東海大學資訊工程研究所

碩士論文

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利用 GPS 輔助的 LTE 無線網路換手機制

A handover scheme for LTE wireless networks under the assistance of GPS

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利用 GPS 輔助的 LTE 無線網路手機制

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摘要

隨著行動裝置的蓬勃發展，行動裝置對於高速網路的品質要求也明顯地比以前高上許多。許多研究人員正盡全力地發展各種不同的通訊方法和通訊服務來服務使用者。同時，行動裝置熱門程度在最近幾年也飛快的成長。另一方面，從 2008 年 LTE 網路被發表以來，直到現在它都還是受到大家矚目。在 LTE 中，行動裝置 UE 從基地台 A 移動到基地台 B 時，LTE 需要協助它執行換手程序，俾讓 UE 順利地從基地台 A 換手到基地台 B，使得行動裝置能夠在保持連線的狀態下繼續移動。如果換手的工作沒有成功地完成，UE 必須重新連接到網路，使用者將會感覺到大量的通訊延遲。現階段決定是否換手仍然還是以無線電波之強弱為主要的參考依據。不過仍然會存在許多問題。這是因為無線電波的特性使然，舉凡行動裝置的位置、移動速度、移動方向都很有可能影響電波的強度。因而在這篇研究當中，我們使用了 GPS 系統來輔助 LTE 之換手機制，並以 UE 當前之狀態，如：移動方向、移動速度、信號強度、距離等因素來決定欲換手的對象，使得 UE 能夠更精準的找到最合適的換手對象，進而提昇 LTE 整體的運作效率。

Keywords: long term evolution, handover, gps, target selection, homogeneous handover

Abstract

With the rising popularity of mobile networks, the requirements of accessing wireless services through mobile devices have been significantly higher than before. Many researches have developed different communication functions and applications to serve users. The population of mobile users increases significantly in recent years. Also, since 2008 Long Term Evolution (LTE for short) has attracted researchers' attention. When a user equipment (UE for short) moves from an evolved Node B (eNB for short) to another, the LTE needs to help the UE to hand over from the serving eNB(SeNB for short)and target eNB(TeNB for short) by managing the provided resources so that the connection between the UE and the SeNB(TeNB) can be well maintained. If handover is incompletely performed, the UE may need to re-enter the network. If it is true, then users will experience a longer communication delay. In face, the connection may also be disconnected. Currently, the radio issue is still considered as the key factor that affects the time consumed by the handover procedure. However, it is insufficient if we only measure the strength of the radio that the UE receives from its SeNB to determine whether UE needs to hand over or not since the UE's location, moving speed and moving direction are also important factors that may affect the handover quality. In this study, we employ the information provided by a GPS and use several status parameters, e.g, UE's location, moving speed, moving direction and distance to help the determination of TeNB for LTE systems during handover so as to more accurately choose the most suitable TeNB and improve handover performance.

Keywords: long term evolution, handover, gps, target selection, homogeneous handover

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1 Introduction

With the rising popularity of wireless network technology, the functions of mobile devices have been vigorously developed. Today, many people access Internet via mobile devices, e.g., smart phones and tablets, to transmit their e-mails, receive online video streams and access web services almost every day[3]. However, the Internet services are also evolved from static to dynamic. To access them, users need fast wireless networks and download speeds. Currently, the wireless services and resources provided by 3G wireless system, e.g., WCDMA/HSDPA[4], cannot sufficiently satisfy the hungriness of transmission rates. Therefore, some technologies are developed to provide 4G services, e.g., WiMAX (802.16m)[5] and Long Term Evolution Advanced (LTE-A for short)[6]. The latter now is the trend of wireless systems. On the other hand, handover[7] is a process which manages the mobility of user equipment (UE for short) to firmly keep the connection of the communication link between UE and evolved Node B (eNB for short). When UE is moving from the serving area of eNB1 to the serving area of eNB2, eNB1 sends all information of radio resources and the connection information of the link between UE and eNB1 to eNB2. Consequently UE does not need to redo the LTE Attach process when it arrives at the serving area of eNB2. So UE will not experience obvious latency.

Generally, the communication environment may deeply affect the handover quality[8]. But such an environment keeps changing. So to avoid conducting a long handover delay, the handover process needs to acquire environmental parameters, e.g., signal strength, UE's location, etc., and continuously monitor the environment. In fact, UE may stay in an area served by multiple eNBs. If we select an unsuitable eNB as the TeNB to hand over, this may increase the communication overhead and waste radio resources since the next handover may come much earlier, or soon after the handover. The communication quality will be poor. So how to select a suitable TeNB from multiple candidates is a challenge.

If we like to improve the LTE handover quality, handover time should be accurately controlled, particularly when we would like to ensure a seamless handover. Seamless handover implies that UE will not experience any obvious delay during handover. The communication can be proceeded as smooth as that in the case in which handover has never occurred. However, if the handover quality is poor, and UE is accessing a latency-sensitive service, such as a voice call, the quality of the service will be low.

Therefore, in this study, we propose a novel handover mechanism, named Predicting-based Handover Scheme (PreHS for short), to substitute for the existing procedure used by the LTE-A, aiming to select the most suitable TeNB for UE. The essential task of the PreHS is gathering environmental data for the candidate eNBs. We also like to change partial behaviors of handover so as to improve its performance.

The rest of this paper is organized as follows. Section 2 describes the related works of this study. Section 3 introduces the proposed system. Performance is analyzed and discussed in Section 4. Section 5 concludes this study and outlines our future studies.

2 Related-works

2.1 LTE Architecture

As shown in Figure 1, LTE is composed of UEs[9], eNBs[10] and Evolved Packet Core network[1] (EPC for short). UE is a terminal device, EPC is the core network and eNB is a base station. To compare it with 3G, the 4G LTE(i.e., LTE-A) aims to be as simple as possible to reduce the complexity of its system architecture. In the LTE-A, messages can be classified into Control Plane messages and User Plane messages[11], which are forwarded through different routing paths. The interface between two adjacent eNBs is X2 protocol, whereas eNBs are connected to EPC via S1 interfaces. EPC is composed of Mobility Management Entity (MME for short), Serving Gateway (S-GW for short) and Packet Data Network Gateway (PDN-GW for short). The MME as the major

