東海大學資訊工程系研究所

碩士論文

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在 5G 無線網路的 Relay Base-Station 中以預測模式進行換手的程序

The Handover procedures with predictive mode under Relay Base-Stations in a 5G wireless Network.

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東海大學資訊工程學系 研究所

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預測模式進行換手的程序

經本委員會審查，符合碩士學位論文標準。

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中華民國 107 年 1 月 15 日

Abstract

隨著可攜式終端設備的發展，人類越來越依賴無線通訊技術來進行社交、商業等行為。若在建築物密集的都市當中，基地台之訊號可能會因建築物的遮蔽導致較差的收訊；而在人口稀少的郊區，用戶則可能處於基地台通訊範圍的邊緣或外部，導致訊號薄弱甚至沒有訊號。無線訊號透過使用中繼技術可以獲得通訊範圍的延伸，當訊號傳遞途中遭遇遮蔽物干擾時，亦可透過中繼站的訊號轉發來達到繞送的效果，進而解決收訊不良的問題。在本文中，我們考量到用戶具有移動性，並因而導致換手過程的差異，因此假設了可能的幾種情境，並整合分析，探討路徑差異導致延遲時間的差異，進而知曉如何選擇較佳的路徑以及基地台之間如何佈署較適當的情境。

中文關鍵詞：進階長期演進技術；中繼基地台；越區切換；移動性；5G 網路

Abstract

With the fast development of mobile networks and technologies, many people have highly relied on wireless communication to carry out their everyday activities, like communicating with their family members or online shopping. However, in the downtown of a city, the radio signals that the user equipment (UE) receives from its nearby eNBs may be sheltered by its surrounding high buildings, resulting in poor mobile QoS. In a rural area, the user staying at the border of an eNB's communication range may also receive weak radio signals from the eNB. In fact, wireless signals emitted by an eNB, e.g., B, can be forwarded by a relay station so as to extend the communication range of B. When the signals radiated by B are interfered or sheltered, a relay station can also help to bypass the interference and shelters, thus effectively solving the problems of poor radio signals reception. In this paper, we deal with handover processes between two relay stations and between a relay station and an eNB, both of which are different from that between two eNBs. But handover concerning relay stations has its problems, e.g., if the base stations before and after handover are two relation stations and they belong to two neighbor eNBs, how to proceed the handover? Should the handover go through the two eNBs? Several handover scenarios are also explored in this study.

Keywords: LTE-Advance; Relay station; Handover; Mobility; 5G network

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1. Introduction

With the fast development of wireless networks and technologies, more base stations have been deployed around us. Consequently, the selection of the base stations during handover is diverse, and the handover procedure has become more complex than before. Currently, the handover procedure between two eNBs has been clearly defined. However, if we deploy relay stations (also called relay nodes, RNs or just relays), the procedures will change depending on the positions these relays locate, e.g., when a relay is now under an eNB, e.g., A, A's neighbor eNB, e.g., B, may be unaware of this, except that the relay's communication range is overlapped with B's [28].

[30] proposed a handover scheme in which UE can synchronize itself with a target eNB and complete the path switch before detach from source eNB, but the premise is that UE travels along a fixed path. In [31], authors introduced an approach to deliver downlink packets from serving gateway and buffer them at the source DeNB, instead of source RN, while UE is already detached from source RN. It reduced the forwarding transmission cost compared with regular forwarding methods. But, if the handover fails, these buffered packets staying in target DeNB could not be delivered to UE successfully, due to the fact that packets are buffered in the predicted target eNB.

[29] did not consider the difference of handover steps when UE moves between two relay

stations belonging to different donor eNBs. By deploying relay stations, during handover, users' data may need to be forwarded via more than two base stations [29]. Also, in different deployment environments, even if the locations of source RN and target RN are known, if the user moves from source RN to target RN through different paths, the procedure may vary, resulting in different handover delays and signaling costs. As our best knowledge, currently no study addresses this. But it is very important for 5G networks (or simply 5G) since in such networks, small cells (like Relay stations and Femto cells) will be massively deployed [32].

Therefore, in this paper, we propose scenarios for UE to hand over between an eNB and an RN and between two neighbor RNs under the assumption that when one of eNB A's RNs, e.g., P, is known to eNB B (or know to B's RN, e.g., Q), if P's and B's (or Q's) communication areas are overlapped, UE can hand over from P to B (P to Q) or vice versa. If the communication areas of A's two RN's (e.g., P and Q) are overlapped, UE can hand over from P to Q without the requirement of handing over from P to A and then A to Q. We will also explore the details of various situations, such as different moving directions of UE and, the possible handover mode which can be predictive or reactive mode when UE is moving across a specific path, etc.

The rest of this paper is organized as follows. Section 2 describes the background and related work of this study. Section 3 introduces the possible scenarios of handover concerning RNs. Simulations and their results are presented and discussed, respectively, both in Section

4. Section 5 concludes this study and outlines our future studies.

2. Background and Related Work

This section describes background and related work of this study.

2.1 Network Interfaces

There are two kinds of handover architecture in an LTE network, including, X2-based handover and S1- based handover [1]. The latter is to provide handover compatibility with which UE can hand over to a heterogeneous network [2], such as from LTE-A to WiMAX or UMTS. The former is to reduce the preparation time of handover by routing a part of control messages delivered between base stations via X2 interface without passing through Evolved Packet Core Networks (EPC) [3].

Generally, LTE system is preset to X2-based handover, unless X2 interface is unavailable between eNBs, or eNBs belong to different MMEs of different Internet Service Providers (ISPs), S1 interface connecting to MME will be chosen. In LTE-A, an eNB besides serving UEs also manages RNs connecting to it. An RN forwards messages received from eNB to UE, or vice versa and the eNB which serves RNs is called Donor eNB (DeNB). From DeNB’s point of view, an RN can be viewed as a UE or an eNB, depending on the role the RN plays [4].

An Un wireless interface connecting RN and DeNB is used to transmit different types of control traffic sent between them. Besides Un interface, like that in an eNB, RN also provides S1 and X2 interfaces. When an DeNB is connected to RNs through the S1-C (control plane) interface, it serves as the MME of these RNs. On the other hand, when it is linked to RNs via an S1-U (user plane) interface, it acts as the S-GW of these RNs.

Furthermore, the interface between the MME and the S-GW is S11. When facing an RN, DeNB may play the role of S-GW (for RN). Therefore, there is also an S11 interface between DeNB and MME.

2.2 LTE-Advanced (LTE-A)

The architecture of LTE-Advanced (LTE-A) is shown in Figure 1. An LTE-A is an enhanced version of an LTE system. Its bandwidth is now 100Mbps (1GBps) at peak rate when UE is moving at a high speed (in its still state). To achieve this, several techniques have been developed to improve LTE-A functions, such as Carrier Aggregation (CA) [5], Coordination Multi-Point (CoMP) [6], and Multimedia Broadcast and Multicast Service (MBMS) [7]. The alternatives include the deployment of RNs, Femto cells (i.e., Home eNodeB, HeNB), small cells, etc.

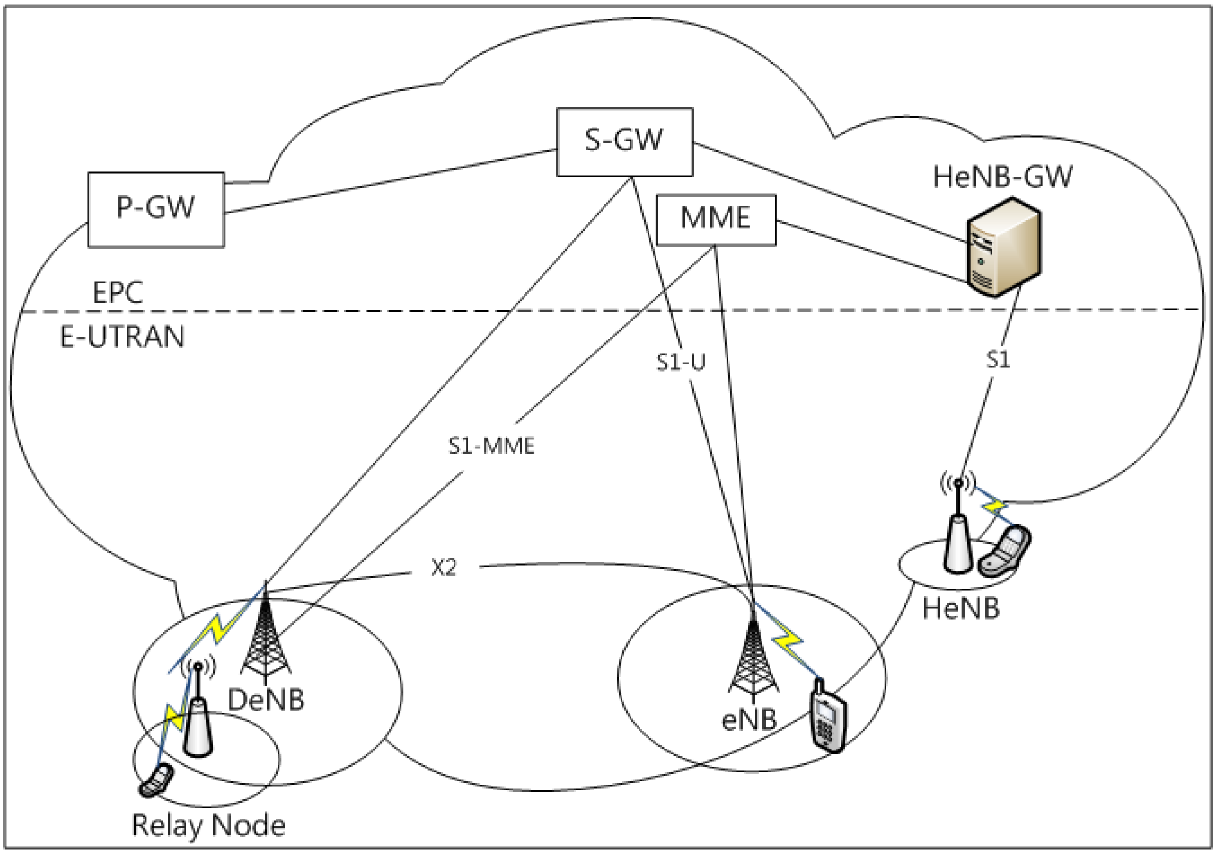

Figure 1. An LTE-A Architecture containing an EPC and E-UTRAN. The former consists of P-GW, MME, S-GW, and HeNB-GW (Home eNB-GW), while the latter comprises eNBs, Relay Nodes, and HeNB (Home eNB).

2.3 Relay node (RN)

Basically, an Un wireless link, also known as a backhaul link, is used to carry different types of signaling traffic for control, such as operations and maintenance (O&M) and X2/S1-AP [8], and user's data at different QoS levels. This wireless link can be divided into three layers. Each has its own functions, such as NAS (Non-Access Stratum) and RRC (Radio Resource Control) in Layer 3, RLC (Radio Link Control), PDCP (Packet Data Convergence Protocol), and MAC (Medium Access Control) in Layer 2, and OFDMA, and MIMO in Layer 1 where layer 1 is the

Physical Layer that transfers data with physical signals.

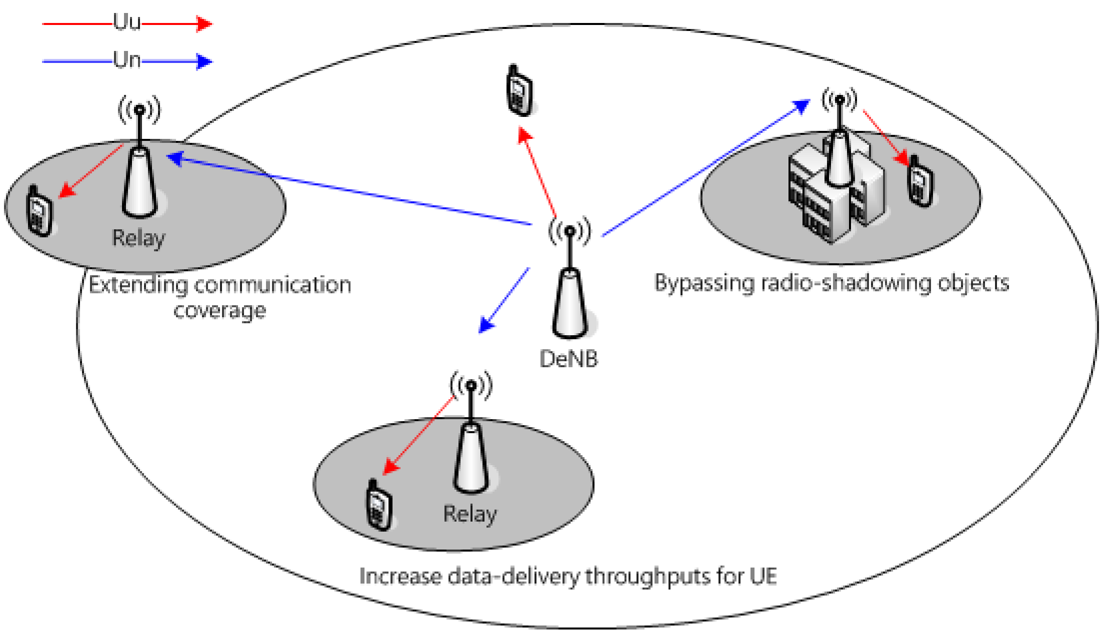

Figure 2. The features of an LTE-A relay node, including extending DeNB's communication coverage, bypassing radio-shadowing objects, and increasing data-delivery throughputs.

The functions of an RN as shown in Figure 2 are as follows [8]:

A. Increasing data-delivery throughputs for UE: The deployment of RNs, particularly for 5G networks, can increase the density of base stations so that users have better signaling quality and network capacity, especially when UE stays at the communication border of DeNBs.

B. Extending communication coverage: By deploying RNs at the border of a DeNB's communication range, the range can be extended through these RNs. Even UE is now a little out of coverage of DeNB, through these RNs, UE can still connect to the serving network.

