User Plane and Control Plane Separation Framework for Home Base Stations

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Home base stations (HBSs), which are considered to be useful extensions to mobile operators' networks, are a promising solution for many issues in mobile communication networks, such as coverage, capacity, and cost. They deliver a great user experience for services in the home or in office buildings using customers' broadband access for backhaul. However, connecting to the mobile operators' networks via the Internet brings uncertain delay and hence unreliability into the HBS access architecture, especially the impact on the handover between an HBS and the surrounding base stations. In this paper, we investigate the handover management performance in a typical HBS deployment scenario by analysing the handover procedure durations. A user plane and control plane separation framework is proposed to support uncoordinated HBS integration with the mobile network through unmanaged, generic Internet protocol networks.

1. Introduction

A home base station (HBS), sometimes also called a femtocell, is considered to be a promising solution for many issues in mobile communication networks, such as coverage, capacity, and cost. HBSs deliver a great user experience for services in homes or in office buildings, at very low cost, using customers' broadband access (such as via digital subscriber line or cable television) for backhaul. Intensive discussion of HBSs is underway in standardisation bodies such as the 3rd Generation Partnership Project (3GPP) for both the 3G HBS (called Home Node B [HNB]) and the LTE HBS (called Home evolved node B [HeNB]), where 3G stands for third generation and LTE stands for Long Term Evolution. In this paper, we concentrate on HBSs for LTE networks, i.e., HeNBs.

The 3GPP's work item on LTE is E-UTRAN (Evolved UMTS [Universal Mobile Telecommunications System] Terrestrial Radio Access Network). A typical HeNB deployment scenario involving E-UTRAN is illustrated in **Figure 1**. The HeNB interconnects with the LTE Evolved Packet Core (EPC) over a fixed-line broadband access network. Similar to the macro evolved node Bs (eNodeBs or eNBs; hereinafter, we use eNBs)[1),2)], the HeNBs are also connected via the S1 interface to the EPC. More specifically, the HeNB is connected to the Mobility Management Entity (MME) via the S1-MME interface, which provides the control functions for *Idle* mode user equipment (UE) reachability and *Active* mode UE handover support. Furthermore, the HeNB is connected to the Serving Gateway (S-GW) via the S1-U interface. In addition, the eNBs (both macro eNBs and HeNBs) may be interconnected with each other via the X2 interface.

In a typical HeNB deployment scenario, extra delay (due to the Internet link) is introduced into the links between the MME or S-GW and HeNBs and between HeNBs and

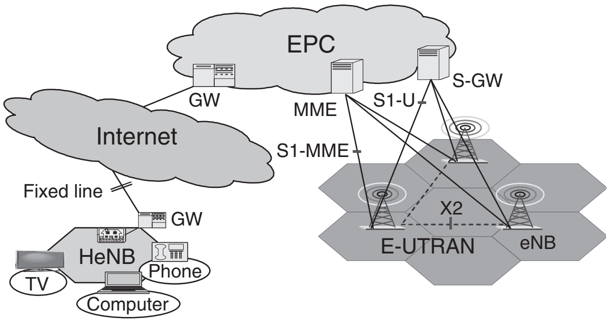


Figure 1
Typical HeNB deployment scenario.

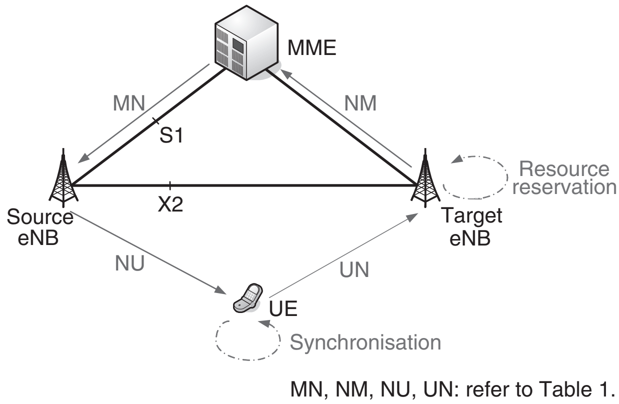


Figure 2
Configuration for intra-LTE handover mechanism.

eNBs. Connecting to the operators' networks via the Internet introduces uncertain delays and hence unreliability into the HNB/HeNB access architecture.