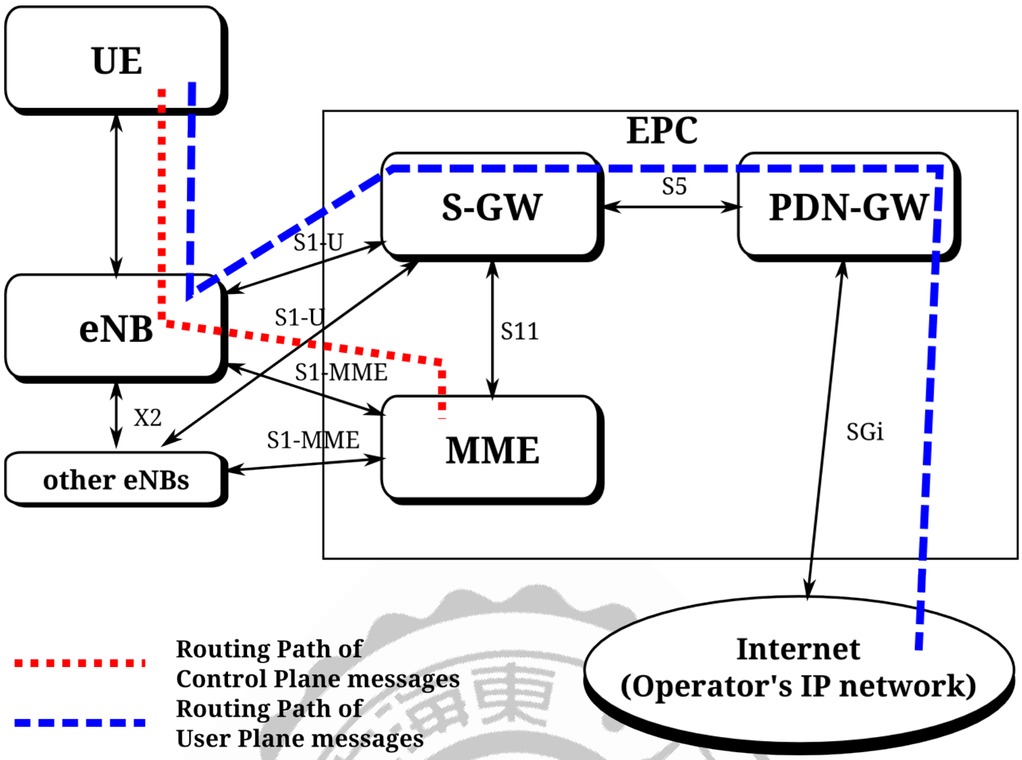


Figure 1: The LTE Architecture[1]

part of EPC is responsible for dealing with message processing and delivery, mobility management and authentication of control plane. The S-GW takes charge of routing and forwarding user plane messages. The PDN-GW provides the connectivity between UE and the external network. The S1-interface allows multiple eNBs to link themselves to multiple MMEs. When an eNB wishes to communicate with another, but currently there is no available X2 interface, the data will be sent to MME through S1 interface. MME then forwards the data to the destination eNB.

2.2 Measurement

Measurement is a mechanism that provides LTE-A with the ability to gather the instant radio information of UE and eNBs. Measured information is sent by UE to SeNB according to the measurement configuration provided by LTE-A. In LTE-A, UE has two cases in which it will send the measurement reports to eNB, i.e., event-triggered and periodical. When it is triggered by an event, the UE sends a measurement reports containing the strength of Reference Signal Received Power(RSRP for short) to SeNB. Otherwise, the measurement reports are sent periodically. Therefore, the event-triggered is more flexible and common than periodical. Therefore, in this study, we choose it as the default case. When RSRP cannot be gathered be eNB due to some reasons, like if RSRP is too weak so that UE cannot send/organize a measurement report, LTE-A then tries a "blind handover". To avoid this since it may result in an unstable handover, we need to propose a new method to assist the measurement.

2.3 LTE Handover Procedure

LTE handover is a complicated procedure which will be described as follows.

Step 1. UE sends a measurement report which contains necessary information for handover to SeNB based on the system policy: Periodically or Event-Triggered[12].

Step 2. On receiving the report, SeNB determines whether handover of UE is required or not according to the context of the measurement report. If the answer is yes, SeNB selects the TeNB and sends *HANDOVER_COMMAND*, which contains the information required by UE for connecting itself to TeNB, to UE.

Step 3. Upon receiving this command, UE starts handing over to TeNB based on the steps of the handover algorithm choosen by PreHS.

Step 4. TeNB registers the new routing path between UE and TeNB with the MME, SeNB delivers its buffered data received from the UE's corresponding node (CN for short) to the TeNB and releases the resources currently provided to serve the UE.

Step 5. Done.

In the LTE-A, UE gathers statuses of its neighbor eNBs, including these statuses contained in the measurement report mentioned in Step 1. The report contains at least the RSRP, and Reference

Signal Received Quality(RSRQ for short) UE receives from its SeNB. Based on the RSRP and the RSRQ, SeNB judges whether handover is necessary or not. If yes, SeNB in Step 2 selects an eNB as the TeNB. In Step 3, the handover starts. Step 4 completes the remaining tasks mentioned above.

A standard LTE handover process can be classified into three parts: Preparation, Execution and Completion. Handover Preparation is composed of Steps 1 and 2, while Handover Execution (Completion) contains Step 3 (Step 4). In the following, we will introduce a new classification to substitute for the standard one of LTE-A. The purpose is to improve the LTE-A's handover quality and performance.

3 Our LTE-A Handover Approach

3.1 The improved handover implementation

LTE-A handover can be classified into two types: X2-based[13] and S1-based[14]. X2-based handover is employed when handover is required and there is an available X2-interface between the UE's SeNB and TeNB. If currently no X2-interface is available due to some reasons, like the case in which there are no X2 connections between the SeNB and the TeNB, S1-based handover is the only choice. To simplify the following description, we use X2-based handover as the default type of handover and assume that every eNB is connected to each other via X2-interface.

LTE-A handover usually occurs when SeNB receives a measurement report showing that the RSRP/RSRQ the UE receives is too low. When UE enters the serving area of TeNB, if handover process has not been successfully performed, it has to re-perform the LTE Attach which is usually more expensive than an LTE-A handover, and will conduct a long handover delay.

In fact, the strength of RSRP/RSRQ received is often not stable. It is easily affected by UE's surrounding environment, like shaded by buildings and interferenced by noises. So it is unsuitable