C. Bypassing radio-shadowing objects: In some cases, the signals emitted by DeNB are obscured by obstacles. If RN is deployed at a specific location, e.g., at the top of the obstacles, the radio signal emitted by DeNB can be forwarded so that UE can receive the signal even its user stands behind the obstacles.

2.4 LTE-Femto (HeNB)

Femtocell as a Home eNodeB is a small base station, the signal strength of which is about 20dBm [10]. The coverage and the maximum number of UEs that a Femto can, respectively, provide and serve at the same time are about 10 to 50 meters and 4 to 32 users, depending on its specifications defined by the venders or telecommunication operators [27]. In fact, they are both less than those provided and served by a DeNB. Its main function is to extend DeNB's communication coverage, while UEs stay in a closed or semi-enclosed space (e.g., home, office, arcade of a building, etc.). In these cases, the macrocell outside the space could not provide UEs with high QoS because the wireless signals spread in these areas from the macrocell will probably be attenuated by walls, shadowing buildings and/or other sheltering objects. Generally, the mobility of UEs in these spaces is low, so a femtocell does not need to support UE with high mobility [27].

Basically, the function of a femtocell in bypassing radio-shadowing objects is similar to that of an RN. But the difference is in that an RN connects to its macrocell with wireless interface Un. The femto does not take part of the wireless spectrum for the relay task because the connection is directly connected to a telecommunications network via a wired interface, such as cable, modem or DSL [27].

When employing a femtocell-based system, as shown in Figure 3, there are two types of handover including handover between macrocell and femtocell, and that between femtocell and femtocell. [11] introduced the handover procedure in detail for a femtocell in an LTE-based network and also analyzed its performance. [19] investigated the performance of an LTE network by using Fixed/Mobile Femtocells.

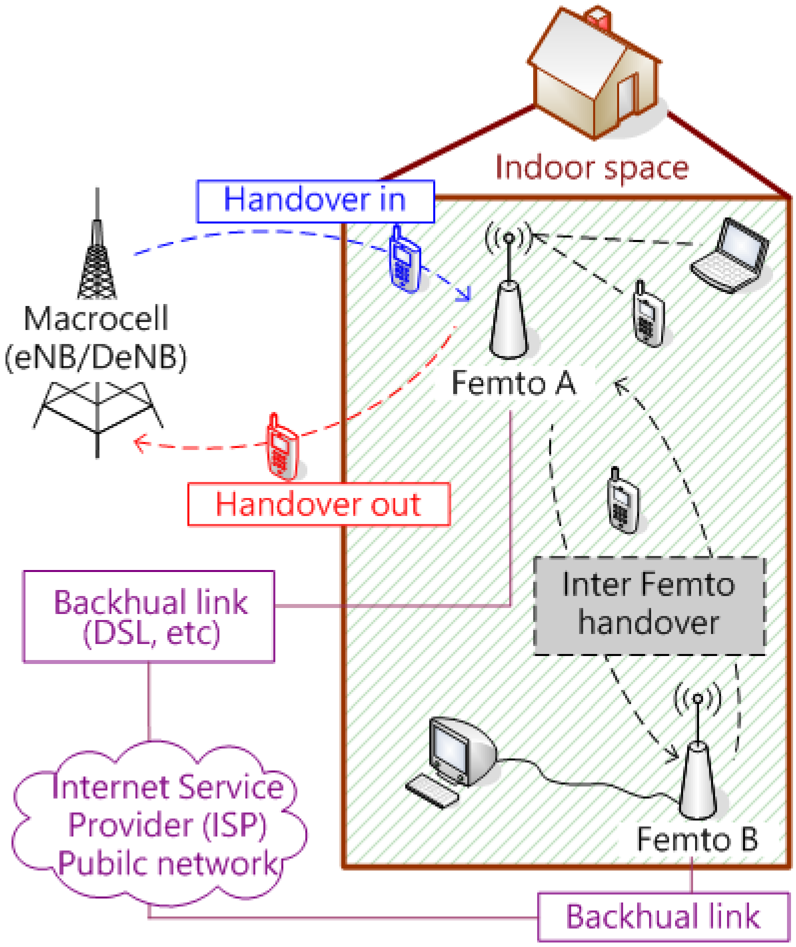

Figure 3. The handover scenarios between femtocell and macrocell, and between femtocell A and femtocell B.

2.5 Related Studies

Recent researchers have tried to improve handover performance for RNs in an LTE-A environment by using LTE Advanced standards. [20] proposed a framework that divided RNs' handover into two types as centralized and distributed, and described how the dynamic association of RNs is performed. Authors also presented a method that activates or deactivates RNs to gain benefits. But, when UE needs to hand over from RN1 under DeNB1 to RN2 under DeNB2, and after UE is detached from RNsrc, the downlink packets are buffered in DeNBsrc rather than in RNsrc, those packets already sent to RNsrc will not be delivered to DeNB2, causing packet loss. [21] introduced an approach to enhance the mobility procedures for mobile RNs by adopting two options, X2 global tunnel and S1 global tunnel. The latter uses the GTP-U protocol to reduce the number of signaling messages in a mobile relay scenario, and evaluates their processing costs. Even though the number of messages and related processing costs can be reduced, the packet is enlarged by employing GTP-U header's Extension Head Flag. Also, to accelerate the execution of the service request procedure, S1 tunnel needs to be kept in its active state. Therefore, an RN's tracking area identity (TAI) ought to be different form that of a DeNB. [22] proposed a Multiple-Radio Access Technology (Multi-RAT) method in a relay architecture, wishing to combine heterogeneous networks for delivering packets via RN and DeNB with a special tunnel through the core network of a network system so as to reduce the packet delivery costs.

[23] introduced a cell selection approach for LTE heterogeneous network, which, called network coordinated cell selection (NC), was compared with reference signal received power (RSRP), and cell range extension (CRE) cell selection. NC selection can associate UE with an extended coverage region to other cells according to the achievable throughputs and cell loads. The scheme presented by Huang et al. [24] used GPS to assist the handover scheme for LTE wireless networks. Authors considered UE's moving direction for preparing handover.

Generally, those parameters employed by this study, like UE's moving speed, eNB's current load and so on [25, 26], are helpful in choosing target eNB. But choosing an appropriate eNB is not the focus of this study.

3. The Proposed of Possible Scenarios

In the following, six handover scenarios will be described. The source eNB is denoted by DeNBsrc, a relay node under DeNBsrc is represented by RNsrc, the eNB as UE's NMAG is called Target eNB expressed as DeNBtar, and a relay node under DeNBtar is named RNtar. To smoothly hand over from a base station, e.g., Ba, to another base station, e.g., Bb, with the predictive mode, the communication areas of Ba and Bb must be overlapped. The six scenarios are as follows:

(1). DeNBsrc is now serving UE, and UE moves to the RNsrc (denoted by DeNBsrc - to – RNsrc).

(2). The RNsrc is now serving the UE, and UE moves to the DeNBsrc (RNsrc - to - DeNBsrc).

(3). The RNsrc is now serving the UE, and UE moves to another RNsrc, e.g., RNsrc', which is also under DeNBsrc (RNsrc - to - RNsrc').

(4). DeNBsrc is now serving to UE, and UE moves to RNtar (DeNBsrc - to - RNtar).

(5). The RNsrc is now serving to the UE, and UE moves to DeNBtar (RNsrc - to - DeNBtar).

(6). The RNsrc is now serving to the UE, and UE moves directly to RNtar (RNsrc - to - RNtar).

With the Predictive-mode handover, the time UE stays in the path segment within the overlapped communication areas of source and target eNBs, denoted by $L_{src\cap tar}$, must be longer than or equal to the time required by UE to finish its HO (Handover) Preparation stages [28], denoted by T_{HO_prepar} , i.e.,

$$\frac{L_{src\cap tar}}{\mathrm{V}_{UE}} \geq T_{HO\_prepar}$$

where V_{UE} is UE's moving speed. Otherwise, meaning that UE cannot receive target eNB's information from source eNB before leaving $L_{src\cap tar}$, handover will change to the reactive mode.

Also, the case in which UE under the DeNBsrc hands over to DeNBtar does not contain any relay node. In fact, its scenario has been clearly defined and is not within the scope of this study. The procedures of the six handover are as follows.

3.1 Scenario 1: DeNBsrc - to – RNsrc

When UE hands over from DeNBsrc to RNsrc, the topology (sequence chart) is shown in Figure 4 (Figure 5). The handover procedure can be divided into three stages: Preparation, Execution, and Completion.

(1). Preparation stage: When the strength of the Received Signal Strength Indicator (RSSI) UE receives from DeNBsrc is lower than the predefined threshold Th_{RSSI}, where the strength of RSSI is carried in the measurement report periodically sent to DeNBsrc by UE, DeNBsrc selects the next base station RNsrc based on the moving direction of the UE, and sends a handover (HO) request to RNsrc. After the admission control, RNsrc returns an HO request Acknowledgement to DeNBsrc to finish the preparation stage. After that, eNB allocates a DL channel and sends RRC conn. Reconfiguration message which includes target eNB's information to UE.

(2). Execution stage: As the UE is ready to hand over, it re-configures the RRC connection [17]. Before connecting to RNsrc, UE disconnects itself from DeNBsrc. Generally, during the disconnection time period, DeNBsrc buffers all the packets sent by correspondent node (CN). When UE successfully contacts DeNBsrc, DeNBsrc will deliver a packet, conveying the sequence numbers (SN), with the up/downlink packet data convergence protocol (PDCP) to RNsrc, and continue forwarding packets received after UE is disconnected from DeNBsrc to RNsrc. RNsrc stores these packets. After UE completes the re-configuration of its connection (i.e., synchronization) to RNsrc, this stage ends. Of course, RNsrc then sends those buffered packets to UE.

(3). Completion stage: When the UE successfully connects to RNsrc, the RNsrc sends a path switch request to the MME through the DeNBsrc since RNsrc cannot contact MME directly.

MME delivers a User plane update request to the S-GW. S-GW transmits an End marker to DeNBsrc telling it that no more packets sent by CN will be delivered to DeNBsrc. After that, the S-GW sends a User plane update response to MME. MME transmits a path switch request acknowledgement to the RNsrc through the DeNBsrc. Then, RNsrc sends a UE context release message to DeNBsrc. DeNBsrc releases all the resources consumed for serving UE (e.g., UL, DL, and buffer reserved for storing packets sent to UE), and the handover procedure terminates.

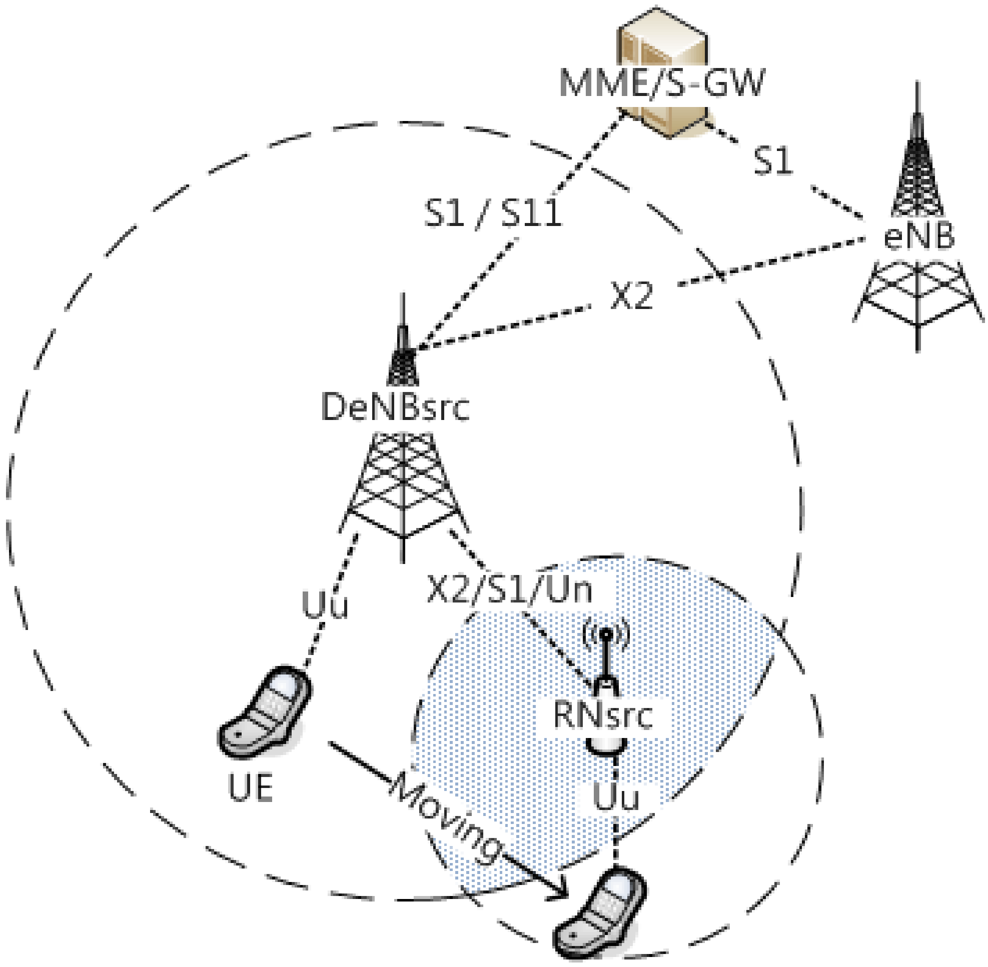

Figure 4. The topology for DeNBsrc- to -RNsrc handover.

