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A moving direction prediction-assisted handover scheme in LTE networks

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Abstract

The 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) defines a wireless network standard for high packet transmission rate and low packet latency provisions. Handover is one of the important features for helping user equipments (UEs) to roam between LTE networks. However, LTE networks adapt a make-before-break handover procedure, which may cause a brief disconnection, therefore results in the packet transmission delay and packet loss problems. In this paper, we propose a moving direction prediction-assisted handover scheme for LTE networks to lower the number of handovers. We first track the location of user equipments (UEs) to predict their moving direction. By referencing previous locations, the next moving direction of UEs is estimated with the cosine function in order to determine the candidate E-UTRAN NodeBs (eNBs) for handover. Then, a target eNB is selected from the candidate eNBs through an angle-based dynamic weight adjustment scheme. By selecting a proper target eNB for handover, thus the quality of network transmission can be enhanced. Simulation results demonstrate the ability of the proposed scheme in reducing 17% average handover times, compared with the standard handover procedure, thereby reducing 12% average number of packet loss and 5% average packet delay time.

Keywords: Handover; Moving direction prediction; LTE networks

Introduction

To meet the increasing demand of wireless data services, the 3rd Generation Partnership Project (3GPP) has proposed UMTS Terrestrial Radio Access Network (UTRAN) Long Term Evolution (LTE) [1]. LTE networks provide high-speed communication within uplink and downlink, as well as aiming to provide more capacity along with less network complexity and low installation and maintenance cost [2]. Two different radio access mechanisms are used in LTE networks, orthogonal frequency-division multiple access (OFDMA) is used for downlink and single-carrier frequency-division multiple access (SC-FDMA) is used for uplink [3,4]. OFDMA provides high spectral efficiency which is very immune to interference and reduces computation complexity in the terminal within larger bandwidths [5]. SC-FDMA has lower peak to average power ratio (PAPR) provisions, which leads toward longer battery use as well as larger radio coverage [6]. Another advantage of using LTE networks is its

capability to switch back to older legacy systems such as Wideband Code Division Multiple Access (WCDMA), when user equipment (UE) gets out of coverage from an LTE network [7].
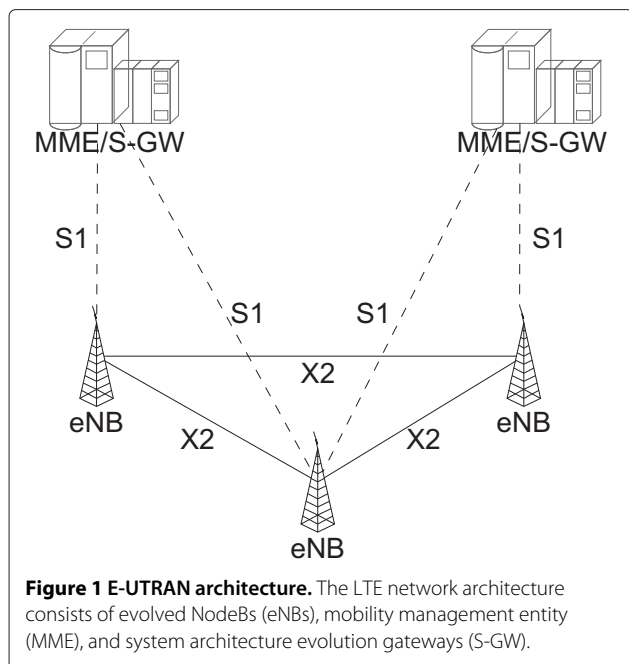
As shown in Figure 1, the LTE network architecture consists of evolved NodeBs (eNBs), mobility management entity (MME), and system architecture evolution gateways (S-GW) [5]. The eNBs are connected to the MME/S-GW by the S1 interface, and they are interconnected by the X2 interface. Handover is one of the important features within LTE networks, which assists UEs to roam within the signal coverage of eNBs. The necessary handover information is exchanged between eNodeBs via the X2 interface. In LTE networks, hard handover has been considered to minimize the radio resource requirement [8]. Because hard handover is more sensitive to radio link failure than soft handover, it is required to minimize the number of handovers for maintaining the given quality of service (QoS) within a communication link. Hence, an efficient handover mechanism with lower number of handovers is necessary for LTE networks [9].