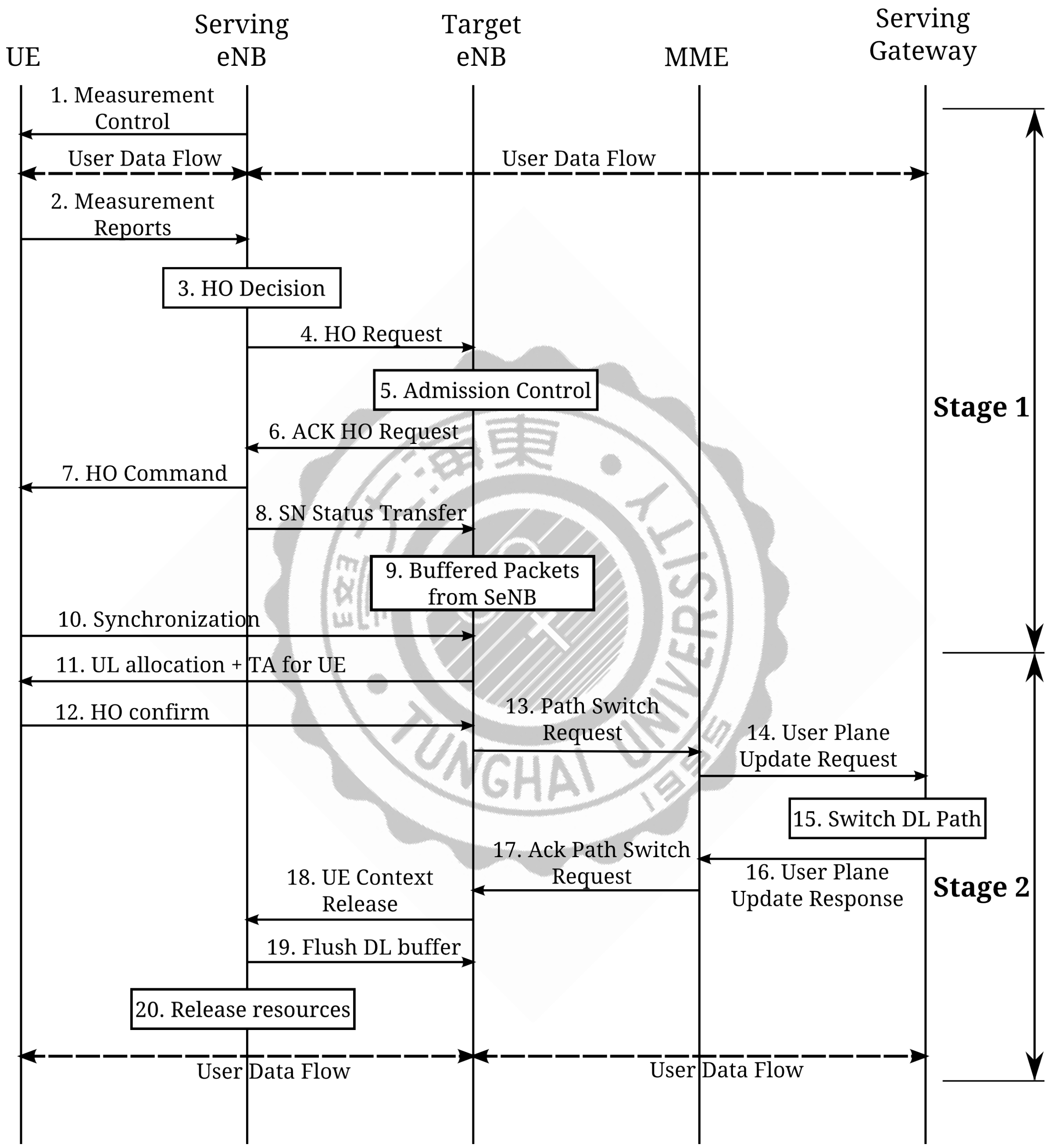


Figure 2: The X2-based Handover procedure[1]

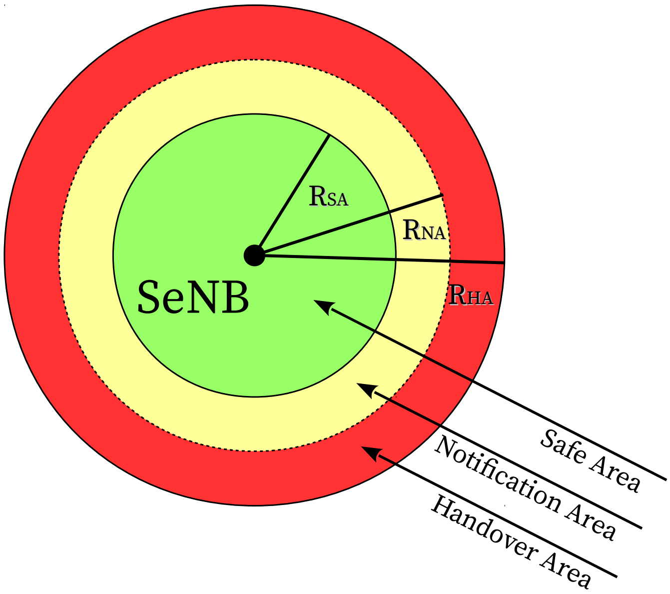


Figure 3: The concentrical areas with different radiuses of an eNB

to consider RSRP/RSRQ as the only factors when determining whether handover is required or not. The movement of UE may also change strength of the received RSRP. If the distance between UE and its SeNB is longer, the RSRP will be weaker.

Generally, LTE-A uses a traditional Power Budget Handover Algorithm (PBGT for short)[15] to judge whether an UE should handover or not. However, this algorithm may conducts longer handover delays.

Comparing with the original handover, our LTE-A handover gathers UE's location by using a GPS system. LTE-A handover may occur suddenly, e.g., weak RSRP/RSRQ or load balancing. The latter is the case in which an overloaded eNB, e.g., eNB1, forces those UEs currently located in the overlapped area between eNB1 and its neighbor eNBs to connect to the neighbor eNBs. The location of a moving UE is not easy to predict. So monitoring UE's location and moving information with GPS and gathering RSRP/RSRQ are helpful. In this way, the drawback of determining whether handover should be performed only based on the RSRP/RSRQ can be solved. Thus, the measurement report needs to be expanded to include the data collected from GPS systems.

3.2 Definitions of Areas

In our study, the communication coverage area of an eNB as shown as in Figure 3 is divided into three areas of different radiuses. From inside to outside, they are Safe Area (SA for short), Notification Area (NA for short), Handover Area (HA for short).

(1)Safe Area (SA): In this area, the RSRP/RSRQ between the UE and the SeNB should be higher than those in NA and HA. So we assume that handover will not soon occur. The measurement policy will be set to 'Event-trigger', meaning only special events can trigger handover. For example, the RSRP/RSRQ goes down since there is an iron barrier located between UE and SeNB. Thus the SeNB should check the RSRP/RSRQ reported by UE. If one of them is lower the predefined threshold, the SeNB should prepare to hand over much earlier to avoid the association between the UE and the SeNB being disconnected.

(2)Notification Area (NA): When UE is moving from SA to NA, indicating that the handover will soon occur. So measurement policy will be set to 'Periodic'. Now the Report should contain the moving direction and speed. Meanwhile, the SeNB will choose some of its neighbor eNBs as the Candidate eNBs(CeNB for short) and notify them to reserve resources for UE's handover. This is the essential portion of our approach. The purpose is to well maintain the association between UE and SeNB. In this study, we develop a 'Preparation precedure' which triggers handover much earlier than the LTE-A regular handover does. Because a handover delay usually consumes less than 200ms(even 100ms)[16]. These resources are reserved in such a short time period. But the reservation can effectively increase handover success rate. To avoid UE just staying at its current location and the resource reservation lasting for a long time, the SeNB simultaneousely triggers a timer. When UE arrives at the TeNB or when the timer times out, all the reserved resources will be released.

(3)Handover Area (HA) When UE arrives at HA, the SeNB should process the remaining handover works as soon as possible, including that (1) it chooses the top-grade eNB as the TeNB from CeNBs, then send *HANDOVER_COMMAND* to TeNB; (2) TeNB will use the reserved resources for the UE to serve the UE; (3a) If handover fails, the SeNB will choose the second-grade eNB as the TeNB for handover. If unfortunely handover fails again and again, the SeNB should repeat (3a) until handover succeeds, or UE redoes the 'Cell Selection' procedure to re-enter to the LTE-A network; (3b) If the UE successfully hands over to the TeNB and switched to a new route, SeNB will release all the resources used to serve the UE and notify all other CeNBs to release those resources reserved for the UE. The TeNB is now the SeNB of this UE.