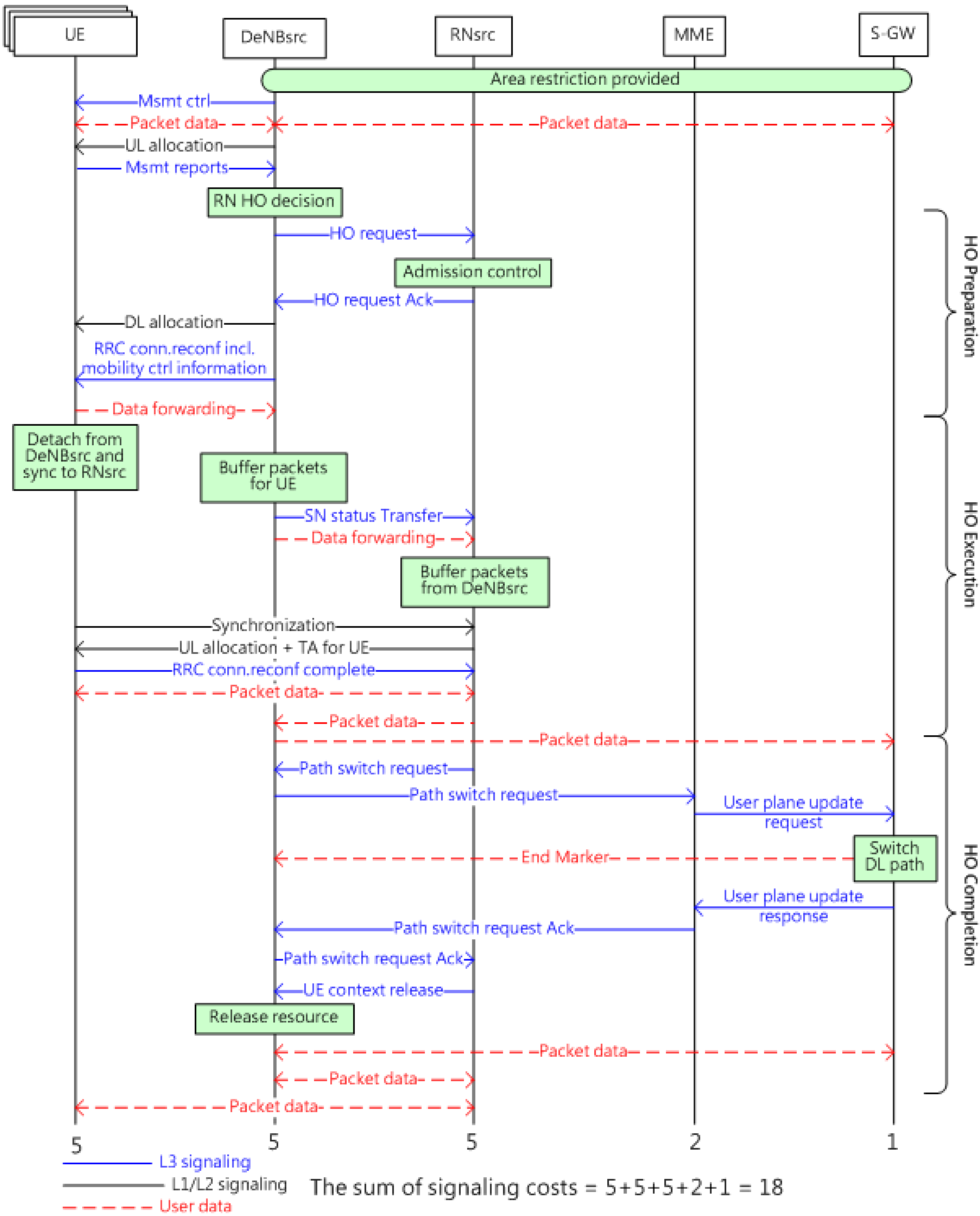

Figure 5. The sequence chart of DeNBsrc- to -RNsrc handover on predictive mode.

3.2 Scenario 2: RNsrc - to - DeNBsrc

The topology for UE to hand over from RNsrc to DeNBsrc is similar to that shown in Figure 4. But the moving direction of UE is from RNsrc to DeNBsrc. The sequence chart is also similar to that illustrated in Figure 5. But DeNBsrc (RNsrc) is replaced by RNsrc (DeNBsrc).

(1). Preparation and Execution stages: The two stages are themselves the same as those of scenario 1. But this time, the source is RNsrc and destination is DeNBsrc.

(2). Completion stage: In this stage, DeNBsrc sends a path switch request is to MME, and then receives the corresponding path switch request acknowledgement from MME; the UE context release is sent from DeNBsrc to RNsrc. The relationship between the MME and the S-GW remains unchanged. Since the connection is UE - RNsrc - DeNBsrc - MME - S-GW, S-GW sends the End marker to RNsrc via DeNBsrc telling RNsrc that no packets delivered to this UE will be sent to it.

3.3 Scenario 3: RNsrc - to - RNsrc’

In this scenario, there is no direct connection between the source station RNsrc and target station RNsrc’. The message exchanged between RNsrc and RNsrc’ must be transmitted via DeNBsrc. For example, data packets and the control packets delivered in HO Preparation stage, including HO request and HO request acknowledgement, and SN status transfer sent in HO

Execution stage, are all passed through DeNBsrc. The Preparation, Execution and Completion stages of this scenario are themselves similar to those of scenario 1. The difference is that in the HO Completion stage, the path switch request is sent by RNsrc’ to MME via DeNBsrc, and the End marker is transmitted to the NMAG, i.e., RNsrc, also via DeNBsrc. Of course, S-GW sends User plane update response to MME. MME then delivers path switch request acknowledgement to RNsrc’s, and RNsrc’ transmits UE context release to RNsrc both via DeNBsrc.

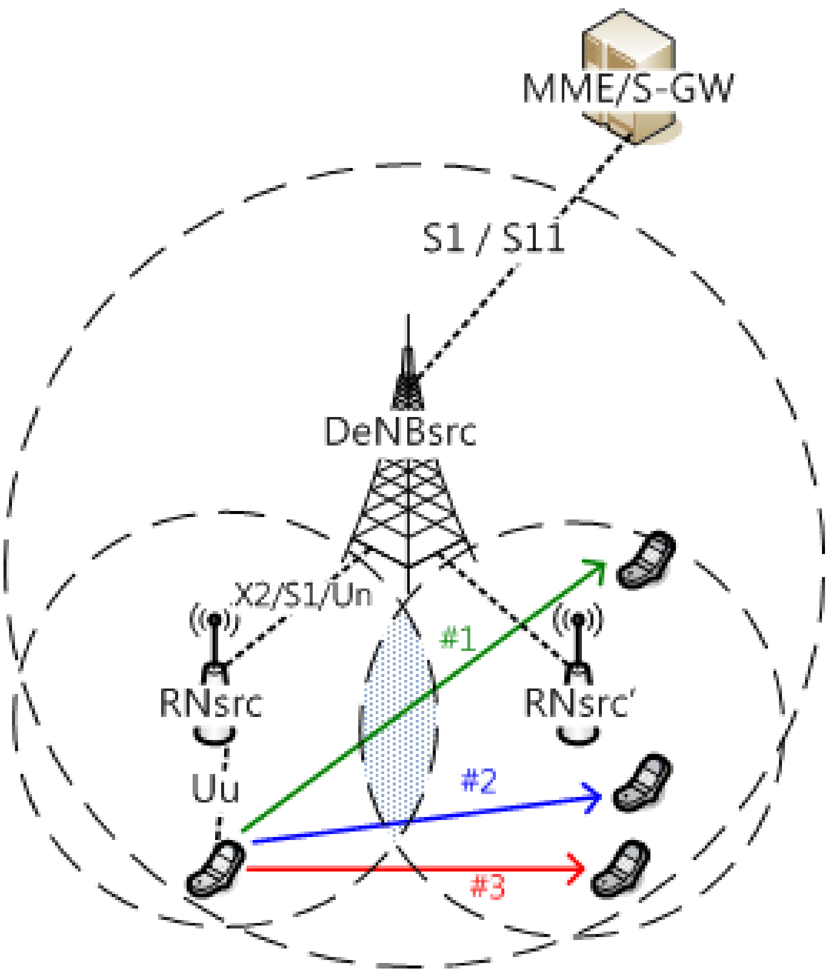

Figure 6. The topology for RNsrc - to - RNsrc’ handover.

When UE wants to hand over in Predictive mode from RNsrc to RNsrc ', the following situations shown in Figure 6 must be considered. It sequences chart is illustrated in Figure 7.

(1). When UE moves along the green path (#1) or blue path (#2), if the time UE stays in $L_{RNsrc \cap RNsrc'}$ between the source and the target, i.e., $\frac{L_{RNsrc \cap RNsrc'}}{V_{UE}}$, is longer than or equal to T_{HO_prepar} , UE can hand over in its predictive mode. Otherwise, once it leaves RNsrc's communication range, the handover will enter its reactive mode.

(2). The red path (#3) clearly shows that $|L_{src \cap tar}| = 0$. Therefore, after UE is disconnected from RNsrc, it may hand over to RNsrc' with a reactive mode, or to DeNBsrc with a predictive mode or reactive mode, depending on whether or not RNsrc has chosen DeNBsrc as the NMAG before UE leaves the communication range of RNsrc's. If yes, UE will hand over from RNsrc to DeNBsrc, and then hand over from DeNBsrc to RNsrc'.

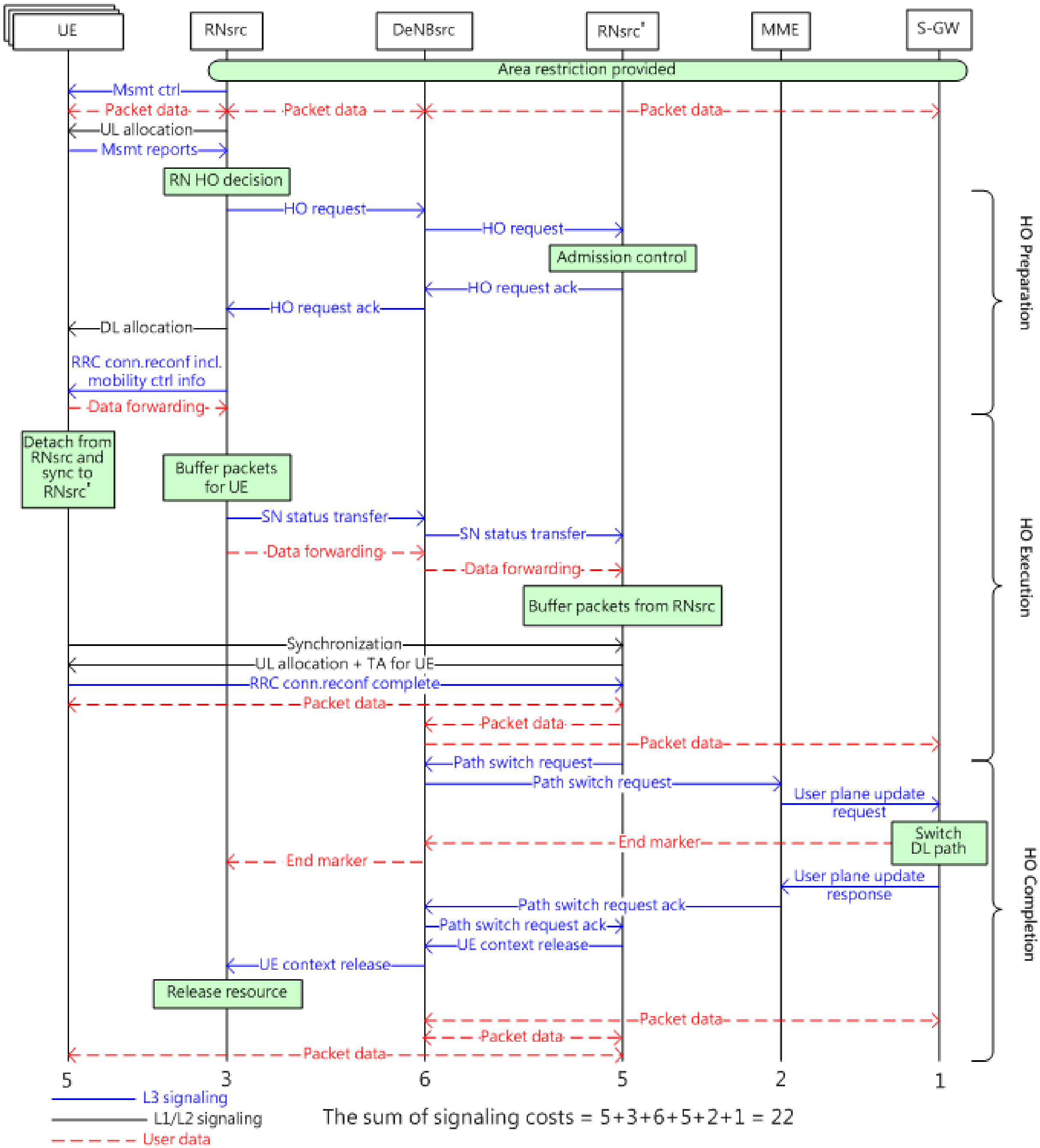

Figure 7. The sequence chart of RNsrc - to - RNsrc' handover on predictive mode.

3.4 Scenario 4: DeNBsrc - to - RNtar

The topology for UE to hand over from DeNBsrc to RNtar is shown in Figure 8, and the sequence chart is illustrated in Figure 9. Its Preparation, Execution and Completion stages are also themselves similar to the stages of previous scenarios. But source and target stations are DeNBsrc and RNtar, respectively, and the messages sent between DeNBsrc and RNtar, including HO request and HO request acknowledgement in HO Preparation and SN status transfer in HO Execution stage, must be transmitted via DeNBtar since RNtar is connected to DeNBtar. In the Completion stage, the path switch messages are sent between MME and RNtar via DeNBtar, and End marker is delivered to the PMAG, i.e., DeNBsrc.

