Abstract—Home eNodeB (HeNB) is a low-power access point using the local broadband connections or a separate RF backhaul to access the mobile operator's network for the user equipment (UE), which can provide better indoor coverage and satisfy the upcoming demand of high data rate for users. Considering the potential frequent mobility between HeNB-HeNB and HeNB-eNB, HeNB mobility enhancement is proposed as one of the most important work items in 3GPP LTE-Advanced. In this paper, four X2 interface based HeNB mobility enhanced architectures are explicitly discussed in terms of signalling overhead evaluation. The numerical results show that the direct-X2 based option 2 in HeNB-HeNB scenario and the X2-GW based option 3 in eNB-HeNB scenario have the best trade-off in signalling overhead and complexity respectively.

I. INTRODUCTION

Nowadays standards for Universal Terrestrial Radio Access Network’s Evolution (i.e. Evolved UTRAN) are being done as Release 10, which aims at reducing delays, increasing user data rate, cell-edge bit-rate and seamless mobility with deployed HeNB [1].

A. Background

HeNB (also called femtocell) is a low power wireless access point which is deployed indoor to divert the traffic load from the macrocell. Recent studies show that more than 50% of all voice calls and more than 70% of the data traffic originate indoors [2]. With smaller-coverage, lower-power and lower-cost HeNB emits lower carbon and is more harmony to the environment. 3GPP has carried out the research on Home eNodeB, however, the application of Home eNodeB also introduces some challenges to the work related to LTE-Advanced.

B. Motivation

Due to the mass deployment of Home eNodeB and frequent mobility of the users in enterprise, mall and campus etc, lots of handovers and signalling flows will bring a great burden to the E-UTRAN/MME. The typical deployment scenarios for HeNB mobility enhancement are the enterprise, campus and mall cases. In these deployment scenarios, the only available handover scheme is S1 handover through core network (CN) which leads to the following drawbacks [3]: (i) Handover event within one company (or campus, mall etc.) is rather frequent, which will make CN suffer from heavy load, (ii) Handover performance goes bad owing to the latency, (iii) X2 based handover has better performance than S1 based handover, because handover preparation and data forwarding through X2 are more efficient than S1 considering the large number of HeNBs in deployment. Moreover, with the deployment of the HeNB, the handover between femtocell and 3GPP macrocell is become more and more crucial in the LTE/LTE-A based networks. Thousand of HeNBs within a macrocell area will create a large number of inbound/outbound handover, so the optimizations of both HeNB-HeNB and eNB-HeNB mobility are utmost necessary. Therefore, X2-based HeNB mobility enhancement schemes are proposed in this paper.

C. Related work

Different mobility management methods have been studied in the literature in order to optimize the handover performance. In [4], 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. In [5], a simple and effective method has been proposed to eliminate unnecessary handovers and reduce handover overhead in femtocell deployed scenarios. In [6], it proposed Femtocell Private Branch Exchange scheme to forwarding the traffic of the HeNBs to the CN in a small area, such as a mall or an enterprise, which can significantly reduce the mobility overhead.

However, the mobility enhanced architecture has not been investigated in the literature mentioned above. Because of the potential massive use of HeNB, large number of handover leads to a mount of signalling overhead. In this paper, the reduction of signalling overhead by introducing X2 interface to HeNBs is quantified.

D. Outline

The rest of this paper is organized as follows: section II provides the HeNB enhanced network architecture options. In section III, handover procedures for HeNB mobility enhancement are introduced. In section IV, a signalling analysis model is introduced and the performance of HeNB mobility enhancement schemes is evaluated in Section V. Finally, Section VI concludes the paper.
II. HeNB Enhanced E-UTRAN 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. Though the architecture has not been finalized, there is a strong consensus to keep it as flat as possible, smoothing the handover of E-UTRAN architecture adopted in the LTE/LTE-A standards. Whether and how to introduce the X2 interface in HeNB related mobility enhancement is still discussed in 3GPP RAN WG3 [7].