3.3 The ranges of areas

The areas of SA, NA and HA are concentered at SeNB with different radiuses where as shown in Figure 3, $R_{HA} > R_{NA} > R_{SA}$ in which R_{HA}, R_{NA} and R_{SA} are radiuses of HA, NA, and SA, respectively. From the information reported by UE, the SeNB knows the distance between it and the UE, denoted by $D(UE, eNB)$, which is

$$D(UE, eNB) = \sqrt{(x_{UE} - x_{eNB})^2 + (y_{UE} - y_{eNB})^2} \tag{1}$$

where (x_{UE}, y_{UE}) is the location of UE and (x_{eNB}, y_{eNB}) is the coordinates of SeNB. From the following statement, we can know which area the UE is now located or stays.

$$\text{UE is in} \begin{Bmatrix} \text{Safe Area} & if R_{SA} \geq D(UE, eNB) \\ \text{Notification Area} & if R_{NA} > D(UE, eNB) \geq R_{SA} \\ \text{Handover Area} & if R_{HA} > D(UE, eNB) \geq R_{NA} \end{Bmatrix}$$

3.4 The Measurement Report

When UE hands over, SeNB needs the measurement report sent by UE to gather information of all its neighbor eNBs. A measurement report as metioned previousely can be sent to SeNB periodically or by event-triggered.

(1) Periodic A measurement report is generated and sent to SeNB by UE periodically, e.g., once for one minute. The interval can be set via *RRCConnectionConfig*[12]. A lower interval increases the amount of reports sent in a time unit, thus increasing, the burden for SeNB and UE, and often wasting required network resources. A higher one slows the reaction speed of the SeNB. Sometimes, the connection between UE and SeNB may be then disconnected.

(2) Event-Trigger A measurement report is generated when one of the events listed in Table 1 occurs.

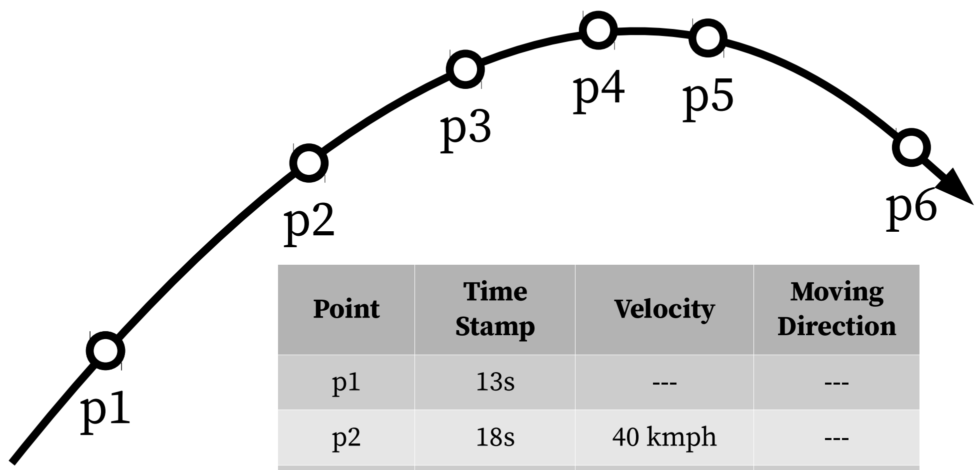
Table 1: Event definitions of an event-triggered measurement report.

Event Name	Definition
Event A1	Serving quality is better than a predefined threshold
Event A2	Serving quality is worse than a predefined threshold
Event A3	The amount of offset received from neighbor eNBs is better than that of serving eNB
Event A4	Neighbor's quality is better than predefined threshold
Event A5	Serving quality is worse than predefined **threshold 1** and Neighbor's quality is better than predefined **threshold 2**
Event B1	Neighbor's quality is better than a predefined threshold
Event B2	Serving quality is worse than predefined **threshold 1** and Neighbor's quality is better than another predefined, i.e., **threshold 2**

The A series of events is used for homogeneous handover(e.g., LTE-A to LTE-A); and the remaining B series events are used for hetergeneous handover(e.g., LTE-A to other Radio Access Technologies (RAT for short)). Because the systems before and after hetergeneouse handover are case-by-case (different RATs with different handover mechanisms), in this study, we do not consider these complex cases.

Each of the two measurement policies has its own characterstics. As mentioned in Section 3.2, one of them will be invoked according to the real handover situation.

The periodical measurement mechanism provides SeNB with RSRP/RSRQ to determine whether handover is required or not. Their thresholds can be set at *RRCConnectionConfig* at initial state and *RRCConnectionReconfig* at reconfiguration state. We add position information into the periodical measurement report, so that UE's velocity(denoted by V_{UE}), moving direction(denoted by $Direction_{UE,eNB}$) from consecutive reported timestamps and UE's positions can be then calculated.



Point	Time Stamp	Velocity	Moving Direction
p1	13s	---	---
p2	18s	40 kmph	---
p3	23s	30 kmph	↗
p4	28s	25 kmph	↗
p5	33s	20 kmph	→
p6	38s	35 kmph	↘

Figure 4: Tracking UE's position, velocity and direction information

3.5 The effect of UE's moving direction

The moving direction of UE (i.e., $Direction_{UE,eNB}$) greatly effect the accuracy of choosing the correct TeNB during handover. Figure 5 introduces an extreme example.

Assuming that when UE enters the communication coverage area of eNB2, both RSRP and RSRQ are still good. But the UE will soon leave eNB2. In this case, the UE may be disconnected if its speed is fast. If the prediction of $Direction_{UE,eNB}$ is possible, eNB3 may be better than eNB2.

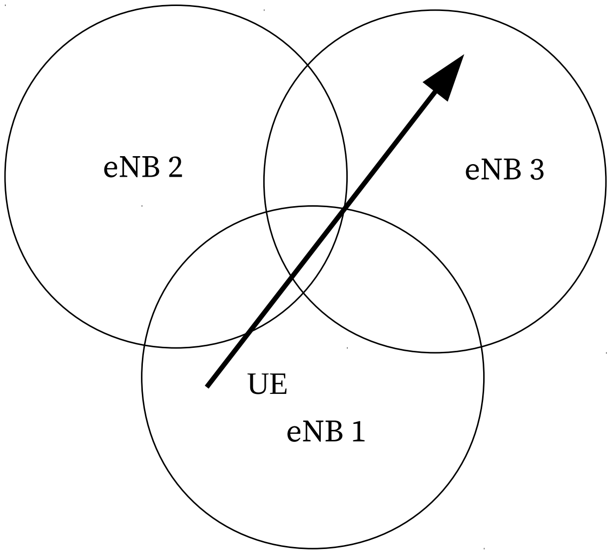
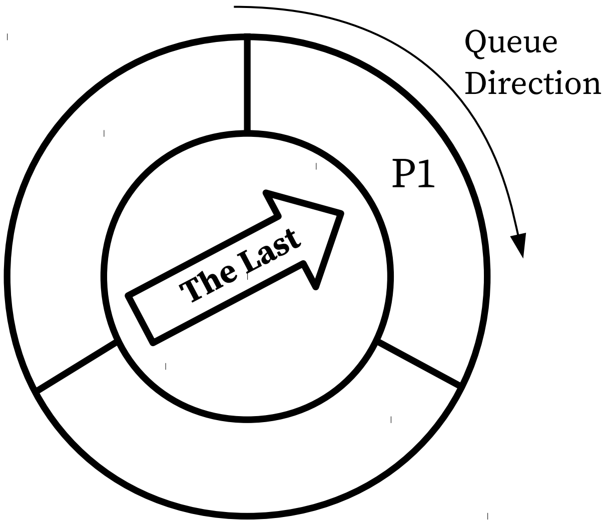


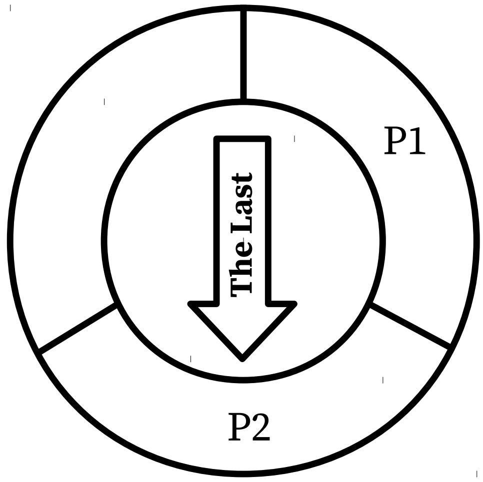
Figure 5: Bad HO if UE hands over to eNB2 rather than to eNB3 from eNB1.