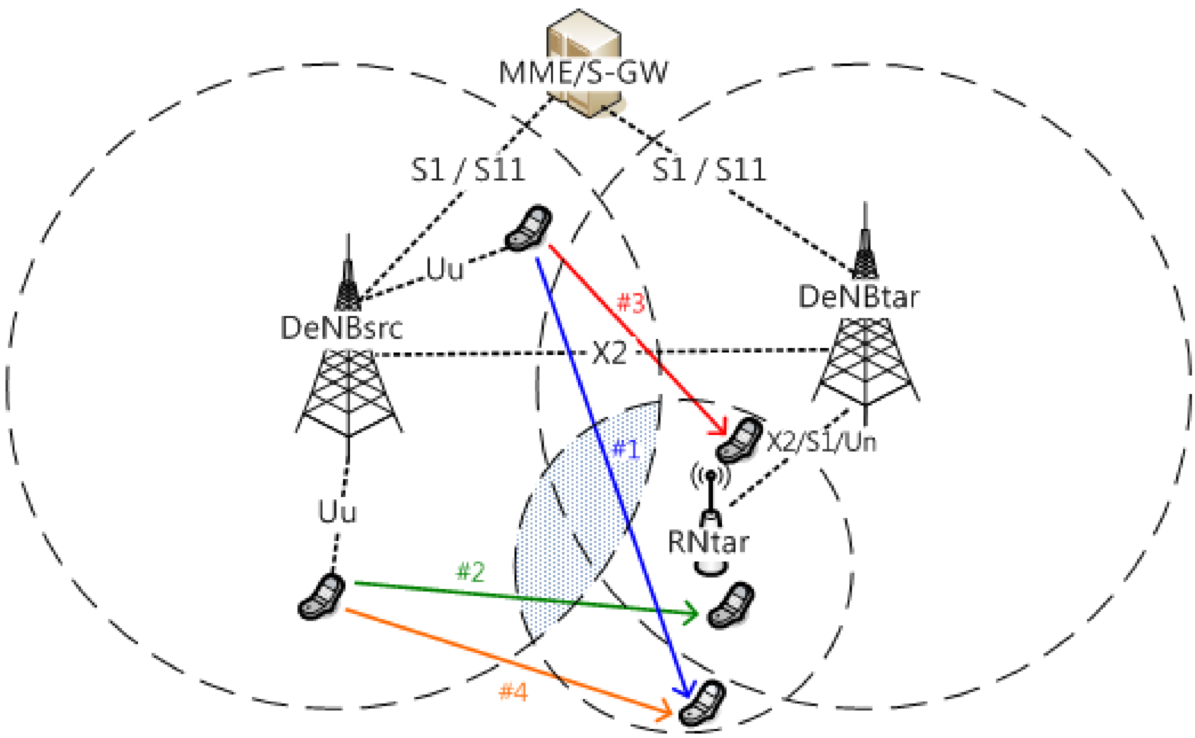

Figure 8. The topology for DeNBsrc - to - RNtar handover.

When UE wishes to hand over in a predictive mode from DeNBsrc to RNtar, the following situations shown in Figure 8 must be considered.

(1). When UE moves following the blue path (#1) and enters the border of the overlapped communication ranges of DeNBsrc and RNtar, denoted by area Ⅰ (i.e., the fish shape between DeNBsrc and RNtar), it may have enough time to hand over from DeNBsrc to RNtar or DeNBtar depending on the strength of RSS of RNtar and DeNBtar that UE receives (it will not hand over to DeNBtar before entering area Ⅰ because it does not reach the border of the communication range of DeNBsrc).

However, when it leaves the DeNBsrc communication range, if the handover fails, it will hand over to RNtar or DeNBtar based on signal strength of them in a reactive mode. If DeNBtar is selected, after handover, DeNBtar may choose RNtar for UE. Finally, UE will hand over to RNtar with a predictive mode.

(2). When UE moves following the green path (#2), if UE in area Ⅰ has enough time for handing over to RNtar, if can then successfully hand over to RNtar with a predictive mode. Otherwise, reactive-mode handover will be performed so as to hand over to RNtar.

(3). When UE moves following the red path (#3), UE will hand over to DeNBtar from DeNBsrc after entering the overlapped communication ranges of DeNBsrc and DeNBtar in a predictive or reactive mode, and then hand over from DeNBtar to RNtar.

(4). When UE moves following the orange path (#4), after UE leaves DeNBsrc, it hands over to RNtar in a reactive mode.

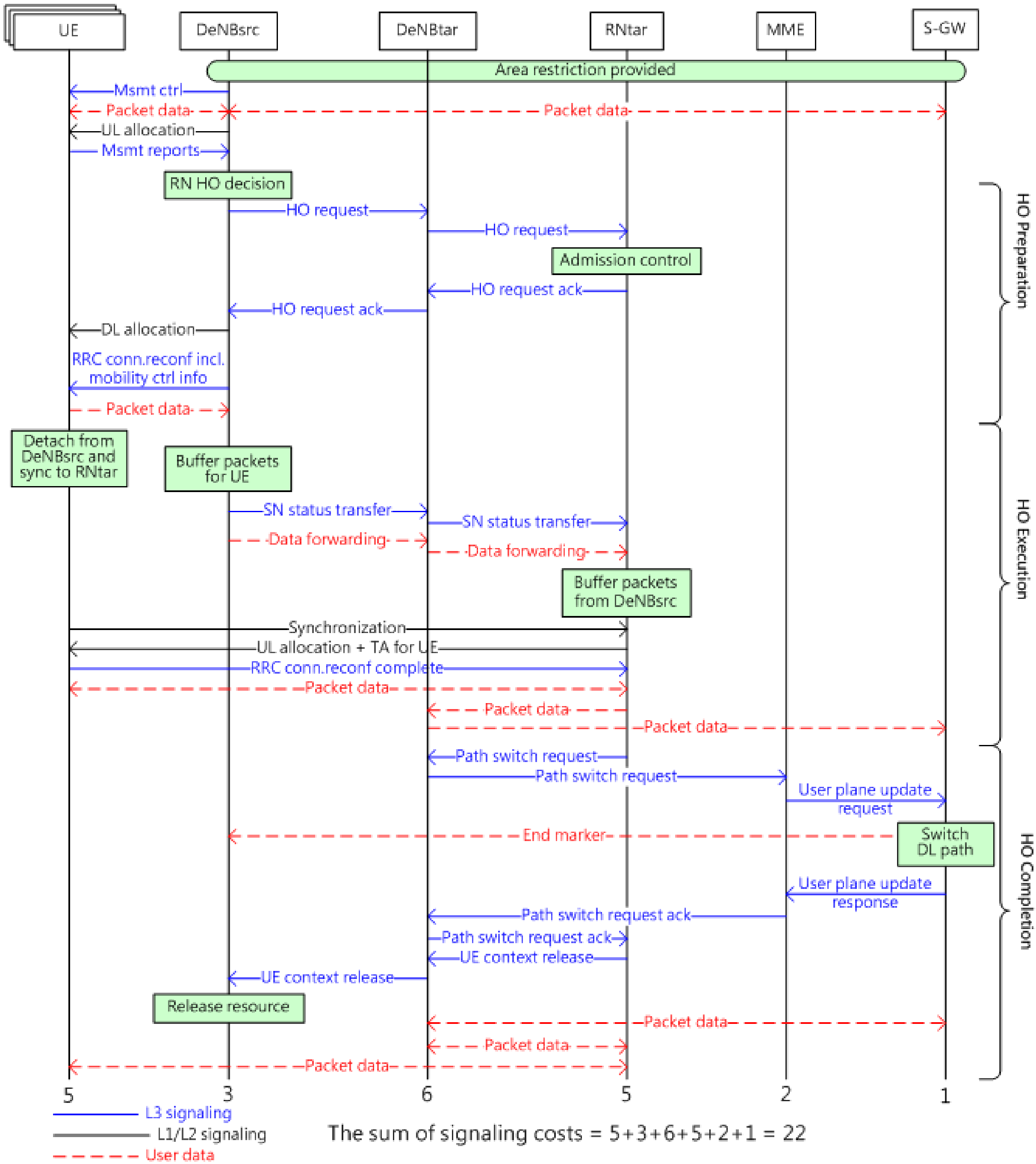

Figure 9. The sequence chart of DeNBsrc - to - RNtar handover on predictive mode.

3.5 Scenario 5: RNsrc - to - DeNBtar

The topology for UE to hand over from RNsrc to DeNBtar is shown in Figure 10, and the sequence chart is illustrated in Figure 11. Its Preparation, Execution and Completion stages are also themselves similar to the stages of previous scenarios. But source and target stations are RNsrc and DeNBtar, respectively. All the messages sent between RNsrc and DeNBtar must be transmitted via DeNBsrc since RNsrc is connected to the core network through DeNBsrc. Also, in the HO Completion stage, the path switch messages are delivered between MME and DeNBtar, and the End marker is delivered to RNsrc via DeNBsrc. DeNBtar sends UE context release message to RNsrc also through DeNBsrc.

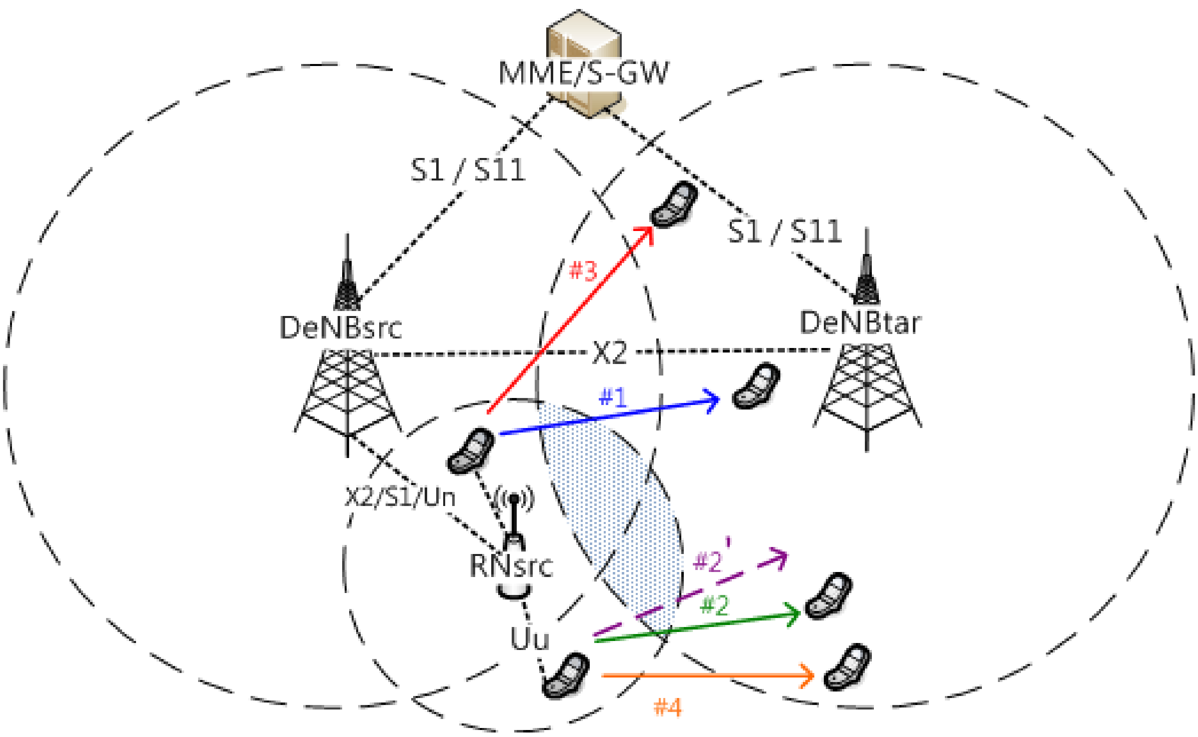

Figure 10. The topology for RNsrc - to - DeNBtar handover.

When UE would like to hand over in a predictive mode from RNsrc to DeNBtar, the following situations as shown in Figure 10 must be considered.

(1). When UE moves following the blue path (#1), and UE enters the border of the overlapped communication ranges of RNsrc and DeNBtar, denoted by area Ⅰ (the fish shape between RNsrc and DeNBtar), UE may hand over to DeNBtar in its predictive mode or reactive mode, depending on the time UE stays in area Ⅰ.

If reactive mode is used, UE may hand over to DeNBsrc or DeNBtar, depending their signal strengths when UE needs to hand over to the next base station. If the latter is selected, then after the handover, if reaches our destination. However, if DeNBsrc is selected, the UE continues to move within the communication range of DeNBsrc. After that, it will hand over to DeNBtar.

(2). When UE moves along the green path (#2), it will hand over to DeNBtar with a predictive or reactive mode.

(3). When UE moves along the red path (#3), UE will hand over to DeNBsrc from RNsrc and then to DeNBtar.

(4). When the UE moves following the orange path (#4), UE will hand over to DeNBtar from RNsrc with a reactive mode since it passes through the area out of both RNsrc's and

DeNBtar's communication ranges.