There are two types of basic scenarios in HeNB related mobility: (a) mobility between eNB and HeNB, (b) mobility between eNBs. As discussed in [8], three options in both types has been proposed. It is assumed that all the mobility enhanced HeNB architectures are deployed default with HeNB-Gateway (HeNB-GW) in this paper.

The HeNB-HeNB mobility enhanced architecture candidates are shown in Fig. 1, which introduces a set of X2 interfaces to enhance the mobility between HeNBs. Option 1 is the traditional HeNB architecture deployed with only S1 interface. Option 2 is the enhanced HeNB architecture deployed with direct X2 interface between HeNBs. Option 3 is the enhanced HeNB architecture deployed with both X2 and S1 interface routed by HeNB-GW.

The eNB-HeNB mobility enhanced architecture candidates are shown in Fig. 2, which introduces a set of X2 interfaces to enhance the mobility between eNB-HeNB. Option 1 is the traditional eNB-HeNB architecture deployed with only S1 interface. Option 2 is the enhanced eNB-HeNB architecture deployed with direct X2 interface between eNBs. Option 3 is the enhanced eNB-HeNB architecture deployed with both X2 and S1 interface routed by HeNB-GW.

III. Handover Procedure

Because the HeNB mobility enhanced network architecture is different from traditional E-UTRAN network architecture, the HeNB related handover procedure should be revised in both HeNB-HeNB handover and eNB-HeNB handover. Here we will present handover call flow based on the E-UTRAN architecture as illustrated in Fig. 1 and Fig. 2.

A. Handover Procedure for HeNB-HeNB Mobility

According to description of option 2 in Fig. 1/2, the X2-based handover procedure between Source (H)eNB and Target (H)eNB via the direct X2 interface is shown in Fig. 3 [9].

B. Handover Procedure for eNB-HeNB Mobility

Similarly, According to description of option 3 in Fig. 1/ Fig. 2, the X2-GW-based handover procedure between Source (H)eNB and Target (H)eNB via the HeNB GW is shown in Fig. 4 [9].
IV. SIGNALLING ANALYSIS MODEL

This section will present a simple analysis model that evaluates the signalling overhead of the HeNB enhanced architecture based on the work in [4][10][11]. There are some crucial assumptions for the mobility model as follows:

a) Only eNB and HeNB are deployed in the LTE/LTE-Advanced service area.

b) Three types of mobility will be considered in eNB/HeNB co-deployed scenario: from HeNB to eNB, from eNB to HeNB and from HeNB to HeNB, a general model is proposed for the different types of mobility mentioned above.

c) It is assumed that handover will occur if UE moves across the border of the source (H)eNB and target (H)eNB without considering other conditions in the model.

d) It is assumed that UE moves to eNB or HeNB with equal probability.

e) It is assumed that sessions arrivals follow Poisson process with average arrival rate $\lambda$.

Two scenarios are considered in handover between source (H)eNB and target (H)eNB. Scenario 1: an UE who initializes a session under the coverage of the source (H)eNB remains in the active state before moving out of the source (H)eNB cell; scenario 2: an UE in active state moves across the macrocell/femtocell, whose session initializes out of macrocell/femtocell, and finally moves out of the macrocell/femtocell, as shown in Fig. 5 [4][10][11]. The probability of the handover happens on the border of the macrocell/femtocell is the sum probability of scenario 1 $P_{s1}$ and scenario 2 $P_{s2}$.

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

Let $T_{C1}$ denotes the UE’s camp time in the (H)eNB cell in scenario 1, that is, the time from an active UE initializes the session in the (H)eNB cell to the time it leaves the (H)eNB cell. $T_{C2}$ is denoted as the UE’s camp time in the (H)eNB cell in scenario 2, which is an active UE who initializes the session out of the (H)eNB cell comes into the (H)eNB cell to the time it leaves the (H)eNB cell; while $T_{SH}$ and $T_{SHR}$ are the session holding time in scenario 1 and scenario 2 respectively.

$T_{SHR}$ is the session holding residual time in scenario 2, while $\delta$ is the time from an UE starting a new session to entering a (H)eNB, as showed in Fig. 5.