Even if currently handover delay is short[16], handover may still fail due to some reasons. To predict $Direction_{UE,eNB}$, the PreHS defines $Angle_{UE,eNB}$, which is the angle between $\overrightarrow{UE\ eNB}$ and UE's current moving direction, to indicate the referenced path the UE moves toward to an eNB. When the $Angle_{UE,eNB}$ is smaller, the UE is moving toward the eNB more directly. The duration in which the UE stays in the eNB's communication area is then longer. So, it whould be better if we can choose an eNB which has smaller $Angle_{UE,eNB}$, as the TeNB.

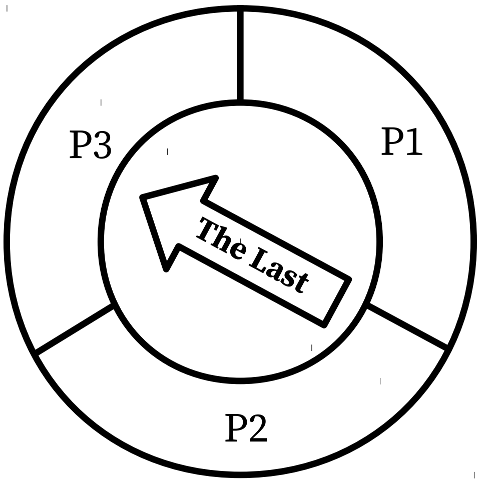
The velocity of UE, i.e., denoted by V_{UE}, can be calculated by using the locations carried in two consecutive measurement reports.



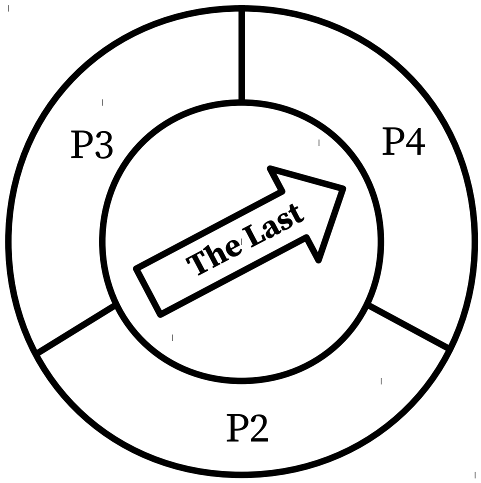
(a) SeNB receives UE's position P1



(b) SeNB receives UE's position P2



(c) SeNB receives UE's position P3



(d) SeNB receives UE's position P4

Figure 6: A Sample for introducing how the moving direction of an UE, i.e., $Direction_{UE,eNB}$, is calculated

Figure 6 shows how the $Direction_{UE,eNB}$ is calculated by using a ring queue. In Figure 6a, SeNB receives position, e.g., P1, and queues it. When the queue is full, the PreHS starts to calulate the $Direction_{UE,eNB}$. Otherwise, it does nothing. In Figure 6b, SeNB receives UE's position P2 and queues it. The queue is still not full. So it does nothing until the queue is full. In Figure 6c, SeNB receives position UE's P3 and queue it. The queue is full now. The PreHS calcutates the $Direction_{UE,eNB}$ by using the oldest position P1 and the newest position P3. In Figure 6d, SeNB received UE's position P4 and queue it. The queue is full again. The PreHS calcutates the $Direction_{UE,eNB}$ by using the oldest position P2 and the newest position P4.

In this section, the SeNB keeps only three last position records and calculates the direction to avoid side effects from a high-mobility of UE.

3.6 Notification Area

In this subsection, we propose a mechanism to inform eNB of the start of preparing handover.

When the UE arrives at NA, SeNB notifies its neighbor eNBs to prepare resources, e.g., IP address and available channels, for UE's handover. But which eNBs will be notified? We will discuss this later.

What is the radius of NA? The answer is that we need to evaluate recent average handover delays of UEs between SeNB and TeNB, the V_{UE} and the $Direction_{UE,eNB}$. In this study, Handover Distance is defined as

$$Handover\ Distance = V_{UE} \cdot cos(Angle_{UE,eNB}) \cdot Avg(HODelay) \tag{2}$$

where $Avg(HODelay)$ is the observed average handover delay, and $Hanover\ Distance > (R_{NA} - R_{SA})$.

In Figure 2, steps 1-3 are performed in SA, step 4-6 are the steps that should be done in NA, and remaining steps (Steps 7-20) comprize HA. If $V_{UE} \cdot cos(Angle_{UE,eNB})$ is higher, the UE is appoaching the eNB more quickly. This means $R_{HA} - R_{NA}$ is dynamic depending on the UE's V_{UE} and $Angle_{UE,eNB}$.

A handover delay is due to the times consumed by step 3 to step 20 (see to Figure 2). In fact, $R_{NA} - R_{SA}$ is the time required to notify CeNBs to reserve resource for UE handover. In the PreHS, we start preparing handover much earlier so that Stage 2 has enough time to be finished. To make sure that steps 4-6 can be completed by all CeNBs, we prolong $R_{NA} - R_{SA}$ to two times the distance required to perform steps 4-6, denoted by $Dist_{4-6}$. Basically, the distance is also dynamic depending on the time consumed by steps 4-6, denoted by t_{4-6}, where $Dist_{4-6} = t_{4-6} \cdot V_{UE} \cdot cos(Angle_{UE,eNB})$. If unfortunely the choosen eNB cannot finish the preparation before the UE leaves the NA, the handover will enter its regular work flow, i.e., the handover will be started when HANDVOER_COMMAND is submitted by SeNB (See Step 7 in Figure 2).

3.7 Handover Area

When UE arrives at HA, the SeNB uses resources reserved for UE to help UE's handover. The steps are as follows.

1. Choosing an eNB as the TeNB from its CeNBs, and perfoming handover. How TeNB is chosen will be explained in Section 3.8.
2. The SeNB and the TeNB execute the steps of Stage 2.
3. If handover fails, the PreHS will choose another neighbor eNB as the TeNB to do handover and the procedure goes to step 2.

3.8 Selecting the TeNB

In this study, an SeNB collects the members of its CeNBs by gathering its neighbor eNBs' RSRP and RSRQ information from measurement report sent by UE. In Stage 1 shown in Figure 2, what the system needs to do is selecting a CeNB as the TeNB and then performing handover.

Also, the SeNB will maintain a *TeNB_Candidate_List* for an UE. Each time when SeNB receives a measurement report from the UE, it updates the information recorded in the *TeNB_Candidate_List*. The update includes adding data to and deleting data on the list. The newly updated *TeNB_Candidate_List* ensures that the chosen TeNB can be assigned as soon as possible.