In LTE networks, the UE performs several downlink radio channel measurements on both serving cell and

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Figure 1 E-UTRAN architecture. The LTE network architecture consists of evolved NodeBs (eNBs), mobility management entity (MME), and system architecture evolution gateways (S-GW).

neighboring cells by using reference symbols (RS) [10]. Those measurements are used to quantify network performance. Handover execution may occur mainly due to poor cell coverage or poor QoS level. The cell coverage is monitored using the reference signal received power (RSRP) from serving cell and neighboring cells. On the other hand, QoS level is measured using the reference symbol received quality (RSRQ) and other parameters [7,11]. The RSRP and RSRQ are measured by UEs during a designated measurement interval. In case of coverage-based handover, if the RSRP of one of the UE neighboring cells is greater than the RSRP of the serving cell plus a designated hysteresis value for at least a time-to-trigger period (TTT), the handover procedure triggering occurs [5]. Once triggering conditions are met, the UE sends the measurement report back to its serving eNB, indicating the triggering event and the target cell with the highest RSRP level when compared with the current serving cell. Based on the received measurement report, the serving eNB starts the handover preparation phase. In contrary, if RSRP in the serving cell becomes higher again than that in the target cell, during TTT period, the handover procedure would not be executed. LTE femtocell architecture has been proposed to gain a better indoor radio signal quality with low-cost deployment. It offers plug and play for configuration, low deployment cost, and traffic offload from the macrocell [12,13]. However, the distributed deployment scheme results in signal interference [14,15]. This can significantly impact on the transmission power measurement of UEs, which consequently impact the handover decision.

The handover procedure takes extra time and signaling overhead to synchronize and communicate between UE and eNB [16], in order to maintain the data connection. Due to the unavoidable handover delay [17], uninterrupted communication can be hardly accomplished, which may seriously affect the performance of a real-time application. Moreover, there is a risk of the handover fail which may result in a radio link failure [18]. The radio link failure rate can be increased because of delayed handover execution during TTT period. This phenomenon has been aggravated by unnecessary handovers, which has adverse effect on the system performance [19]. Too many unnecessary handovers may also result in signaling overhead [8,20]. Therefore, to lower the number of handover, we propose an improved handover mechanism by predicting the moving direction of UEs in this work. By referencing the previous locations of UEs, the next moving direction for each UE is estimated with the cosine function in order to determine the candidate eNBs for handover. An accurately target cell for handover is selected from the numbers of filtered candidate eNBs through an angle-based dynamic weight adjustment scheme. The number of handover is expected to be reduced through an accurately target cell selection, thereby also reducing packet loss and packet delay time.

This paper proceeds as follows: the 'Related work' section describes the researches on prediction-based handover algorithm and TTT. The proposed mechanism is described in 'A moving direction prediction-assisted handover mechanism' section. The simulation results are shown in the 'Simulation and results' section. Finally, the 'Conclusions' section concludes the paper and summarized the future work.

Related work

The handover procedure is required when UE moves between eNBs, which leads to extra handover cost to ensure the network connection quality. In [21], wireless *ad hoc* networks have been introduced to assist the handover procedure of the UE. Before UE handovers to a target eNB, a relay node is selected from wireless *ad hoc* networks. All handover-related information of the UE has been transferred to the target eNB via the selected relay node in advance. Fast handover can be achieved with the cost of increasing the loading of the relay node and may have security issues.

For the researches on TTT, in [22], the authors examined the handover performance by using various TTT values in LTE networks, depending on UE speeds and cell configurations within an allowable radio link failure rate. In the first step, the adaptive TTT values for each UE speeds were selected in macro-macro handover and macro-pico handover scenarios. And then, the authors fitted the curve by using the result of selected

TTT values for both neighboring cell configurations. From the TTT curve, the authors suggested the criteria for grouping UE speeds and the proper TTT values in accordance with the cell configurations. The simulation results showed that the performance was comparable with that of the case when applying the adaptive TTT values for an arbitrary UE speed, and the performance is significantly improved as compared to that of the cases when a fixed TTT value was applied in both cell type configurations.