In the work described in this paper, we investigated the handover management performance in a typical HNB/HeNB deployment scenario by analysing the handover procedure durations. A user plane (UP) and control plane (CP) separation framework is proposed to support uncoordinated HNB/HeNB integration with the mobile network through unmanaged, generic Internet protocol (IP) networks. The rest of paper is organised as follows. The related CP delay budget and the message flow charts for the handover procedures, as well as the handover delays for different scenarios are analysed in Section 2. The proposed UP/CP separation framework is introduced in Section 3. The conclusions and main benefits of the proposed framework are summarised in Section 4.

2. Handover duration analysis

To investigate the handover management performance, we analysed the following handover scenarios in terms of the S1 handover procedure duration:

- LTE macro -> LTE HeNB
- LTE HeNB -> LTE macro
- LTE HeNB -> LTE HeNB

Table 1
CP delay budget in E-UTRAN.

Abbr.	Description	Delay budget
MN	Transmission from MME to eNB (7 ms) and processing in eNB (2 ms)	9 ms
NM	One-way transmission from eNB to MME (7 ms) and processing in MME (2 ms)	9 ms
NU	One-way transmission from eNB to UE (2 ms) and processing in UE (2 ms)	4 ms
UN	One-way transmission from UE to eNB (2 ms) and processing in eNB (2 ms)	4 ms
RR	Resource reservation in eNB	5 ms
Sync	Synchronisation time at UE	20 ms

2.1 Delay budget

2.1.1 Delay budget in E-UTRAN (macro eNBs)

The configuration for an intra-LTE handover mechanism in shown in **Figure 2**. The intra-LTE handover is a UE-assisted network-controlled handover. Here, part of the handover command comes from the target eNB and is transparently forwarded to the UE by the source eNB, the source eNB passes all necessary information to the target eNB to prepare the handover, the UE synchronises with the target cell, and the target eNB sends a PATH SWITCH message to the MME to inform it that the UE has changed cell.

We investigated the CP delay budget in E-UTRAN. The applied one-way transmission times and the associated processing times are summarised in **Table 1**. We assumed that the processing times in the UE, eNB, MME, and S-GW are 2 ms each. The one-way transmission delay for the downlink from eNB to UE and uplink from UE to eNB were assumed to be 2 ms each. We also assumed that the synchronisation time at the UE is 20 ms.

Note that in this study, we aimed to analyse the handover procedures on the CP. Therefore, the values were chosen to be higher than the UP latency values found in Reference 1). All the conclusions made later on are also valid for lower values.

2.1.2 Delay budget in HeNB scenarios

In a typical HeNB deployment scenario, extra delay (due to the Internet link) is introduced into the links between the MME and HeNBs, and between HeNBs and eNBs. The delay budget in HeNB scenarios is given in **Table 2**, assuming that the average one-way Internet delay is $D_{internet}$ (ms).

2.2 Intra-LTE S1 handover

The intra-LTE S1 handover procedure where MME is involved is defined in ref. 2). As shown in **Figure 3**, during the S1 handover procedure, the handover preparation phase is initiated by the Source eNB by sending a

Table 2
Delay budget in HeNB scenarios.