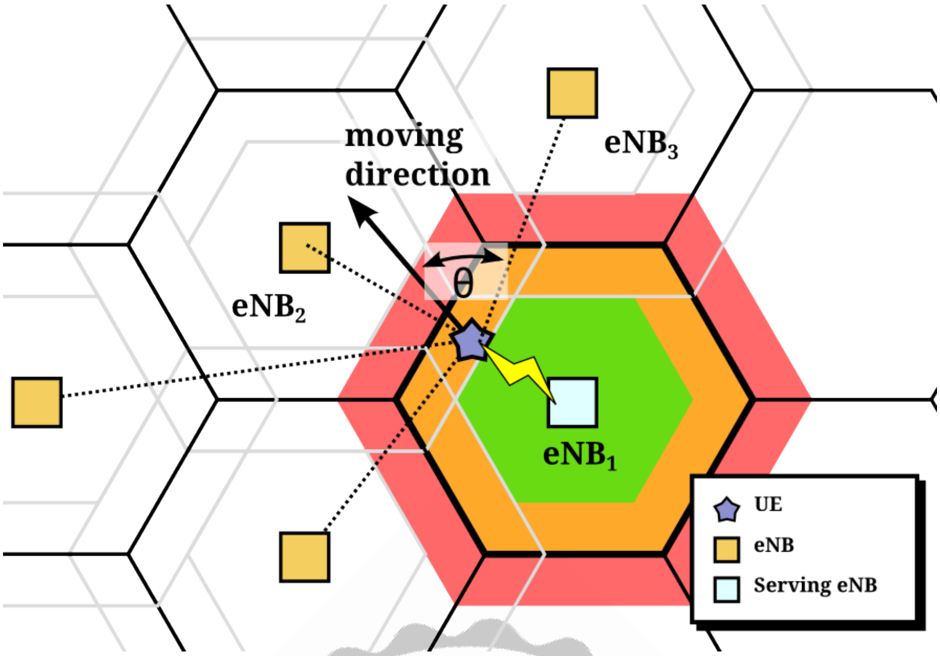


Figure 7: The angle between UE's moving direction and the choosen CeNBs (θ: the angle between UE's moving direction and the line between UE and eNB_3 when we evaluate eNB_3)

The order of weights of parameters is $V_{UE} \cdot cos(Angle_{UE,eNB}) \geq$ RSRQ $>$ RSRP $\geq$ Distance(see Table 2).

The *CeNB_SCORE* is calculated as follows.

$$\begin{aligned} CeNB_{SCORE} = {} & score(V_{UE} \cdot cos(Angle_{UE,eNB}) \times weight(V_{UE} \cdot cos(Angle_{UE,eNB}) \\ & + score(\text{RSRQ}) \times weight(\text{RSRQ}) \\ & + score(\text{RSRP}) \times weight(\text{RSRP}) \\ & + score(\text{Distance}) \times weight(\text{Distance}) \end{aligned} \tag{3}$$

To compute the *CeNB_SCORE*, we grade CeNB parameters by some rules, and give them the corresponding scores. Table 2 provides the rules of weights and points of these parameters. Therefore, with Eq. 3 and Table 2, we can calculate the *CeNB_SCORE* and use it to rank the eNBs collected in the TeNB_Candidate_List, from which the PreHS can choose the best eNB as the TeNB. If due to some reasons, the selected TeNB cannot serve the UE, each CeNB in the TeNB_Candidate_List will be evaluated whether it is suitable to serve as TeNB or not by the weighted sum of the CeNB parameters listed in Table 2.

Table 2: Details of Parameters used to evaluate the eNBs collected in TeNB_Candidate_List.

Parameters	**Weight**	**Conditions and Points**
RSRP(0-97)	0.2	**STRONG(61-97)**: 3 points **MEDIUM(41-60)**: 2 points **WEAK(0-40)**: 1 point
RSRQ(0-34)	0.3	**STRONG(27-34)**: 3 points **MEDIUM(16-26)**: 2 points **WEAK(0-15)**: 1 point
$V_{UE} \cdot cos(Angle_{UE,eNB})$	0.3	**0-30 degrees**: 3 points **30.1-60 degrees**: 2 points **60.1-90 degrees**: 1 point
Distance	0.2	**NEAR(< 1 km)**: 3 points **MEDIUM(1-2 km)**: 2 points **FAR(> 2 km)**: 1 point

Algorithm 1: Calculating *CeNB_SCORE* for an eNB in TeNB_Candidate_List

Input: Parameters retrieved from a measurement report

Output: *CeNB_SCORE*

while Receive a measurement report sent by UE **do**

  $CeNB\_SCORE = 0$

  for each Parameter in the measurement report **do**

    $CeNB\_SCORE{+}= Calc\_score(\text{Parameter}) \times weight(\text{Parameter})$

  end for

end while

return *CeNB_SCORE*

Figure 8: Calculating *CeNB_SCORE* for an eNB in TeNB Candidate List

```
Algorithm 2: Maintaining TeNB_Candidate_List
Input: CeNB_SCORE, UE.id, eNB.id
Output: TeNB_Candidate_List(UE.id)
if TeNB_Candidate_List(UE.id) does not exist then
    create TeNB_Candidate_List(UE.id);
end if
for each eNB in TeNB_Candidate_List do
    calculate CeNB_SCORE for the eNB;      /* invoking Algorithm 1 listed in Figure 8 */
    update the eNB's CeNB_SCORE in TeNB_Candidate_List;
end for
sort TeNB_Candidate_List(UE.id) on CeNB_SCORE;
choose the eNB with the highest CeNB_SCORE as the UE.id's TeNB;
return TeNB_Candidate_List(UE.id);
```

Figure 9: Maintaining TeNB_Candidate_List for CeNB_List

```
Algorithm 3: Handover
Input: measurement report sent by UE.id
while received a measurement report from UE.id do
    Calculating CeNB_SCORE;                 /* by invoking Algorithm 1 in Figure 8 */
    Maintaining TeNB_Candidate_List;        /* by invoking Algorithm 2 in Figure 9 */
    if UE.id arrives at HA then                                  /* Handover Starts */
        Choosing the CeNB with the highest CeNB_SCORE as the TeNB;
        repeatHandover(UE.id, TeNB)
            if Handing over to TeNB fails then
                Deleting the TeNB from TeNB_Candidate_List;
                Choosing the CeNB with the highest CeNB_SCORE as the TeNB;
            end if
        until Handover succeeds
    end if
end while
```

Figure 10: Handover Procedure

4 Performace Analysis

In this section, we use the LTE module (LENA) in Network Simulator-3 [17](ns-3 for short) to analyze the performance of handover for the PreHS and the regular LTE handover algorithm. Table 3 lists the parameters and their default values for the following test. The default values may be changed during the test when necessary.

Table 3: Default values of Parameters used in the following test.

Parameter Name	**Value**
Band	1800 Mhz
Bandwidth	20 Mhz(100 Resouce Blocks)
Propagation Model	Friis Model [18]
eNB TX power	30 dbm
V_{UE}	60-150 kmph
HO_Algorithm	PBGT Algorithm & PreHS
eNB_Distance	3000 m
Packet Size	1 Kbit
Bandwidth of X2 wired links	1 Gbps
Attenna	SISO
Simulation Time	100 s

Then, we will compare the performance of different handover algorithms given different senarioes.