Different research approaches try to use movement predictions as an addition to classical handover preparation and triggers. In [23], the authors proposed a mobility management technique which uses simple handover prediction based on cross-layer architecture. Their prediction technique uses both simple moving average for inertial movements and simple mobility pattern matching for non-inertial movements. They also introduced a new reporting event for UE's measurement reports and designed a handover prediction algorithm for eNodeB's handover preparation. Although they have outperformed in terms of number of handovers and rate of ping-pong handover, a simple knowledge database is required to overcome the unnecessary handover issues, thereby increases the complex of operations and extra cost.

In [24], the authors proposed a handover approach with a simple handover prediction based on acts of users of mobile history. They used the user mobility database and simple mobility pattern matching as well. A valid update database approach is proposed to ensure the database time in tracking the user mobility actions. However, both approaches reduce the evaluating cost of more candidate target eNBs, while increase the cost of mobility database. When the current move pattern of the user is regular, the candidate base station is filtered out in advance for a handover preparation, which can reduce number of handovers. However, in order to reduce the evaluating cost for eNBs, the cost of mobility database is increased.

In [25], a method for minimizing unnecessary handovers in heterogeneous wireless networks has been proposed. When a macro user moves into a micro cell, the traveling distance is estimated based on the signal measurements and the velocity of the user. The traveling distance is compared with a predefined threshold, in order to determine the handover decision. The proposed scheme has outperformed in minimizing the probability of handover failures and unnecessary handovers when compared with conventional methods. However, the handover in homogeneous networks is out of their scope.

A moving direction prediction-assisted handover mechanism

As UEs move around the signal coverage of LTE networks, the terrain may influence the received signal power,

especially when UEs locate far away its serving eNB. To maintain a certain communication quality, eNBs will inform UEs, which have the weaker feedback radio signal strength, to trigger handover procedures. The handover procedures in LTE networks can be divided into three distinct phases: the preparation, execution, and completion phases. Before UEs enter in handover preparation phase, UEs have feedback measurement reports to its serving eNB periodically. The measurement reports include the signal strength of its serving and neighbor eNBs. The neighbor eNBs form as candidate eNBs for handover, and it takes time to select a target eNB for handover. The make-before-break handover strategy may result in disconnection and data loss, where a real-time service impacts. Therefore, a direction prediction scheme and a dynamic weight adjustment scheme are proposed to reduce the number of handovers.

Direction prediction scheme

In the proposed moving direction prediction scheme, we adopt the Global Positioning System (GPS) to identify the position of each eNBS and UE [26]. The GPS is a satellite navigation system and provides accurate positioning, velocity, and precision standard time for most of the Earth's surface area. Since most of the smartphones have been already embedded with the GPS service, it is convenient for devices to acquire its position. The position of each eNB also can be measured by GPS, because the deployment of each eNB is planned and designed by network operators. Therefore, with the help of GPS, the position of each eNB and UE can be identified separately for tracing.

Since the moving direction of a UE may be toward a specific group of neighbor eNBs, the moving path of the UE has to be recorded at first for its direction prediction. The position of the UE can be retrieved from the GPS and represented by P_1, P_2, P_3, where P_3 is the position at the current time stamp, P_2 is at the previous time stamp, and P_1 is the position before the previous time stamp as shown in Figure 2. Recalling the trigonometric functions and inner product formula, giving three points, a θ angle is obtained by a function of angle calculator as shown in Algorithm 1.

Algorithm 1 Angle calculator
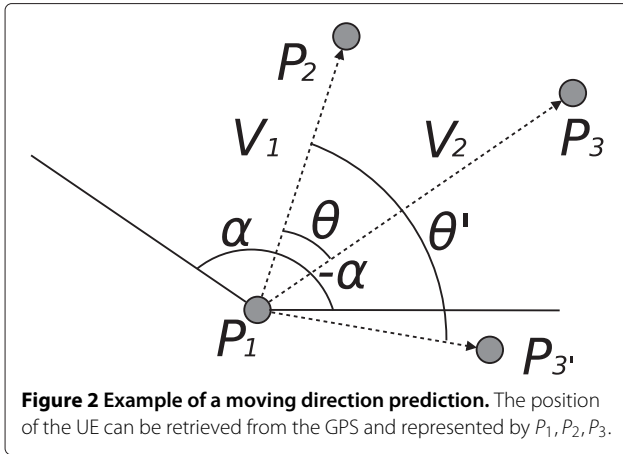

1: *Input: $P_1, P_2,$ and P_3.*

2: *Output: θ.*

3: $\vec{V_1} = \overrightarrow{P_1 P_2}$

4: $\vec{V_2} = \overrightarrow{P_1 P_3}$

5: $\theta = \arg\cos\left(\frac{\vec{V_1} \cdot \vec{V_2}}{\left|\vec{V_1}\right| \times \left|\vec{V_2}\right|}\right)$

6: *return θ*

Figure 2 Example of a moving direction prediction. The position of the UE can be retrieved from the GPS and represented by P_1, P_2, P_3.

