu$ is set as 3 minutes, the upper limit of femtocell users’ camp time $U$ is set as 400 minutes, the mean of $T_H$ $1/\zeta$ is set as 2 minutes. As the Fig.4 shows, for the higher $\alpha$, with the probability of the numbers of handovers in traditional algorithm increases, while the proposed handover algorithm has a lower number of handovers, in the algorithm presented in this paper, we do not allow the high speed users handover from macrocell to femtocell while low speed users are allowed. Therefore, when the $\alpha$ increases near to 1, the number of handover in traditional algorithm comes down to zero, and the handover signalling cost has a correspondent performance as the handover number. From the figure, it can be seen that as the average session holding time increases, the signalling cost both in traditional algorithm and proposed algorithm increase, since there will be more handover with the increase of the session holding time.

In traditional femtocell related handover algorithm, the high speed users and low speed users are same treated, two unnecessary handovers was happened as the UE handover happened especially the UE moving from macrocell to femtocell.

As the rejecting of the unnecessary handovers access request, the total cost of the handover is reduced, so there is a big decrease in proposed algorithm’s performance.

Fig. 5 shows the signalling overhead versus the mean of the session holding time in scenario 2 with the value of $\alpha$ set as 0.1, corresponds to the low proportion of high mobility user in real life. As seen in Fig.5, the total signalling overhead increases as the mean of session holding time increases. The reason is that the bigger of the session holding time, the probability of cell-crossing would be bigger, which means a high probability of handover.
VI. CONCLUSION

In this paper, revised signalling procedure of handover is presented based on the Home eNodeB GW in femtocell integrated LTE-Advanced network. A handover algorithm based on the UE’s mobility state has been studied and evaluated in terms of handover signalling. The comparison with the traditional algorithm shows that the algorithms proposed in this paper have a better performance in handover signalling overhead and, especially for the high proportion of high mobility users scenario.

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