4.1 Performace on different numbers of UE

This experiment is performed given the topology shown in Figure 11. The parameters used are listed in Table 4.

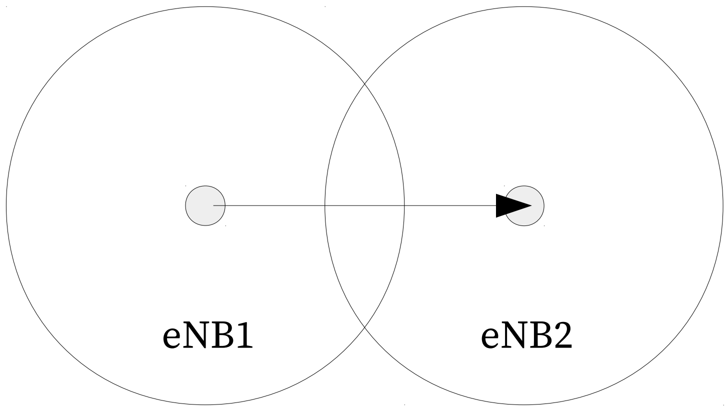


Figure 11: Numbers of UE moving from eNB1 to eNB2

Table 4: Parameters for the experiment on different numbers of UE.

Parameter Name	**Value**
enbTxPower	30 dbm
ueTxPower	10 dbm
Distance between eNBs	3000 m
Moving Speed	60 kmph

The results are shown in Table 5. We found that when the number of the UEs is over 15, the handover of some UEs fails. This is the restriction of LTE preamble ID, i.e., an eNB has 64 IDs[12]. But the default number of UE in ns-3 is 14. So by default, only up to 14 UEs can hand over altogether at the same time[19]. Note that in the note field in Table 5, *1 represents that 14 UEs of the 64 IDs can be active and the remaining IDs can only keep the connection in their inactive state. Of course, the number of UEs can be adjusted. But in this experiment, we keep it 14 UEs. *2 means that the number of active UEs is restricted by LTE SRS Periodicity[2, 20]. Given a SRS Perioidicity value,e.g., m, the number of UEs that can be served(i.e., active state) as shown in Table 6 is also m. For example, when SRS Periodicity is 40, an eNB can only serve 40 UEs at the same time. So UEs can not be served unless any active UE quits[2, 20]. Both *1 and *2 have a problem which occurs only on specific usage scenarios, and LTE providers need to tweak these parameters when installing cells. Fortunately, we do not need to worry about that since it is rare in following tests.

Note that according to the results illustrated in Table 5, PreHS's handover delay is a little shorter than that of the PBGT, because the preparation is performed much earlier. This feature gives eNB a little longer time to hand over to avoid handover failure. If handover starts at a later time or handover request queue at the TeNB end is long, UEs may lose its own connection to SeNB. But the PreHS's handover delay on 10 UEs is 1.1(= 52.5 − 51.4) ms shorter than that of the PBGT, because the PreHS can finish handover requests more quick than the PBGT can. But PreHS performs handover much earlier.

Table 5: The handover delays when different numbers of UEs move from *eNB1* to *eNB2* simultaneously (see Figure 11)

Number of UEs	**Avg.HO Delay(PBGT)**	**Avg.HO Delay(PreHS)**	**Note**
1	20 ms	20 ms	
5	23.5 ms	22 ms	
10	52.5 ms	51.4 ms	
15	— ms	— ms	*1
50	— ms	— ms	*2

Table 6: SRS Perioidicity vs UE Capacity[2]

SRS Periodicity	UE Capacity
2	2 UEs
5	5 UEs
10	10 UEs
20	20 UEs
40	40 UEs
80	80 UEs
160	160 UEs
320	320 UEs

4.2 Performance on different numbers of UEs with different velocities

This experiment compares the tested algorithms on different numbers of UEs with different velocities. The parameters and their values are, respectively, the same as those parameters and their values listed in Table 4, except velocity. The velocities of one half of UEs are 40kmph. The remain half of UEs' speeds are 60kmph. The start time of handover of an UE is randomly chosen. But the time period between the start times of two consecutive handovers ranges between 0 and 3 sec. The average handover delays on different numbers of UEs moving from eNB1 to eNB2 are shown in Table 7. According to row 3 in Table 7(i.e., when number of UE is 10) and the experiment result, the HO delays, unlike that between row 3 and 4 in Table 5, do not change significantly.

Since eNB2 prepares resources for up-coming UEs much earlier, eNB2 has a longer time to complete handover. When number of UEs is 10, the delay is only 22 ms which is much shorter than 52.5ms illustrated in Table 5 since all UEs move toward eNB2 seperately, meaning that both SeNB and TeNB do not face the handover requests jam. The handover request queue is now not stuffed like before, so all handovers can be performed more smoothly. Compared with those in Table 5, PreHS effectively reduce handover delays when the number of UEs is higher. If a part of handover requests is finished earlier, eNB will have many more resources to perform the remain handovers. Also, Table 7 indicates that the PreHS's handover delays are a little shorter than those of the PBGT algorithm.

Table 7: The handover delays when different numbers of UEs move from *eNB1* to *eNB2* with different velocities and start times (see Figure 11)

Number of UEs	**Avg.HO Delay(PBGT)**	**Avg.HO Delay(PreHS)**
1	20 ms	20 ms
5	22.6 ms	20 ms
10	22 ms	20 ms
15	23.9 ms	21.2 ms
20	27.2 ms	23.2 ms

4.3 Performace with randomly moving model

In this experiment, we put UEs in a rectangle area, in which UEs move with their own velocities following their moving paths.

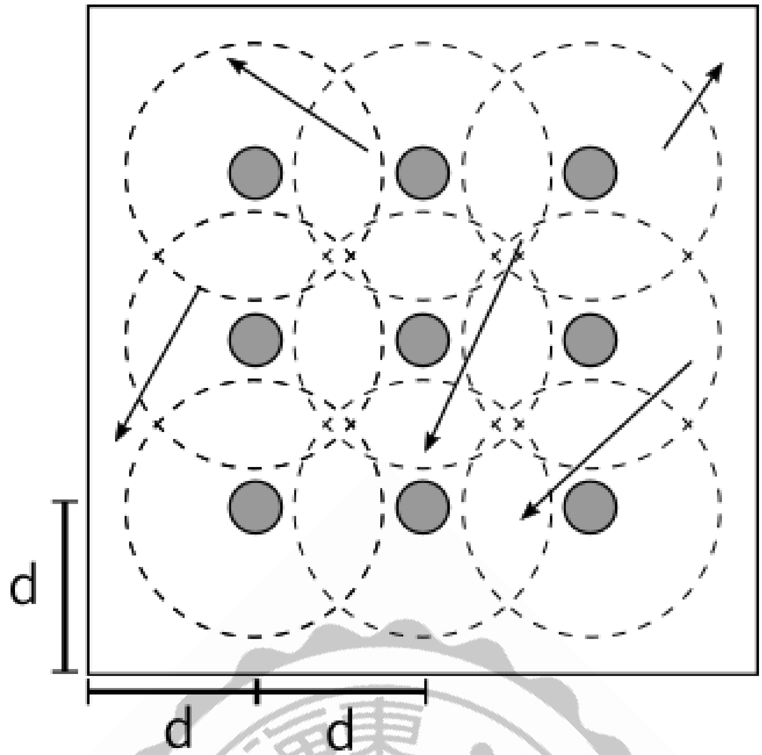


Figure 12: UEs move with their own velocities following their own moving paths.