We illustrate the moving direction prediction scheme with Figure 2 as follows. V_1 is the vector of P_1P_2, V_2 is the vector of P_1P_3, and θ is the angle of $\angle P_2P_1P_3$. The θ is calculated along with the moving path of a UE. It is used to determine if the UE moves in a specific direction.

Initially, positions P_1 and P_2 of a UE are obtained from GPS. Each time the new position P_3 of the UE is updated to its associated eNB, the angle calculator is called with P_1, P_2, P_3 parameters to find out a θ value and return. The α is an angle offset value, which is used to determine if a new location, P_3, located within another predefined angle offset range, $\pm\alpha$. θ is compared with α value to check if the moving directions of P_1P_3 and P_1P_2 are the same. If it is, then the eNBs, which are located with the range of α, that will be considered as candidate eNBs. Since each eNB is assumed to be equipped with three antennas to provide its signal coverage. Each antenna can provide signal coverage with the range of 120° angle and form as a cellular network. Therefore, we defined α has ±60° angle offset for a main direction boundary of a UE in this study; the moving path within the range of 120° angle (±α degree based on P_1P_2) totally is determined as the same direction of P_1P_2. In short, the moving path P_1P_3 has the same direction with P_1P_2 in the case of the angle $\angle P_3P_1P_2$ less than $|\alpha|$ as shown in Figure 2.

In the case of P_1P_3' which has a different moving direction with P_1P_2, where θ' is not less than $|\alpha|$, the main moving direction of the UE is re-defined. The dynamic weights of candidate eNBs, as described in the next subsection, are reset to zero. Then, P_2 is transferred to P_1, and P_3' is transferred to P_2. As a result, the new direction of P_1P_2 becomes a new main moving direction of the UE.

Dynamic weight adjustment scheme
In the case of P_1P_3 which has the same moving direction with P_1P_2, the candidate eNBs are required to be filtered from all neighbor eNBs. In order to filter the candidate

eNBs, the ±α degree is defined based on P_2P_3. For each neighbor eNB of the UE, the angle offset value, θ_{eNB}, is calculated. The θ_{eNB} is compared with $|\alpha|$; if its value is less than $|\alpha|$, the eNB is designated as a candidate eNB. As shown in Figure 3, eNB_0 is a serving eNB of the UE. After UE moves to P_3 from P_1 via P_2, P_3 is determined within the main moving direction of P_1P_2. The θ_{eNBs} for eNB_1, eNB_2, and eNB_3 are calculated. Only eNB_2 and eNB_3 are filtered and designated as candidate eNBs for the UE.