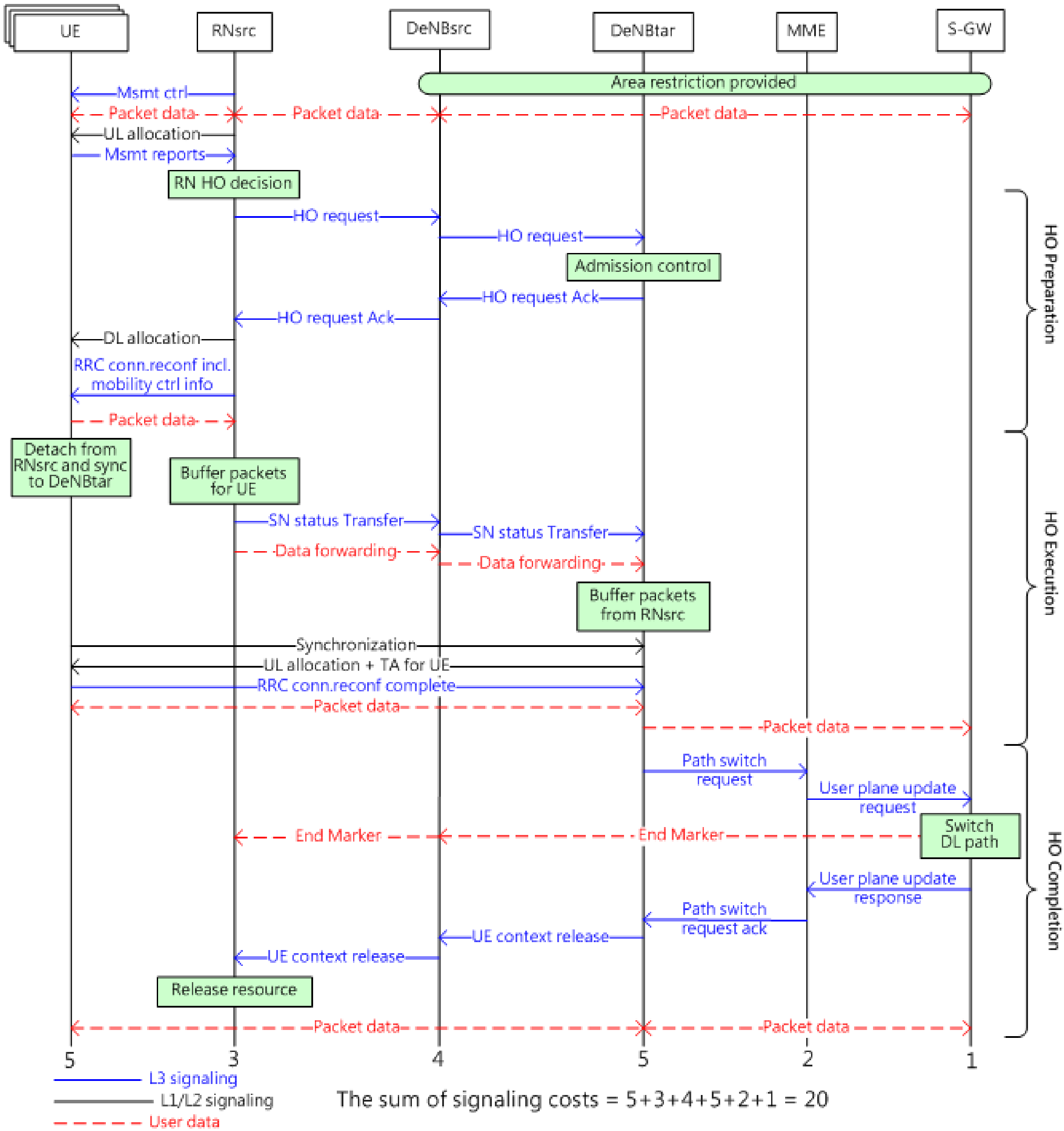

Figure 11. The sequence chart of RNsrc - to - DeNBtar handover on predictive mode.

3.6 Scenario 6: RNsrc- to - RNtar

The topology for UE to hand over from RNsrc to RNtar is shown in Figure 12, and the sequence chart is illustrated in Figure 14. Its Preparation, Execution and Completion stages are also themselves similar to the stages of previous scenarios. But source and target stations are RNsrc and RNtar, respectively. All messages delivered between RNsrc and RNtar, including control traffic, like HO request and HO request acknowledgement and data packets both delivered in HO Preparation stage, and SN status transfer sent in HO Execution stage, will be transmitted via DeNBsrc and DeNBtar. In the HO Completion stage, the path switch messages are sent between MME and RNtar via DeNBtar, and the End marker will be transmitted to RNsrc via DeNBsrc.

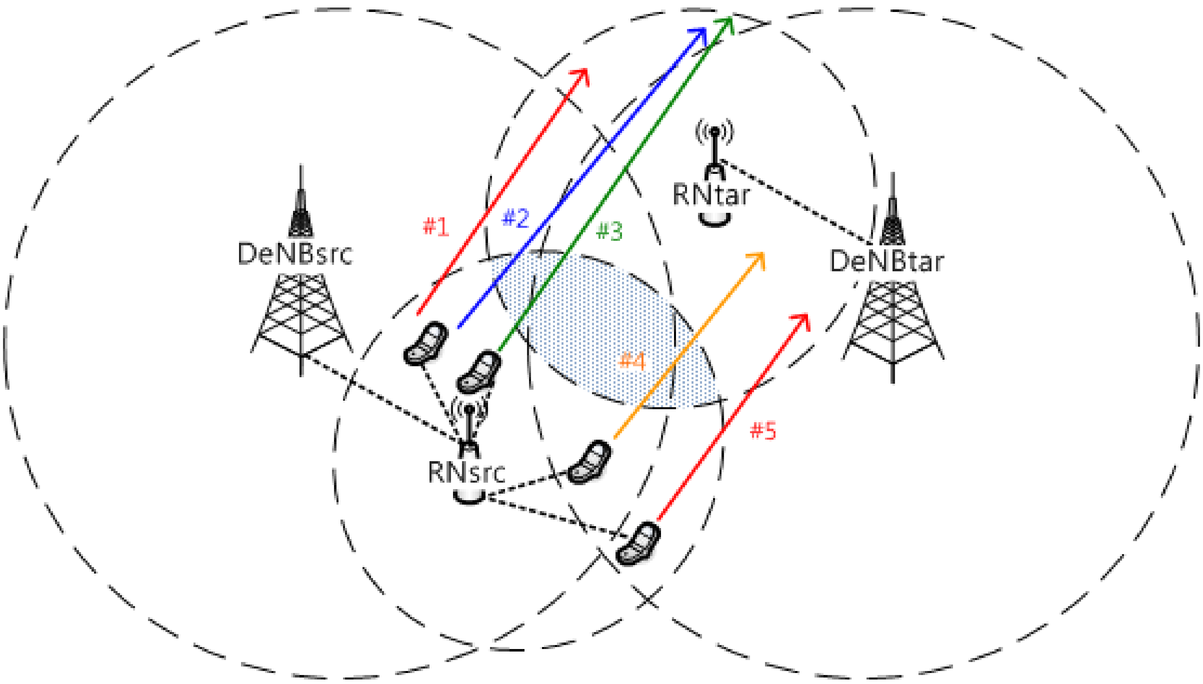

Figure 12. The topology for RNsrc - to - RNtar handover.

When UE wants to hand over from RNsrc to RNtar, the following situations shown in Figure 12 must be considered.

(1). When UE moves along path #1, UE will hand over to DeNBsrc and then to RNtar.

(2). When UE moves following the blue path (#2), green path (#3), or orange path (#4), since it will go through the overlapped communication ranges of RNsrc and RNtar, also denoted by area Ⅰ, before leaving RNsrc, UE will try to hand over to RNtar by using predictive mode. Following paths #2 and #3 (#4), UE may hand over to DeNBsrc (DeNBtar) and then to RNtar.

(3). When UE moves along path #5, it will hand over to DeNBtar and then to RNtar.

It is noteworthy that, even if the eNB to which an RN belongs does not change, the change of the location of the RN will affect the NMAG to which UE subsequently connects.

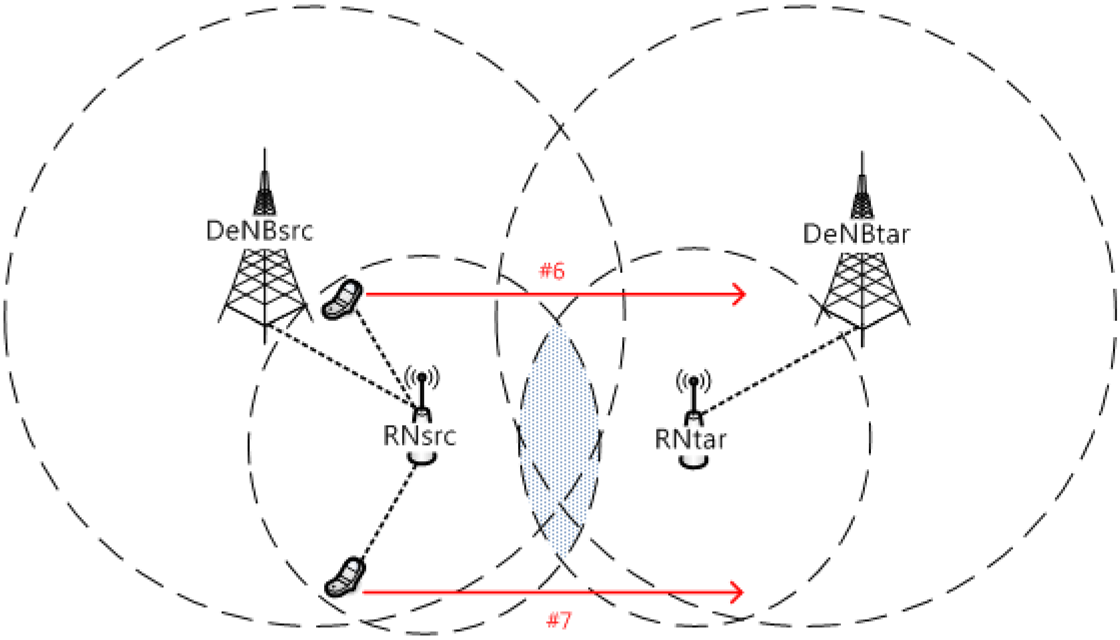

Figure 13. When the location of RN deployment changed.

Compared with Figure 12, it can be seen that in Figure 13, we move RNtar from the North-west to the west-south of DeNBtar. Paths #6 and #7 in Figure 13 are similar to paths #1 and #5 in Figure 12. Note that UE in its reactive mode may select different target base stations, depending on the signal strengths of their nearby base stations. In Figure 12, when UE leaves RNsrc following path, #1, it first detects the signal of DeNBsrc, while along path #5, it senses the signal of DeNBtar first. Following path #6, it can detect DeNBsrc and DeNBtar signals at the same time. Along path #7, it will disconnect from the network because UE will receive no signal from nearby base stations. It will be unable to hand over until reaching the communication range of RNtar. Therefore, we can see that under the same scenario, even though DeNBs to which RNs belong are not changed, when the locations where RNs are deployed vary, different paths that UE has passed through will result in different handover behaviors. In fact, it is impossible to exhaustively list all probable paths in one of deployed location.

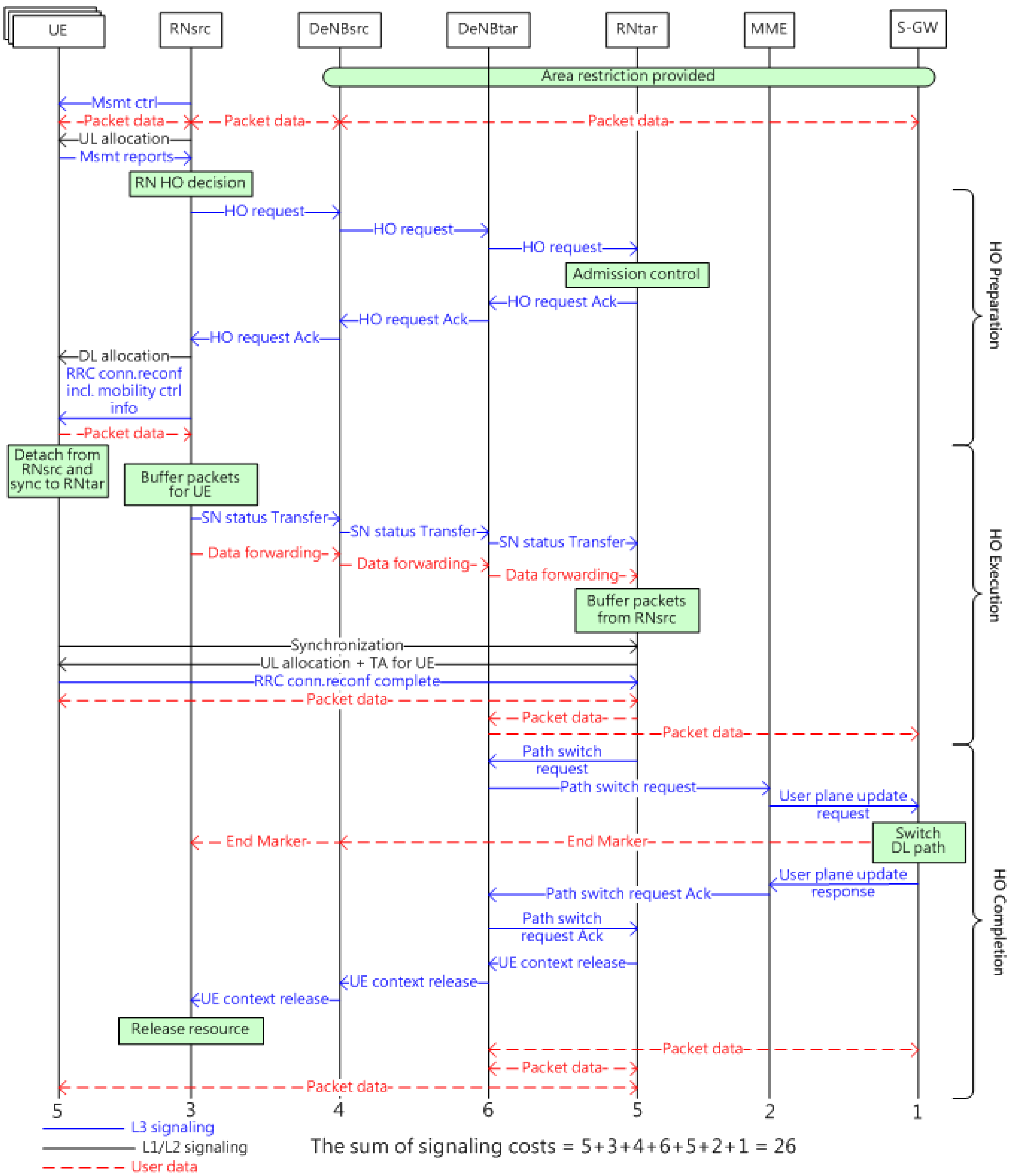

Figure 14. The sequence chart of RNsrc - to - RNtar handover on predictive mode.