Abbr.	Description	Delay budget
MH	Transmission from MME to HeNB ($D_{internet}$ ms) and processing in HeNB (2 ms)	($D_{internet}$ + 2) ms
HM	One-way transmission from HeNB to MME ($D_{internet}$ ms) and processing in MME (2 ms)	($D_{internet}$ + 2) ms
HU	One-way transmission from HeNB to UE (2 ms) and processing in UE (2 ms)	4 ms
UH	One-way transmission from UE to HeNB (2 ms) and processing in HeNB (2 ms)	4 ms
RR	Resource reservation in HeNB	5 ms
Sync	Synchronisation time at UE	20 ms

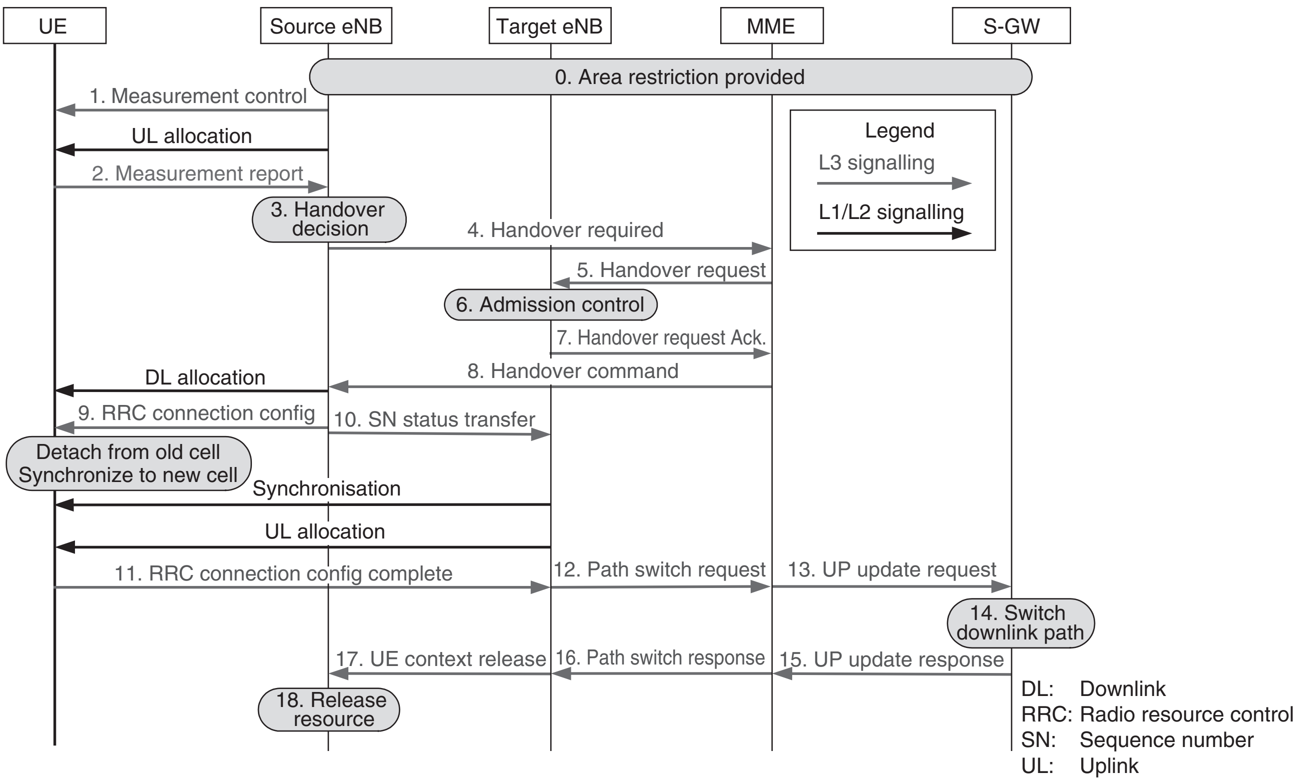


Figure 3
Handover procedure with MME involvement (S1 handover).

HANDOVER REQUIRED message to the MME to initiate the handover via the S1 interface, and it is finished upon reception of the *HANDOVER COMMAND* message in the Source eNB. The handover execution phase mainly includes the procedures where the UE detaches from the Source eNB and attaches to the Target eNB. The handover procedure is completed by "Path Switch" procedures that allow the core network to update the UP paths with the S-GW.