Since too many candidate eNBs will increase the probability of unnecessary handover, UEs also waste power to do unnecessary measurement reports from these filtered candidate eNBs. Therefore, once the main moving direction of each UE is predicted and the candidate eNBs is filtered, the target eNB is selected with a dynamic weight adjustment scheme as shown in Algorithm 2.
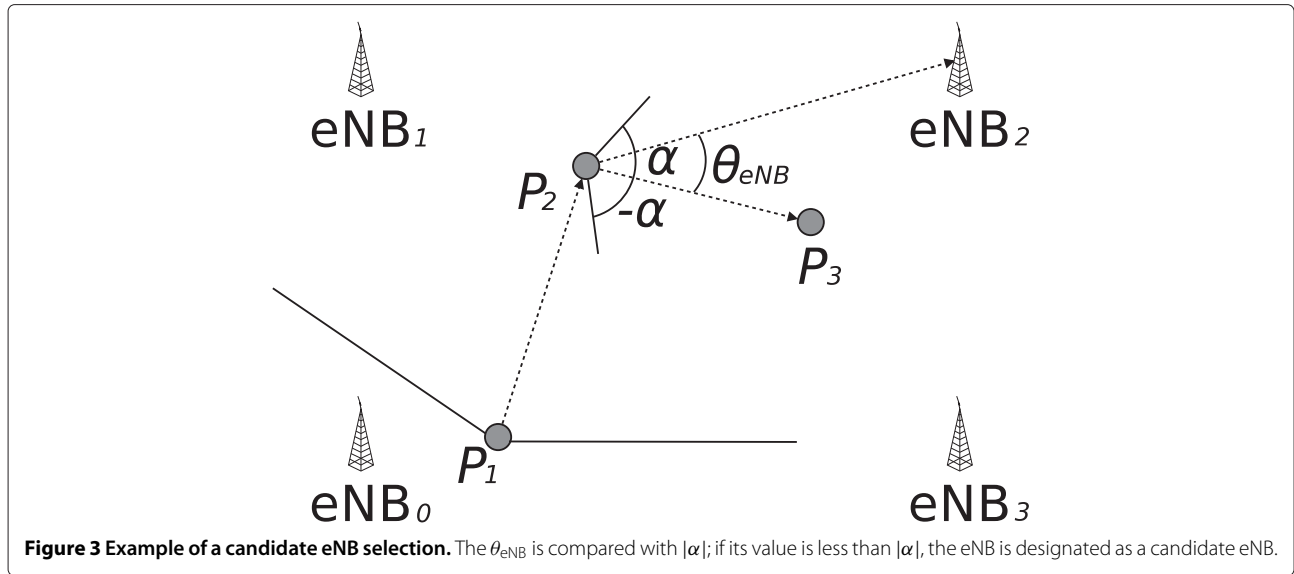

Algorithm 2 Dynamic weight adjustment

1: *Input: θ_{eNB} and d.*
2: *Output: W.*
3: $\Theta = (\alpha - \theta_{eNB})/\alpha$
4: $D = (2r - d)/2r$
5: $W = (1 - \lambda) \times \Theta + \lambda \times D$
6: *return W*

Both θ_{eNB} and distance (d) between UE and candidate eNBs are taken into consideration for a weight (W) calculation. The smaller θ_{eNB} and distance indicates that the UE is approaching to that candidate eNB. Since the eNB with θ_{eNB} less than ±α is filtered as a candidate eNB, the θ_{eNB} is normalized with α and stored in Θ. The distance is normalized with r, where r is a transmission range of the eNB, and stored in D. A variable λ, where $0 \le \lambda \le 1$, is adopted to control the angle offset and distance value. W is then returned for a target eNB selection.

Moving direction prediction-assisted handover procedure
Together with the previous two subsections, a direction prediction-assisted handover procedure is presented in Algorithm 3. The algorithm executes on each eNB. Initially, P and Q are two set of eNBs, where P contains all eNBs but Q is empty. For a UE-associated eNB, it is assumed that P_1 and P_2 of the UE are already reported to eNB. When serving eNB receives P_3 information in line 3 which is reported by the UE, it calls the function of angle calculator in line 4 with parameters P_1, P_2, and P_3 and gets the returned θ value. If θ is less or equal $|\alpha|$ in line 5, it indicates that P_3 locates within the main moving direction of P_1P_2. The serving eNB then retrieves all its neighbor eNBs from P sequentially in line 6 and calls the function of angle calculator again with parameters P_2, P_3, and P_{eNB} in line 7, in order to get the θ_{eNB}. If θ_{eNB} is less or equal $|\alpha|$

Figure 3 Example of a candidate eNB selection. The θ_{eNB} is compared with $|\alpha|$; if its value is less than $|\alpha|$, the eNB is designated as a candidate eNB.

in line 8, it indicates that the eNB is a candidate and put it into Q set in line 9.