3.7 Signaling Cost of Scenarios

Scenario 1, the handover and signaling cost of DeNBsrc to RNsrc, is:

T(DeNBsrc-UE) + T(DeNBsrc-UE) + T(DeNBsrc-RNsrc) + T(RNsrc-DeNBsrc) + T(UE-DeNBsrc) + T(DeNBsrc-UE) + T(DeNBsrc-UE) + T(DeNBsrc-RNsrc) + T(UE-RNsrc) + T(RNsrc-UE) + T(UE-RNsrc) + T(RNsrc-DeNBsrc) + T(DeNBsrc-MME) + T(MME-SGW) + T(SGW-MME) + T(MME-DeNBsrc) + T(DeNBsrc-RNsrc) + T(RNsrc-DeNBsrc) = 18T

in which 5T(UE-DeNBsrc) is the cost including measurement messages, RRC procedure and L2 signals (e.g., UL/DL allocation), and 6T(DeNBsrc-RNsrc) is the cost for admission control, packet data SN status information, path switch message and UE context release signal. 3T(UE-RNsrc) is for synchronization procedure, and 2T(DeNBsrc-MME) is the path switch signaling forwarding to MME via DeNBsrc from RNsrc, 2T(MME-SGW) is for User plane update.

Scenario 2, the handover and signaling cost of RNsrc to DeNBsrc, is:

T(RNsrc-UE) + T(RNsrc-UE) + T(UE-RNsrc) + T(RNsrc-DeNBsrc) + T(DeNBsrc-RNsrc) + T(RNsrc-UE) + T(RNsrc-UE) + T(RNsrc-DeNBsrc) + T(UE-DeNBsrc) + T(DeNBsrc-UE) + T(UE-DeNBsrc) + T(RNsrc-DeNBsrc) + T(DeNBsrc-MME) + T(MME-SGW) + T(SGW-MME) + T(MME-DeNBsrc) + T(DeNBsrc-RNsrc) + T(DeNBsrc-RNsrc) = 18T

The cost in this scenario is similar to scenario1, but the direction of signaling forwarding is from RNsrc to DeNBsrc.

Scenario 3, the handover and signaling cost of RNsrc to RNsrc', is:

T(RNsrc-UE) + T(RNsrc-UE) + T(UE-RNsrc) + T(RNsrc-DeNBsrc) + T(DeNBsrc-RNsrc') + T(RNsrc'-DeNBsrc) + T(DeNBsrc-RNsrc) + T(RNsrc-UE) + T(RNsrc-UE) + T(RNsrc-DeNBsrc) + T(DeNBsrc-RNsrc') + T(UE-RNsrc') + T(RNsrc'-UE) + T(UE-RNsrc') + T(RNsrc'-DeNBsrc) + T(DeNBsrc-MME) + T(MME-SGW) + T(SGW-MME) + T(MME-DeNBsrc) + T(DeNBsrc-RNsrc') + T(RNsrc'-DeNBsrc) + T(DeNBsrc-RNsrc) = 22T

in which 5T(UE-RNsrc) is the cost including measurement messages, RRC procedure and L2 signals (e.g., UL/DL allocation), and 4T(RNsrc-DeNBsrc) is the cost for admission control, packet data SN status information and UE context release signal. 3T(UE-RNsrc') is for synchronization procedure, 6T(DeNBsrc-RNsrc') for signaling forwarding, path switch request and UE context release signal, and 2T(DeNBsrc-MME) for signaling forwarding, 2T(MME-SGW) is for User plane update.

Scenario 4, the handover and signaling cost of DeNBsrc to RNtar, is:

T(DeNBsrc-UE) + T(DeNBsrc-UE) + T(UE-DeNBsrc) + T(DeNBsrc-DeNBtar) + T(DeNBtar-RNtar) + T(RNtar-DeNBtar) + T(DeNBtar-DeNBsrc) + T(DeNBsrc-UE) + T(DeNBsrc-UE) + T(DeNBsrc-DeNBtar) + T(DeNBtar-RNtar) + T(UE-RNtar) + T(RNtar-UE) + T(UE-RNtar) + T(RNtar-DeNBtar) + T(DeNBtar-MME) + T(MME-SGW) + T(SGW-MME) + T(MME-DeNBtar) + T(DeNBtar-RNtar) + T(RNtar-DeNBtar) + T(DeNBtar-DeNBsrc) = 22T

in which 5T(UE-DeNBsrc) is the cost including measurement messages, RRC procedure and L2 signals (e.g., UL/DL allocation), and 4T(DeNBsrc-DeNBtar) is the cost for admission control, packet data SN status information and UE context release signal. 3T(UE-RNtar) is for synchronization procedure, 6T(DeNBtar-RNtar) for signaling forwarding, path switch request and UE context release signal, and 2T(DeNBtar-MME) for signaling forwarding, 2T(MME-SGW) is for User plane update.

Scenario 5, the handover and signaling cost of RNsrc to DeNBtar, is:

T(RNsrc-UE) + T(RNsrc-UE) + T(UE-RNsrc) + T(RNsrc-DeNBsrc) + T(DeNBsrc-DeNBtar) + T(DeNBtar-DeNBsrc) + T(DeNBsrc-RNsrc) + T(RNsrc-UE) + T(RNsrc-UE) + T(RNsrc-DeNBsrc) + T(DeNBsrc-DeNBtar) + T(UE-DeNBtar) + T(DeNBtar-UE) + T(UE-DeNBtar) + T(DeNBtar-MME) + T(MME-SGW) + T(SGW-MME) + T(MME-DeNBtar) + T(DeNBtar-DeNBsrc) + T(DeNBsrc-RNsrc) = 20T

in which 5T(UE-RNsrc) is the cost including measurement messages, RRC procedure and L2 signals (e.g., UL/DL allocation), and 4T(RNsrc-DeNBsrc) is the cost for admission control, packet data SN status information and UE context release signal. 3T(UE-DeNBtar) is for synchronization procedure, 4T(DeNBsrc-DeNBtar) for signaling forwarding, UE context release signal, and 2T(DeNBtar-MME) for path switch request, 2T(MME-SGW) is for User plane update.

Scenario 6, the handover and signaling cost of RNsrc to RNtar, is:

T(RNsrc-UE) + T(RNsrc-UE) + T(UE-RNsrc) + T(RNsrc-DeNBsrc) + T(DeNBsrc-DeNBtar) + T(DeNBtar-RNtar) + T(RNtar-DeNBtar) + T(DeNBtar-DeNBsrc) + T(DeNBsrc-RNsrc) + T(RNsrc-UE) + T(RNsrc-UE) + T(RNsrc-DeNBsrc) + T(DeNBsrc-DeNBtar) + T(DeNBtar-RNtar) + T(UE-RNtar) + T(RNtar-UE) + T(UE-RNtar) + T(RNtar-DeNBtar) + T(DeNBtar-MME) + T(MME-SGW) + T(SGW-MME) + T(MME-DeNBtar) + T(DeNBtar-RNtar) + T(RNtar-DeNBtar) + T(DeNBtar-DeNBsrc) + T(DeNBsrc-RNsrc) = 26T in which 5T(UE-RNsrc) is the cost including measurement messages, RRC procedure and L2 signals (e.g., UL/DL allocation), and 4T(RNsrc-DeNBsrc) is the cost for admission control, packet data SN status information and UE context release signal. 3T(UE-RNtar) is for synchronization procedure, 4T(DeNBsrc-DeNBtar) for signaling forwarding, and 6T(DeNBtar-RNtar) is the cost for signaling forwarding, path switch request, and UE context release signal, 2T(DeNBtar-MME) for signaling forwarding, and 2T(MME-SGW) for User plane update.

4. Simulations and Discussions

In this following, we use the LTE module provided by the Network Simulator-3 (NS-3) [12] as our experimental tool to simulate three employed networks, and adopt scenario 5 in which UE hands over from RNsrc to DeNBtar as an example to analyze the behaviors of UE. Four experiments were performed. The first measured the accumulated HO-delay for the 4 paths shown in Figure 10. The second re-did the first on a fixed path given different UE's moving speeds. The third re-did the second experiment on different numbers of UEs, e.g., they are now taking a vehicle, which is now under the same eNB. The last one simulated the random paths with a randomly selected direction and speed that UE may move, e.g., UE is now in a wide plaza or square. He/she may move toward any direction.

Table 1. Default values of Parameters used in the following simulation [33].

Parameter Name	**Value**
Carrier frequence	2 GHz
DeNB_TxPower	43 dbm
Bandwidth	20 MHz
RN_TxPower	30 dbm
RN_Bandwidth	10MHz
Distance between RNsrc and DeNBsrc	1200 m
Distance between DeNBs	3000 m
Moving Speed	60 – 500 km/h
The number of an UE group	10

4.1 Experiment on Different Paths

As shown in Figure 10, when UE moves from RNsrc and then enters the overlapping area of at least two base stations' communication ranges following different directions, since in this overlapping area, the RSRQ/RSRP of each base station at different points is different, the selected base station varies. Through variety of paths, even if UE finally arrives at DeNBtar, costs may be different.

In the first, UE hands over to DeNBsrc from RNsrc in Predictive mode via Path #3. The number of successful handovers is two, before UE arrives at DeNBtar. Figure 15 shows the results (red line). The 1st and 2nd handover points are 281 m and 1012 m, respectively, away from UE's start point, the point where distance = 0. The accumulative handover delay is 101.4 (=50.6+50.8) msec. When passing through path #1, due to the RSRQ/RSRP, DeNBsrc is selected. This hand over occurs at the location 408 m away from its start point. After that, UE hands over to DeNBtar at the point of 964 m. The accumulative handover time is also 101.4 msec.

It is worth mentioning that due to moving toward different directions, and then receiving different RSRQs/RSRPs from different base stations, even though UE passes through the same overlapping area, different base stations may be selected, causing different numbers of handover. For example, assuming that a path has the same origin as that of path #1 and passes the overlapped communication ranges of DeNBsrc, RNsrc and DeNBtar. But the direction is shifted to the lower right, or the location where RNsrc is deployed is closer to DeNBtar. Even though the RNsrc is connected to DeNBsrc, when UE comes close to the border of RNsrc's communication range, it may be that the RSRP/RSRQ of the DeNBtar is stronger than that of the DeNBsrc. As a result, UE directly hands over to DeNBtar, and the number of handover is only one. This is the best case. So if there is an existing route, we can adjust the position of relay nodes so that when UE goes along this route, the number of handover occurred is the least.

When passing through path #2, UE may hand over to DeNBtar in reactive mode after leaving the communication range of RNsrc because the distance of the path segment in the overlapped communication ranges of RNsrc's and DeNBtar's is too short for UE to finish its HO Preparation phase. At the point of the 193 m (green line), the unfinished handover lasts about 15 ms which is an unnecessary signaling overhead. At last, it spends about 50 ms to hand over to the target eNB, i.e., DeNBtar.

In the case of path #4 (yellow line), since the UE cannot detect the signals of other base stations before leaving the communication range of RNsrc, the active link, the connection between UE and RNsrc, will be disconnected after leaving the communication range of RNsrc at about 182 m. It detects the signal of DeNBtar at the location 1119 m away from its start point.

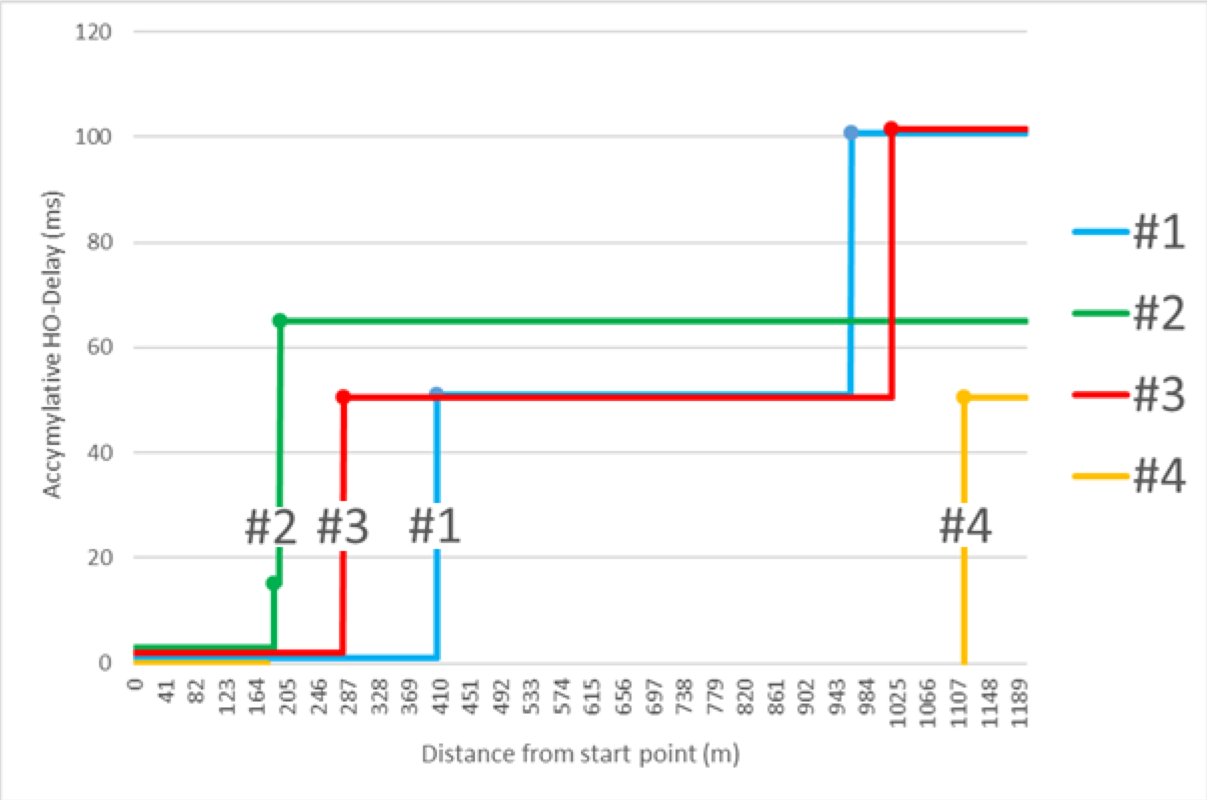

Figure 15. Numbers of handover and of the position, where UE hands over, from UE's start point when UE moves through different paths with speed = 350 km/h (at 193 m, there is an unfinished predictive-mode handover).