2.2.1 Handover procedure duration

In this study, we examined four handover cases to investigate the S1 handover procedure duration (**Table 3**). In case 4, which is treated as a reference case for comparison, handover takes place between two macro eNBs.

We also assumed that the S1 handover procedure duration starts when the Source eNB sends out "Handover Required" and ends when the MME receives "Path Switch Request".

<u>*S1 handover duration*</u>

Case 1: $D_{S1} = 3HM + 2MH + HU + UH + RR + Sync$

Case 2: $D_{S1} = NM + MN + 2HM + MH + NU + UH + RR + Sync$

Case 3: $D_{S1} = HM + MH + 2NM + MN + HU + UN + RR + Sync$

Case 4: $D_{S1} = 3NM + 2MN + NU + UN + RR + Sync$

Here, HM, MH, HU, UH, RR, Sync, NM, MN, NU, and UN are defined in Tables 1 and 2.

Table 3
Handover cases.

Target eNB \ Source eNB	HeNB	Macro eNB
HeNB	case 1	case 2
Macro eNB	case 3	case 4

2.2.2 Numerical results

The effect of Internet delay on the handover procedure duration was investigated. The durations for four handover cases are shown in **Figure 4**.

With increasing Internet delay, the duration for S1 handover between macro eNBs remained unchanged, while the duration increased in all the other three handover cases involving HeNB. In general, S1 handover duration is greater when a UE is handed over to an HeNB than to a macro eNB. The worst case occurs when the handover is between HeNBs.

3. UP/CP separation framework

In the light of the above observations, we can see that in general the performance of LTE HeNBs in terms of latency is not reliable. It is particularly critical for control signalling that maintains the communication between HeNBs and the operator's network. To tackle this issue,

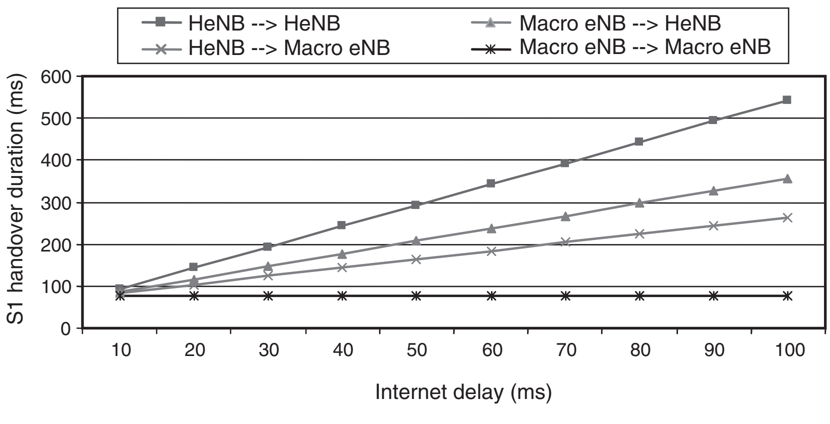


Figure 4
S1 handover procedure durations.

we propose a UP/CP separation framework for the LTE HeNB.

3.1 Overview

The LTE HeNB functional architecture is shown in **Figure 5**. The key consideration for the proposed architecture is the route split between the HeNB's CP and UP. In this architecture, we propose that the HeNB provides the S1 CP functionalities via the relay eNB (e.g., by microwave transmission). As shown in the figure, the S1-MME interface between HeNB and MME is relayed through an eNB, while the S1-U interface between HeNB and S-GW is set up through the public network (e.g., the Internet).