Algorithm 3 Direction prediction-assisted handover procedure

1: *Initially, P is a set contains eNBs. Q is an empty set.*
2: **for** *each UE* **do**
3:     **while** P_3 **do**
4:         $\theta = AngleCalculator(P_1, P_2, P_3)$
5:         **if** $\theta \leq |\alpha|$ **then**
6:             **for** *each eNB $\in P$* **do**
7:                 $\theta_{eNB} = AngleCalculator(P_2, P_3, P_{eNB})$
8:                 **if** $\theta_{eNB} \leq |\alpha|$ **then**
9:                     $Q \leftarrow eNB$
10:                 **end if**
11:             **end for**
12:             **for** *each eNB $\in Q$* **do**
13:                 $d = $ *the distance between UE and eNB*
14:                 $W_{eNB} = (W_{eNB} + DynamicWeightAdjustment(\theta_{eNB}, d))$
15:             **end for**
16:         **else**
17:             *Reset W_{eNB} of all eNBs by 0*
18:             $P_1 \leftarrow P_2$
19:             $P_2 \leftarrow P_3$
20:         **end if**
21:         *Target eNB=The eNB with the maximum W_{eNB}.*
22:         **if** $RSRP_t > (RSRP_s + Hysteresis)$ *and last for TTT duration* **then**
23:             *Handover to the target eNB.*
24:             *Reset W_{eNB} of all eNBs by 0*
25:         **end if**
26:     **end while**
27: **end for**

After the *for* loop in line 11, Q contains all candidate eNBs. The candidate eNBs then are retrieved from Q sequentially in line 12, and the distance between UE and each candidate eNB is calculated and stored in a d variable in line 13. The function of dynamic weight adjustment with parameters θ_{eNB} and d is called in line 14. It returns W value which is summarized with its previous W_{eNB} value. W_{eNB} variable stores the weight for each candidate eNB.

If the condition of line 5 is not true, it indicates that the UE moves out of the main direction of P_1P_2. Then, W_{eNB} resets to zero for each candidate eNB in line 17. The location of P_2 and P_3 then are transferred to P_1 and P_2, respectively, in lines 18 to 19. The obtained P_1P_2 will become a new moving direction.

The target eNB is selected from the candidate eNBs which has the maximum W_{eNB} in line 21. The UE continually measures and reports the signal strength from its serving eNB and target eNB. If the radio signal strength of the target eNB is larger than the serving eNB plus a predefined hysteresis value, and last for TTT duration in line 22, the handover procedure is activated in line 23. All W_{eNB} are set to zero since the UE is expected to be handover to a target eNB in line 24.

Simulation and results

To verify the proposed mechanism, a LTE-sim downlink system level simulation (SL simulator) [27] was adopted to evaluate the performance. The average number of measurement report, average number of handover, packet loss rate, and average transmission delay of handovers are evaluated with various velocities of UEs. We first introduce the simulation environment and related parameters, and then the simulation results are presented.
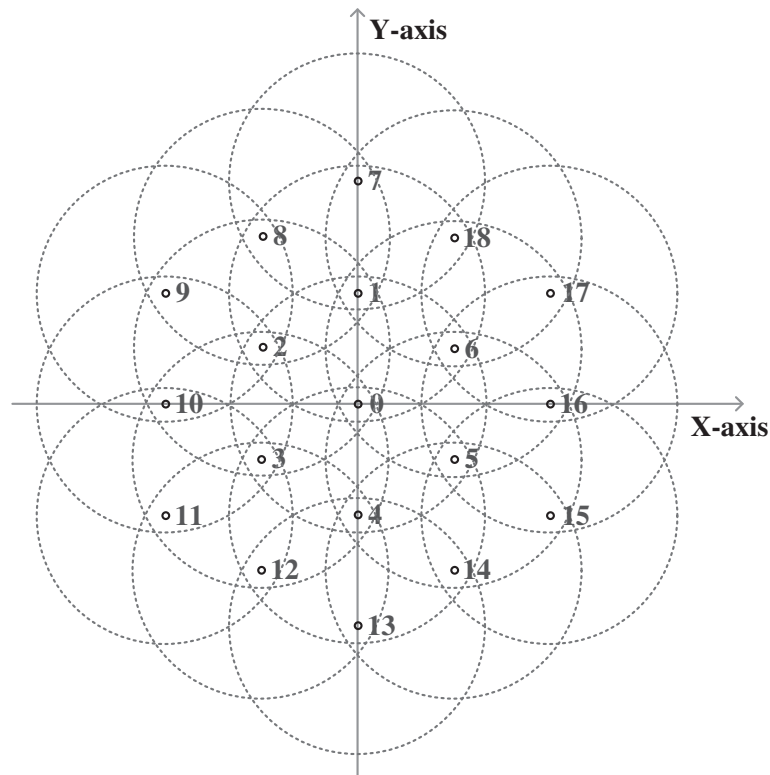
Figure 4 Network topology of simulation. The network topology of simulation consists of 19 eNBs indexed from 0 to 18.