As shown in Figure 15, the accumulative handover delays of paths #2 and #4 are shorter than those of paths #1 and #3. But, along path #4, UE is disconnected from the network at 182 m, and of course, UE loses its network services for about 9.6 (=$\frac{(1118-182)}{350km/h}$) seconds. In other words, path #2 is better than others, even though it fails on predictive mode at the point of 193 m, causing the unnecessary overhead. Basically, it is hard for us to exhaustively explore the behaviors of all possible paths. For example, rotating path #2 counterclockwise 15°, denoted by #2', the duration in which UE stays in the overlapped communication ranges will be longer so that it has enough time to complete handover on predictive mode. Consequently, the 15 ms due to unsuccessful predictive-mode handover can be avoided. That is, we can adjust the position of RNsrc, e.g., shifting it right a little, to enlarge the overlapped communication ranges of RNs and DeNBtar so that when UE follows path #2, it will hand over to DeNBtar directly, of course, with predictive mode, and the number of handover is one.

4.2 Experiment on Different Moving Speeds

As shown in Figure 16, when UE goes through the fish shape area, i.e., the overlapping area of the two eNBs' communication ranges, in different directions, the time UE stays in this area varies since their segment lengths in this area are different. In the second experiment, we fix UE's moving direction, i.e., going right straight (green path), given different moving speeds. The path segment in the overlapped area is 1 m. The results are shown in Figure 17.

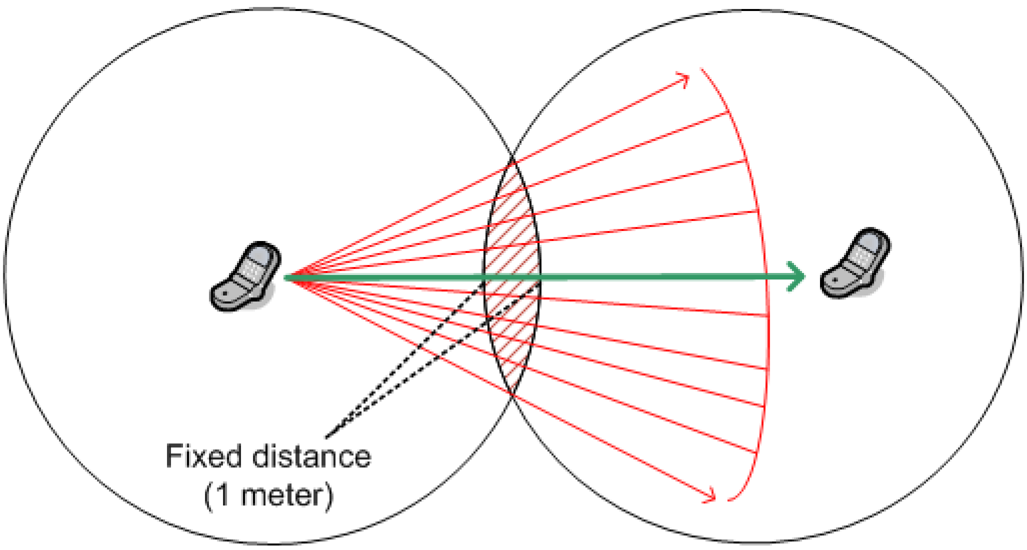

Figure 16. When UE moves in a fixed velocity and goes across the overlapped area of the two communication ranges, resulting in different stay time due to different lengths of different path segments.

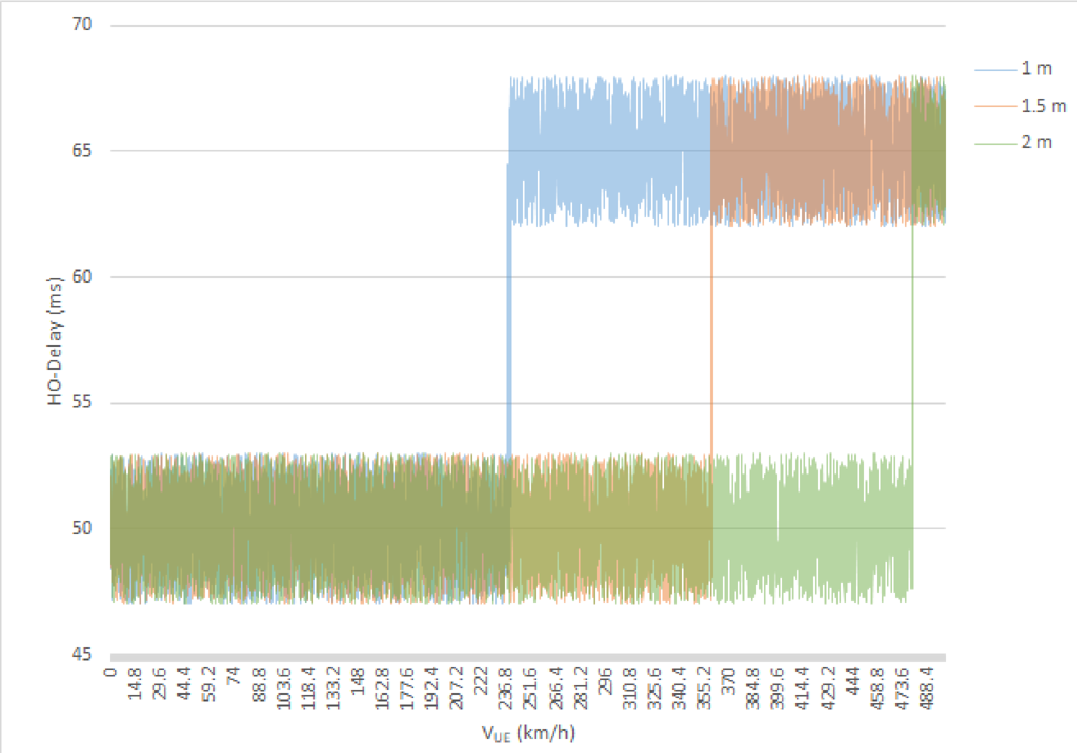

Figure 17. Handover delay at the same path with different velocities given the lengths of the segment which are 1, 1.5 and 2 meters, in communication ranges of two eNBs.

When the moving speed is lower than 240 km/h and the length of the segment in communication ranges is 1m, the handover delay is about 50 ms in average. However, when the speed is over this, the delay is risen to 65 ms because UE during its stay in the overlapped communication area is unable to complete the HO Preparation stage with predictive mode. When the lengths of the segment are 1.5 m and 2 m, the handover delays go up at the speeds of 360 and 480 km/h, respectively. That is, when an UE's moving path and speed are predictable or traceable, e.g., a railroad or a freeway, as mentioned above, we can then determine where to deploy RNs so as to enlarge the overlapped communication ranges and lengthen the path length in this overlapped area, making UE able to successfully hand over to DeNBtar with predictive mode. The purpose is to reduce the handover times, minimize its delays and lower its energy consumption.

4.3 Experiment on Different Numbers of UEs

The third experiment redid the second one given different numbers of UEs. Currently, a group of UEs now stays in a vehicle (for example, in a train), and the train moves in the communication range of an eNB. We simulate two cases of handover as two sub-experiments. The first is that when these UEs individually hand over (see Figure 18), they may impact the performance of the target eNB. The second is that a Mobile RN (MRN), equipped at the top of the train, acts as a proxy of all the UEs (see Figure 19), and the MRN hands over to target eNB. Of course, the connection between each UE and the MRN remains, and the MRN serves as an UE of the target eNB. The second sub-experiment will be performed given different paths and different moving speeds.

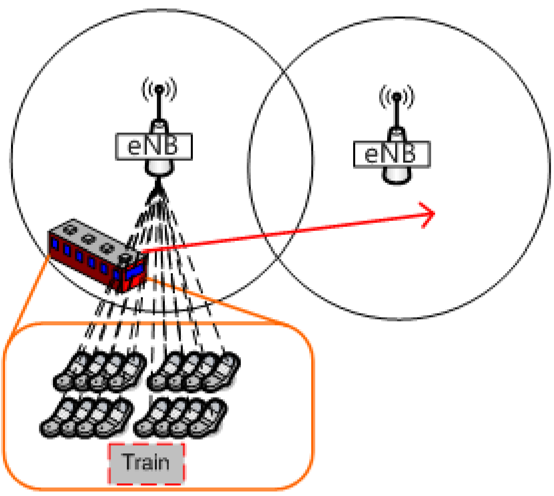

Figure 18. The train carries a group of UEs and all UEs hand over to their target eNB individually.

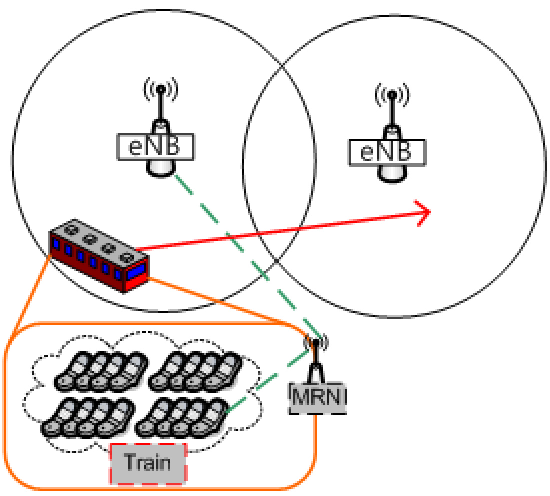

Figure 19. A train carries a group of UEs and its RN (i.e., MRN) serves as a proxy of these UEs.

4.3.1 Handing over individually

In the first sub-experiment of experiment 3, UEs hand over individually at the same time.

Table 2. SRS Periodicity v.s. UE Capacity [15]

SRS Periodicity	UE Capacity (No. of UEs
2	2
5	5
10	10
20	20
40	40
80	80
160	160
320	320

In general, as listed in Table 2, the maximum number of UEs staying in their active states is usually the same as the valid value of the Sounding Reference Signal (SRS) [18]. For example, when the SRS period is 80, the eNB can serve only 80 UEs simultaneously. However, the SRS in the employed LTE module is likely to be lower than 80 [15].

Table 3. The impact on HO delays with predictive mode given different numbers of UEs.

Number of UEs	Avg.HO_delay (delay of one UE)
1	50.3 ms
5	50.8 ms
10	82.3 ms
> 14	×

The default number of UEs in NS-3 is 14 [16], which is the max number of UEs that can hand over at the same time. Those other than this 14 cannot hand over at that moment, resulting in the fact that their HO delays cannot be measured simultaneously. Another times of measurement sometimes later is required. Thus, it is inappropriate to put them together. In fact, an eNB actually has 64 preamble IDs [17]. In other words, during the time duration when the 14 UEs hand over, the remaining 50 can only maintain a connection in an inactive state. Generally, the number of UEs in their active state is limited by the SRS Periodicity [15] [18].

In this sub-experiment, the number of UEs given is 10. Their signal strengths received from the same eNB are almost the same, and they hand over to the target eNB at the same time. Therefore, the eNB needs to deal with these UEs' control signals all at once, resulting in longer handover delay. Table 3 shows HO delays on different numbers of UEs.

4.3.2 UEs moving along different paths with the same speed

In the second sub-experiment, a group of 10 UEs moves together with the same speed each time along one of the paths shown in Figure 10. Since an MRN serves as the proxy of these UEs and acts as an UE of the target eNB, the handover is accomplished by the MRN and the DeNB. These UEs connecting to MRN keep their active connections. The accumulative HO delays are shown in Figure 20.

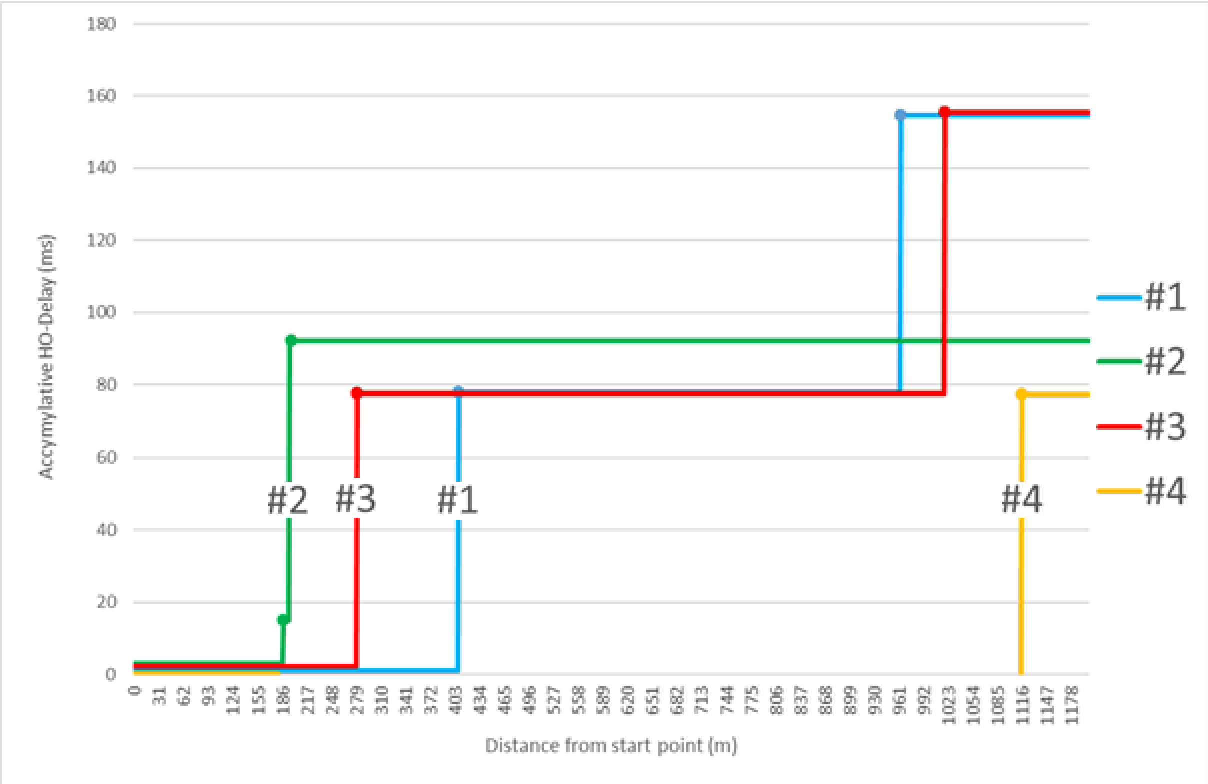

Figure 20. The accumulative of HO delays on different paths.