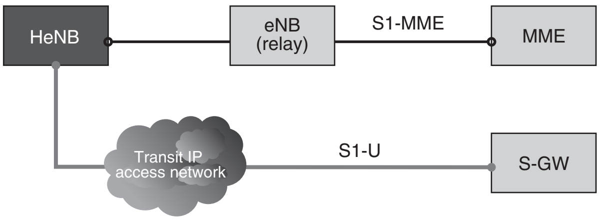
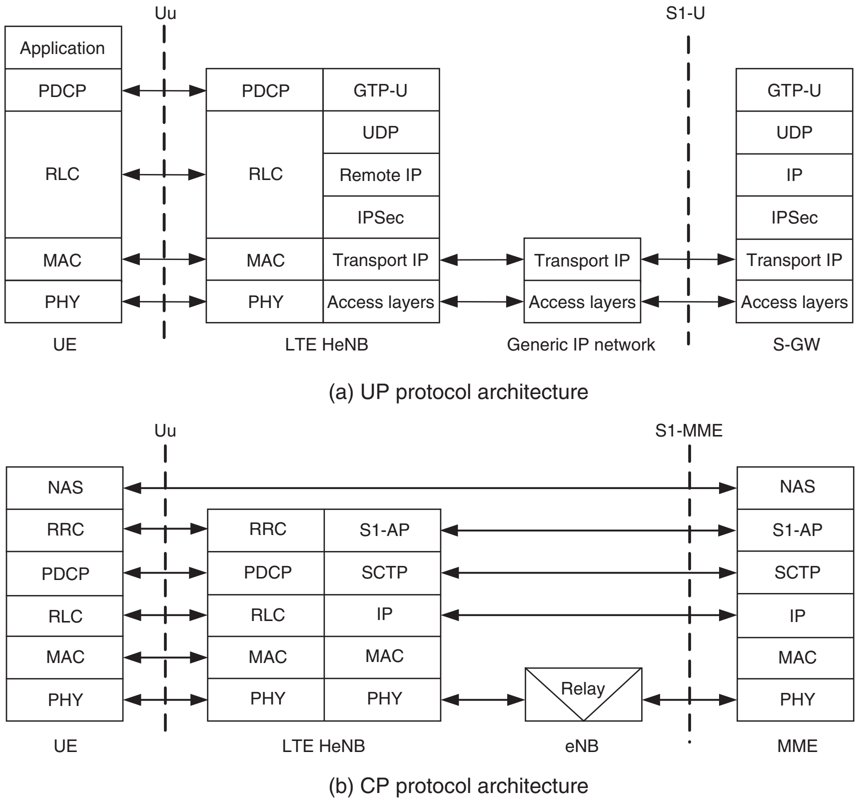


Figure 5
LTE HeNB architecture with UP and CP separation.

The UP protocol architecture for S1-U[3] is shown in **Figure 6 (a)**, where a GTP-U tunnel (GPRS [general packet radio service] tunnelling protocol for UP) is set up between HeNB and S-GW.[4] For security reasons, a secure IPSec (IP security) tunnel is set up between the HeNB and the core network for mutual authentication,



MAC: Media access control
NAS: Non-access stratum
PDCP: Packet data convergence protocol
PHY: Physical layer
RLC: Radio link control
S1AP: S1 application part
SCTP: Stream control transmission protocol
UDP: User datagram protocol
Uu: Interface between UE and LTE HeNB

Figure 6
LTE HeNB UP/CP protocol architecture.

encryption, and data integrity.

The CP protocol architecture for S1-MME[5] is shown in **Figure 6 (b)**, where a macro eNB relays all the signalling messages between the HeNB and an S-GW. The method by which the HeNB links to a relaying macro eNB is outside the scope of this paper.

3.2 Performance evaluation

The performance of the proposed framework was evaluated by analysing the S1 handover procedure duration for the handover cases listed in Table 3. The delay budget in the proposed framework is summarised in **Table 4**. We assumed that the one-way transmission delay between the HeNB and its relaying eNB is 5 ms and that the one-way transmission delay between the HeNB and the MME via the relaying eNB is 10 ms.