Simulation environment and parameters

As shown in Figure 4, the network topology of simulation consists of 19 eNBs indexed from 0 to 18, where each eNB has three sectors and each sector has one UE associated. There are 57 UEs totally deployed. Some main simulation parameters are listed in Table 1, which are referenced from [28]. UEs move randomly with predefined speed in 30 s of simulation time. The velocities of UEs are configured into 3, 30, 120, and 150 km/h.

When UE enters into LTE networks, it would measure the signal strength of serving eNB and neighbor eNBs. The measurement report will feed back to its serving eNB to select a target eNB for handover. Too many frequently signal measurements would waste the power of the UE. When UE roams within LTE networks, hard handover is required to keep data connection, which may result in packet loss and transmission delay. We compare the performance metrics of the average number of measurement report, average number of handover, packet loss rate, and average transmission delay for standard handover scheme. The performance metrics are listed in the following equation:

$$\text{Average number of measurement reports} = \frac{M}{N \times T}.$$

$$\text{Average number of handovers} = \frac{H}{N \times T}.$$

$$\text{Number of packet loss} = \frac{P_s - P_r}{T}.$$

$$\text{Average transmission delay} = \frac{\sum_{i=1}^{P_r} T_i^r - T_i^s}{P_r}.$$

Table 1 Main simulation parameters

| Parameters	Value
Frequency	2 GHz
Bandwidth	5 MHz
Thermal noise density	−174 dBm/Hz
Receiver noise value	9 dB
eNB's transmission power	46 dBm
Resource blocks per eNB	25
Bandwidth per eNB	180 kHz
TTI (subframe duration)	1 ms
Numbers of UE	57
Cell layout	19 sites, 3 sector per site
Simulation time	20 s
UE speed	3, 30, 120, and 150 km/h
Mobility model	Random waypoint
Scheduling strategy	Proportional fair
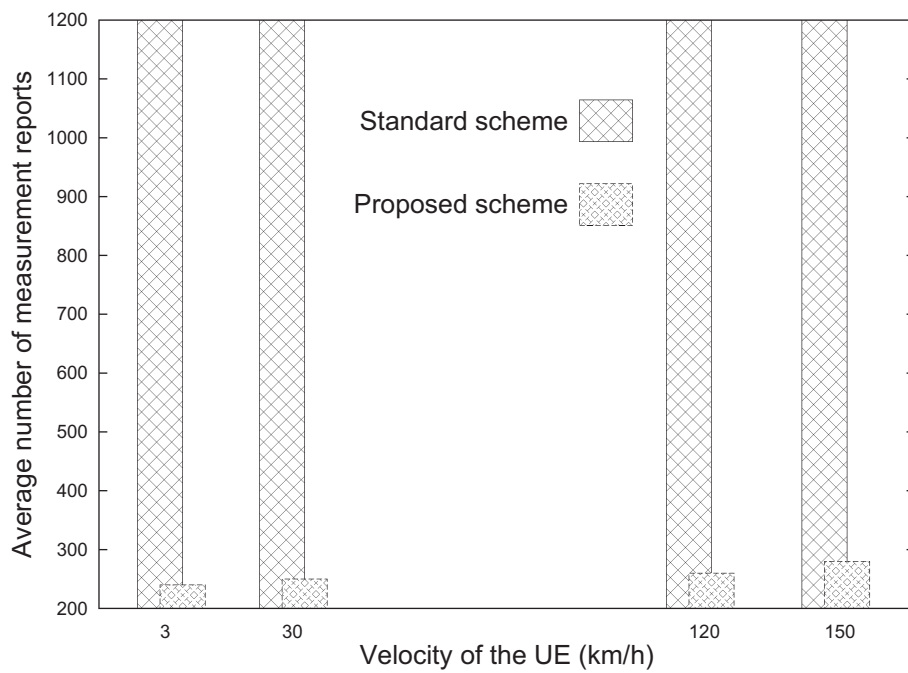
Figure 5 The average number of measurement reports for different handover schemes. UE periodically measures the single strength of serving and target eNBs with our proposed scheme, instead of measuring all its neighbor eNBs with the standard scheme.
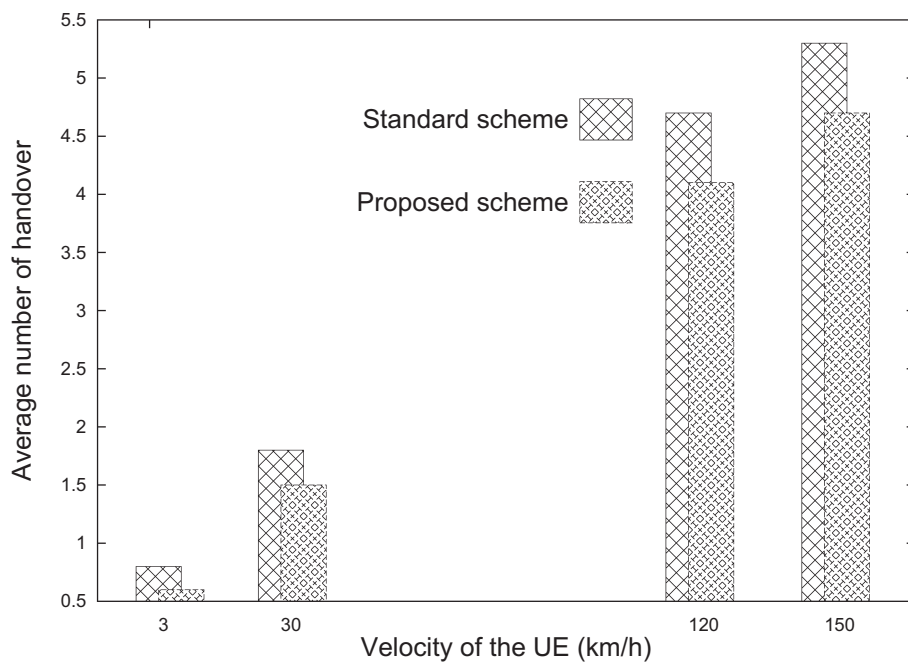