The delay of each handover is about 27-30 ms higher than the corresponding one shown in Figure 15 due to aggregating and forwarding data packets for the 10 UEs by MRN. From the eNB's viewpoint, it only receives a handover request from one UE i.e., (MRN), rather than from 10 UEs, thus reducing the burden of eNB. Following path #2 (green line), when MRN cannot successfully hand over with predictive mode, the wasted time (about 15 msec) is similar to that shown in Figure 15. Because the handover fails in Preparation stage, MRN will not enter its Execution and Complete stages. Of course, reactive mode is utilized.

4.3.3 UEs moving along the same path with different speeds

In the second part of experiment 3's second sub-experiment, the group of 10 UEs staying in a bus or train moves along the same path with the same speeds. Their moving distances are identical. Figure 21 illustrates the results.

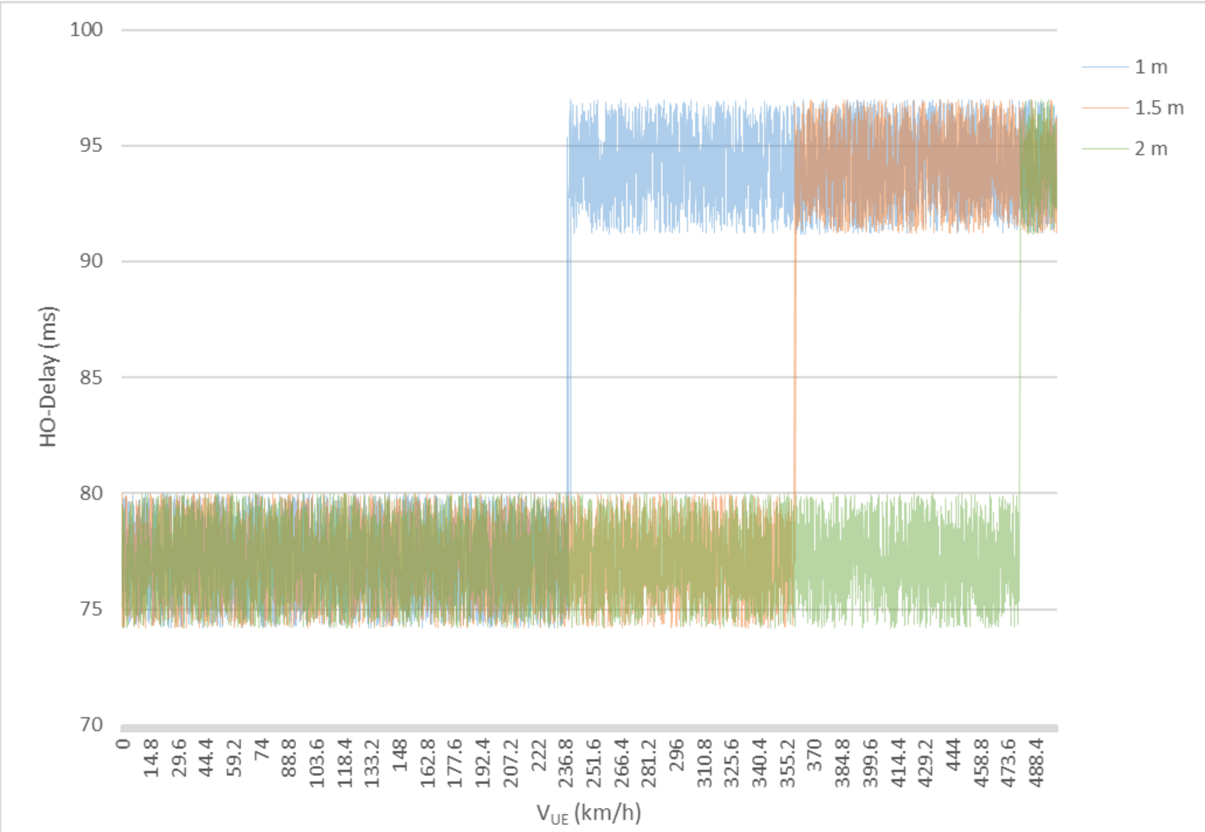

Figure 21. The handover delay for one UE when a group of UEs hands over given different moving speeds and different lengths of the segment, which are 1, 1.5 and 2 meters, in the communication ranges of two eNBs.

As shown in Figure 16, the path segment in the overlapped communication ranges of two eNBs is one-meter long. When the group of UEs' speed is higher than 240 km/h, handover delays rise from 74-80 to 92-97 msec. The latter is about 17 or 18 ms higher than the former. The reason is that 1 meter is too short for MRN to successfully hand over with predictive mode.

The handover will be changed to reactive mode. The 17 ~ 18 ms increase is about 15 msec ($=\frac{1\text{m}}{240\text{km/h}}$) for performing predictive-mode handover in this overlapped area plus the time for mode change and that for eNB scanning. Actually, the predictive-mode handover delay for one UE (10 as a group) listed in Table 3 is about 5.3 ($=82.3-\frac{74+80}{2}$) msec higher than that illustrated in Figure 21 since the experimental environments, including network parameters and H/W and S/W of testbeds, between the one in [15] and ours in Table 1 are different.

4.4 Experiment on Random Moving Model

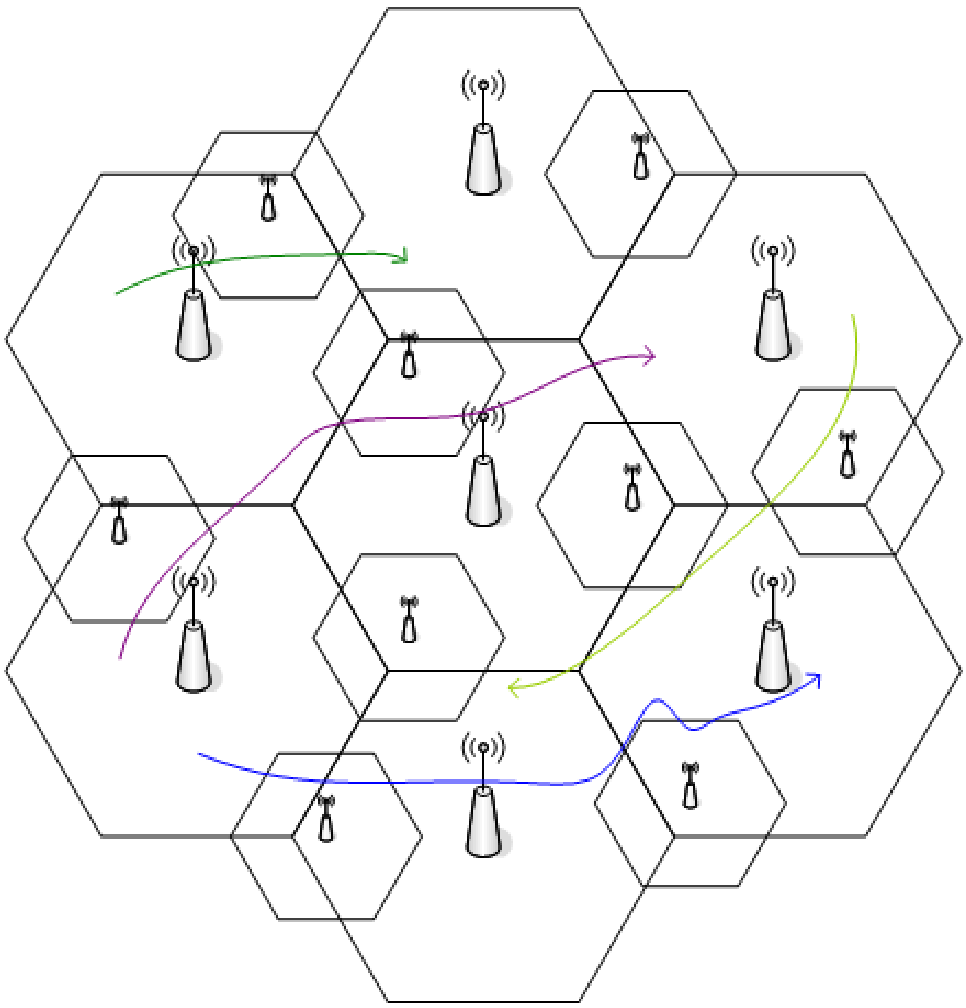

Figure 22. UEs move with their own velocities following different paths.

In the real world, the actual path that an UE may move sometimes is hard to predict, particularly when the user stays in a wide plaza or square. In the fourth experiment, the network topology is shown in Figure 22, in which each UE's moving direction and speed are both randomly assigned every 5 seconds to simulate its unpredictable behaviors. The parameters of the experimental environment are also those listed in Table 1. A total of 10 UEs is employed. The simulation time is 3000 seconds. Figure 23 illustrates the accumulative HO-redo delays defined as the accumulated time periods of unsuccessful predictive-mode handover. Of course, reactive-mode handover is then performed.

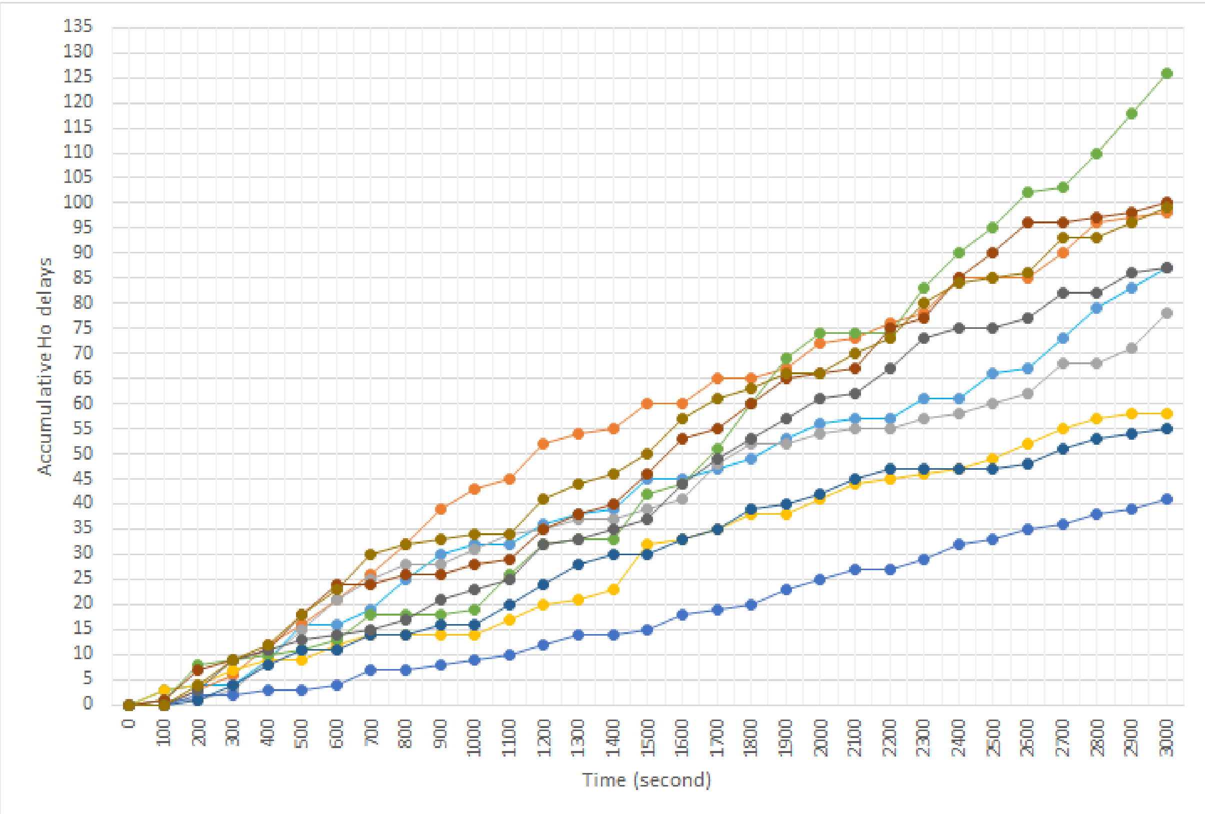

Figure 23. The accumulative HO redo times given random speeds and random directions.

The simulations have been redone ten times in the timeline, when the accumulative handover delays keep in the same value along X-axis, predictive-mode handovers are all successfully accomplished. After this same-value duration, due to different moving speeds and paths, UEs are unable to finish its predictive-mode handover in the overlapped communication ranges of two neighbor eNBs. Even though UE's moving speed is fixed, the length of the path segment in the overlapping communication range may be still too short.

5. Conclusions and Future Studies

With the quick evolution of mobile devices, people heavily relies on wireless communication in their everyday lives. Therefore, how to select a better base station during handover to ensure network QoS is one of the key concerns nowadays. In this paper, we propose several scenarios for UE to hand over to its target base station, including the scenarios between different RNs and DeNBs where RNs are under the same DeNB or different DeNBs. We also explore their signaling sequence charts. Experiments show that when different RNs are deployed at different positions in its DeNB's communication range, and RNs' and DeNBs' communication ranges are overlapped, handover behaviors vary since different paths may result in different handover sequences. Consequently, the handover delays will change. Therefore, when a path that an UE may pass through is fixed, like a freeway or railway, the location that an RN is deployed needs to be dealt with. Otherwise, handover costs may be higher.

In the future, with the progress of 5G, relay stations (i.e., small cells) will be massively deployed, so we will develop a universal method, which can be applied to a variety of scenarios, and improve their working efficiencies. Beside, we would also like to consider the cost-effective and QoS requirements before UE hands over to a target base station so as to select the most suitable one for handing over. The purpose is maintaining the service quantity it receives from the serving network. These constitute our future studies.

6. Acknowledgement

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