$T_{C1}$ and $T_{C2}$ are exponentially distributed with the mean of $1/\mu$, $T_{SH}$, $T_{SHR}$ and $T_{SHR}$ are exponentially distributed with the mean of $1/\eta$. The camp time and session holding time are independent random variables. Since the sessions arrivals follow
Poisson process with average arrival rate $\lambda$, the probability of
one session arrives in a time period $t$ is $\lambda e^{-\lambda t}$.

Based on the assumptions mentioned above [4][10][11], the
closed-form expression of $P_{s1}$ and $P_{s2}$ can be derived as
follows:

$$\begin{align*}
P_{s1} &= P(t_1 < t_2 < t_3) \cdot P(T_{H}^{1} > T_{C}^{1}) \\
&= \int_{0}^{\infty} \lambda t e^{-\lambda t} f_{H}^{1}(t) dt \cdot \int_{t}^{\infty} \mu e^{-\mu t} dt \int_{t}^{\infty} \eta e^{-\eta x} dx \\
&= \lambda \mu \int_{0}^{\infty} t e^{-(\lambda + \mu)t} dt \cdot \int_{0}^{\infty} \mu e^{-(\lambda + \mu)t} dt \int_{0}^{\infty} \eta e^{-\eta x} dx dt \\
&= \lambda \mu \int_{0}^{\infty} \mu e^{-(\lambda + \mu)t} dt \cdot \int_{0}^{\infty} \eta e^{-\eta x} dx dt \\
&= \lambda \mu \int_{0}^{\infty} \mu e^{-(\lambda + \mu)t} dt \\
&= \lambda \mu \frac{1}{(\lambda + \mu)^2 (\mu + \eta)} \\
&= \lambda \mu \frac{1}{(\lambda + \mu)^2 (\mu + \eta)}^{(2)} \
\end{align*}$$

$$\begin{align*}
P_{s2} &= P(t_1 < t_2 < T_{H}^{1}) \cdot P(T_{H}^{1} > T_{C}^{1}) \\
&= \int_{0}^{\infty} \lambda t e^{-\lambda t} f_{H}^{1}(t) dt \cdot \int_{0}^{\infty} \mu e^{-\mu t} dt \int_{t}^{\infty} \eta e^{-\eta x} dx dt \\
&= \lambda \mu \int_{0}^{\infty} t e^{-(\lambda + \mu)t} dt \cdot \int_{0}^{\infty} \mu e^{-(\lambda + \mu)t} dt \int_{0}^{\infty} \eta e^{-\eta x} dx dt \\
&= \lambda \mu \int_{0}^{\infty} \mu e^{-(\lambda + \mu)t} dt \cdot \int_{0}^{\infty} \eta e^{-\eta x} dx dt \\
&= \lambda \mu \int_{0}^{\infty} \mu e^{-(\lambda + \mu)t} dt \\
&= \lambda \mu \frac{1}{(\mu + \eta)^2}^{(3)} \
\end{align*}$$

The handover signalling overhead can be divided into
transmitting overhead and processing overhead. The signalling
overhead in the HeNB related handover are list as follows:
$P_{HeNB}$ is denoted as the signalling processing overhead at
HeNB; $P_{NB}$ is denoted as the signalling processing overhead at
eNB; $P_{MME}$ is denoted as the signalling processing overhead at
MME; $P_{UE}$ is denoted as the signalling processing overhead
at UE, which contains the detached time in the
handover; $P_{HeNB_GW}$ is denoted as the signalling processing
overhead at HeNB Gateway; $T_{HeNB}$ is denoted as the trans-
mitting overhead between UE and (H)eNB; $T_{HeNB_GW}$ is
denoted as the transmitting overhead between HeNB gateway
and HeNB; $T_{MME}$ is denoted as the transmitting overhead
between HeNB gateway and MME/S-GW; $T_{HeNB_GW}$ is
denoted as the transmitting overhead between HeNB gateway
and eNB; $T_{HeNB}$ is denoted as the transmitting overhead
between eNB and HeNB; $T_{HeNB}$ is denoted as the trans-
mittinng overhead between HeNBs; $T_{MME}$ is denoted as the
transmitting overhead between eNB and MME.