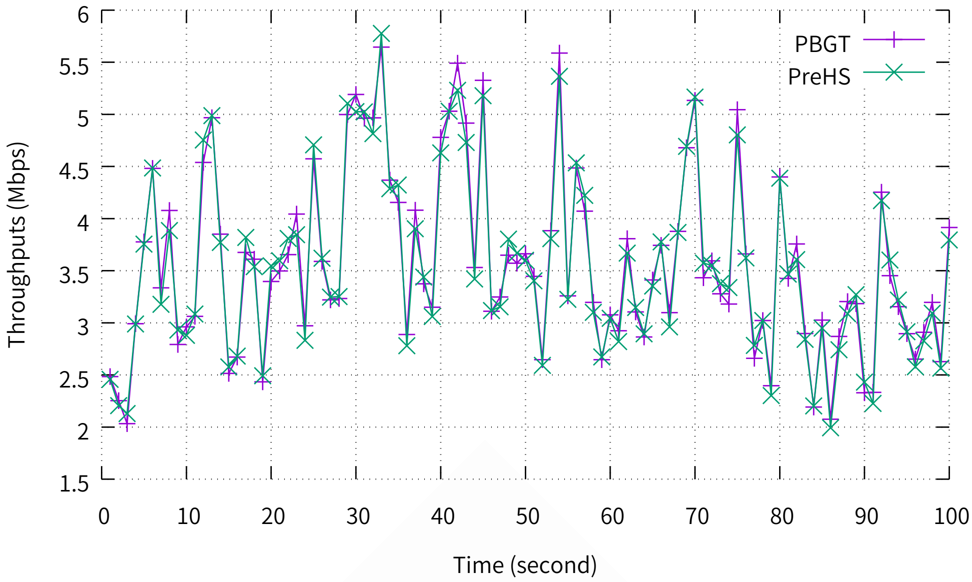
In Figure 12, the dashed circles are the signal coverage of an eNB. The gray circles indicate the locations of eNBs. The rectangle which covers all objects is the UEs' moving area. UEs cannot move out of this rectangle boundary. If a UE touches the boundary, it will change its own velocity and direction, and then continue moving. The eNBs are not movable objects, the distance between two neighbor eNBs(eNB to the rectangle boundary), denoted by d, is 3000 meters.

Table 8 shows the parameters of the experiment of the randomly moving model which is established as follows. At first, all of UEs are placed in the rectangle randomly, attach themselves to the closest eNBs and change their own velocities and directions every 5 seconds. Each UE receives data sent by a remote host behind the epc network via its SeNB continuously. Also, the PreHS and PBGT utilize the same UE mobility for comparing performance in the same environment.

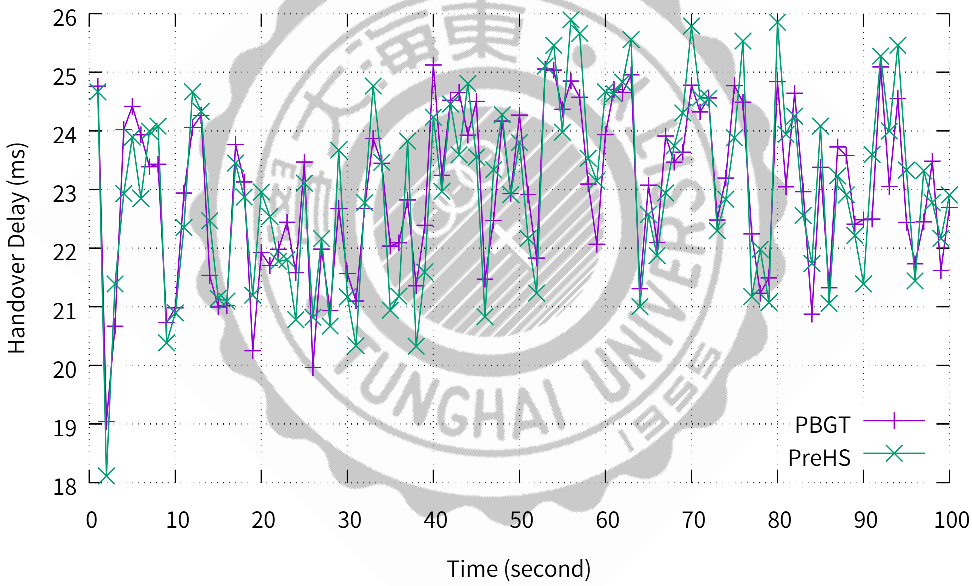
Table 8: Parameters for the experiment of the randomly moving model.

Parameter Name	**Value**
enbTxPower	30 dbm
ueTxPower	10 dbm
Distance between eNBs	3000 m
Moving Speed	60-150 kmph
Number of UEs	15

The experimental results of this model are shown in Figure 13a and Figure 13b, which respectively illustrate throughputs and handover delays. The average throughput per UE is 3.48 Mbps for PBGT and 3.34 Mbps for PreHS. Also, the difference of throughputs between PreHS and PBGT is insignificant. The reason is that the main task of the PreHS is choosing the best TeNB. Consequently, UE can hand over to the TeNB as soon as possible. The delays shown in Figure 13b are due to the fact that UE's mobility has no difference between PreHS and PBGT. The total number of handover is 14 for PBGT and 10 for PreHS because the PreHS always chooses the best TeNB for UE to avoid unsuitable handovers and reduce the waste of eNB resources. That is why it can reduce 4 times of handover in the same experimental environment and in the same UE moving model.



(a) The throughputs



(b) The handover delays

Figure 13: The performance of the randomly moving model with PreHS and PBGT algorithms

5 Conclusions and Future studies

In the PreHS, we use the data including UE's moving direction, moving velocity, distance, RSRP, RSRQ, etc., as the parameters provided by a GPS system to achieve a more efficient and reliable handover than original one of LTE-A. Comparing with the selection mechanisms of the improved handover and the original one, although our handover needs additional environmental data, it can more accurately select a suitable TeNB. A higher accuracy of selecting the right TeNB shows that the probability with which the LTE-A system will redo the handover procedure in a short time due to some reasons, e.g., buildings' shading, interfered by noise or moving direction's change, is low, thys avoiding wasting network resources. The Notification area is also a solution to prevent the handover failure when UE is moving very fast. Even the UE cannot gather any RSRP from neighbor CeNBs, SeNB can also select a TeNB with the locations of UE and neighbor CeNBs. But compared with LTE-A handover algorithm, the PreHS algorithm does improve the LTE-A handover performance, smooth the performance during handovers, and decrease handover delays due to earlier handover preparation and choosing the best TeNB, meaning that eNB can handle many more handover requests at the same time. The PreHS also reduces the number of handover to save many more resources because it prevents some unnecessary handovers by choosing the best TeNB for UE. This feature brings a more stable handover environment for LTE-A.

In the future, we would like to derive the reliability model for the proposed system, so that we can predict the reliability that an UE handover may fail, and develop a behavior model to predict the behaviors of the proposed system for more applications, e.g., traffic control, natural disasters notification. For a more stable LTE network, we can also use the prediction feature of PreHS to develop a new method for load balance. These constitute our future studies.

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