We compared the S1 handover procedure duration in the proposed framework with that in a typical deployment scenario. The results, shown in **Figure 7**, compare S1 handover durations for the worst case "handover between HeNBs" for a typical HeNB architecture and the proposed CP/UP separation framework.

In general, compared with the existing mechanism, the proposed CP/UP separation framework demonstrates an obvious advantage in terms of S1 handover procedure duration. With increasing Internet delay, the S1 handover duration increases in the typical HeNB deployment scenario whereas it remains the same in the proposed framework. In general, the S1 handover duration is greater in a typical HeNB deployment than in the proposed framework. With increasing Internet delay, the gap between these two widens significantly.

Table 4
Delay budget in CP/UP separation framework.

Abbr.	Description	Delay budget
MH`	Transmission from MME to HeNB via eNB (10 ms) and processing in HeNB (2 ms)	12 ms
HM`	One-way transmission from HeNB to MME via eNB (10 ms) and processing in MME (2 ms)	12 ms
HU	One-way transmission from HeNB to UE (2 ms) and processing in UE (2 ms)	4 ms
UH	One-way transmission from UE to HeNB (2 ms) and processing in HeNB (2 ms)	4 ms
RR	Resource reservation in HeNB	5 ms
Sync	Synchronisation time at UE	20 ms

4. Conclusion

In this paper, we discussed the S1 handover procedure duration in different HeNB handover scenarios. In a typical HeNB deployment scenario, HeNB interconnects with the EPC over a fixed-line broadband access network and through the Internet. Extra delay (due to the

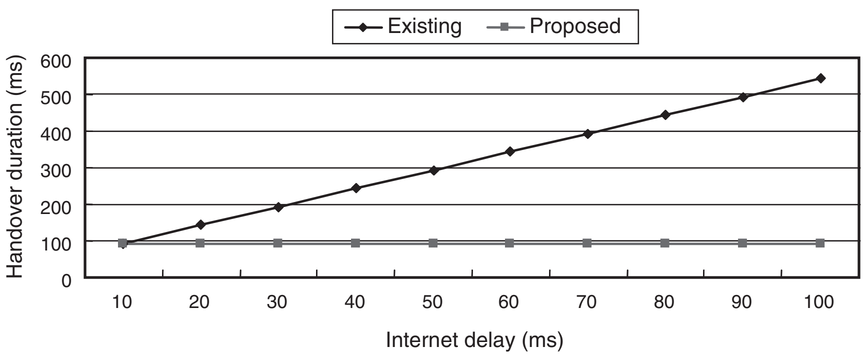


Figure 7
Comparison of S1 handover durations between HeNBs based on existing and proposed approaches.

Internet link) is introduced into the links between S-GW/MME and HeNB, and between HeNB and eNB/HeNB.

The numerical results show that with increasing Internet delay, the S1 handover duration increases in handover cases that involve an HeNB. In the case of S1 handover, the handover duration is greater for handover to an HeNB than to a macro eNB. The worst case (longest duration) occurs when the handover is between HeNBs.

To guarantee reliable communication in terms of the control signalling exchange between HeNBs and MMEs, a UP/CP separation framework for the HeNBs was proposed. The performance evaluation results show that this framework demonstrates an obvious advantage in terms of S1 handover procedure latency compared with the existing mechanism.

In general, the proposed architecture provides the following benefits for supporting uncoordinated HeNB integration into the mobile network through unmanaged, generic IP networks:

- Reliable CP signalling delivery via a macro eNB relay. This is particularly important for femtocell enterprise deployment scenarios, where reliability is crucial for business customers.
- Flexible UP data delivery via a public network (e.g., the Internet) at very low cost. Using public transportation for UP data delivery supports various application services in homes, on campuses, or in offices at very low cost. It also has great potential to create a totally new set of services in a “connected home”, “connected classroom”, or “connected office”.
- The proposed framework does not require the introduction of a new node into an operator’s network, so the effect on existing standards is minimal. This is important in order to protect the investments of operators.

References

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