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

$$O = P \left( \sum T_{j}^{i} + \sum P_{k} \right)$$

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 overhead
in the scenario.

V. PERFORMANCE EVALUATION

In order to verify the performance of the algorithms pre-
seved in this paper, we compare the proposed algorithm with
the 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 [4][12], the overhead 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 overhead parameters are possible. Here we use the
parameters in table presented in [4] as follows:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$P_{HeNB}$</th>
<th>$P_{UE}$</th>
<th>$P_{HeNB_GW}$</th>
<th>$P_{NB}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>2</td>
<td>40</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$P_{MME}$</th>
<th>$T_{HeNB}$</th>
<th>$T_{HeNB_GW}$</th>
<th>$T_{MME}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table I

PARAMETER VALUES FOR SIGNALLING COST EVALUATION

![Fig. 6 shows the signalling overhead versus average session
arrival rate $\lambda$ with $1/\mu = 2$ minutes, $1/\eta = 2$ minutes.
From the figure, it can be seen that as the average session
arrival rate increases, the signalling overhead in both HeNB-
HeNB and eNB-HeNB for all the possible options increase.
This is because more handovers occur with the increase of
the session arrivals. The figure also shows that option 2 in
HeNB-HeNB scenario has lower signalling overhead than
option 1/option 3, this is because that handover in option2
does not involve the HeNB-GW routing delay, but with the
direct X2 interface introduced between HeNBs, which also
shortens the delay required to send a signalling message.
Similarly, direct X2 interface based option 2 has the lowest
signalling overhead in eNB-HeNB scenario’s three HeNB
mobility options, while X2-GW based option 3 has a medium
performance of signalling overhead.

Fig. 7 shows the signalling overhead versus the average session
holding time with the value of $\lambda$ set as 0.1. As seen in the
figure, the total signalling overhead increases as the average
session holding time increases. The reason is that the bigger of
Average session arrival rate \( \lambda \) (sessions/minute)

Fig. 6. Signalling overhead versus average session arrival rate \( \lambda \)

the session holding time, the bigger of the cell-boundary crossing’s probability, introduces a higher probability of handover. Similar to the Fig. 6, option 2 in HeNB-HeNB scenario has the smallest handover overhead while option 1 in eNB-HeNB scenario has the worst signalling overhead performance.

Because MME is not involved in the options based on X2-GW and direct X2, the signalling load of handover impact on MME is drastically decreased. Due to possible co-deployment of X2 interface and S1 interface in HeNB-HeNB option 3 and eNB-HeNB option 3, the possible mutual authentication between HeNBs or eNB-HeNB can be achieved by S1 and MME, even by the HeNB-GW. While in direct X2 based options, due to the direct X2 interface between HeNBs or eNB-HeNB, if the function of mutual authentication between HeNBs or eNB-HeNB not deployed, the security problem would be a key factor for the deployment of X2 interface between HeNBs or eNB-HeNB, since the security is important for most of the deployment scenarios (e.g. enterprises).

From the comparison of the HeNB mobility enhanced options, the conclusion was drawn as follows: X2-GW based option 3 has strength in security and compatible between eNB-HeNB and HeNB-HeNB, while direct X2 based option 2 has better performance in signalling load reduction.

VI. CONCLUSION

In this paper, different HeNB mobility enhancement options were introduced firstly. Then, based on the handover procedure for each option, signalling overhead was evaluated using the analysis model. Afterwards the comparison with the traditional HeNB mobility architecture shows that the mobility enhanced architectures have a better performance in handover signalling overhead. Option 2 and option 3 in HeNB-HeNB scenario are the promising solutions with little drawbacks, while option 3 is optimal in eNB-HeNB scenario. For eNB-HeNB option 2, though the solution reduces the signalling significantly, the complexity of the mass X2 deployment needed between eNB-HeNB reject the option.

ACKNOWLEDGMENT

This work was supported by the Sci-tech Projects sponsored by the Committee on Science and Technology of Beijing (D08080100620802, Z101101004310002), the National Natural Science Foundation of China (60743007), and National Key Technology R&D Program of China (2010ZX03003-001-01).

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