Figure 6 The average number of handovers for different handover schemes. By selecting a proper target eNB for handover with our proposed scheme, unnecessary handovers are reduced.
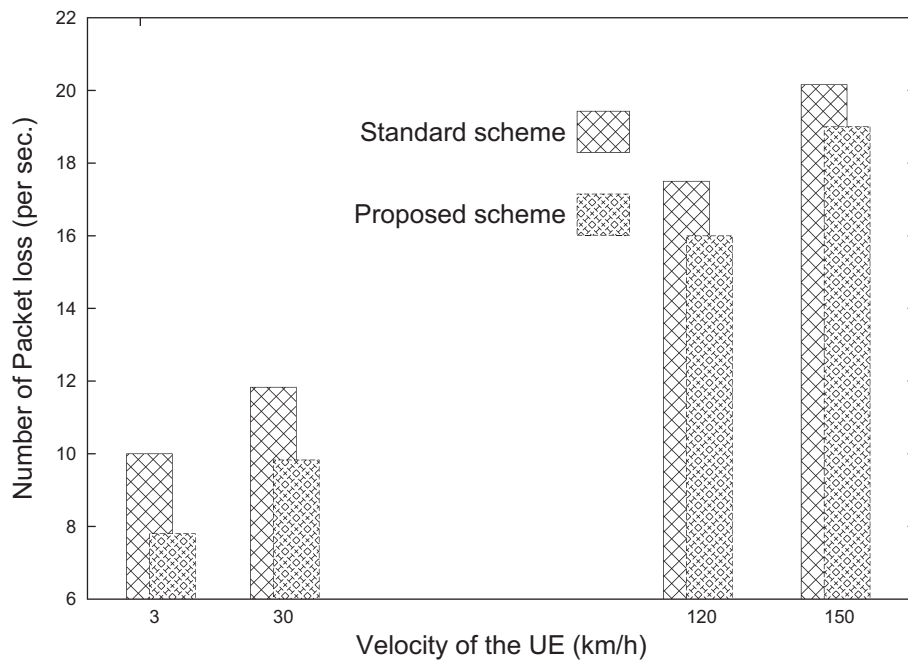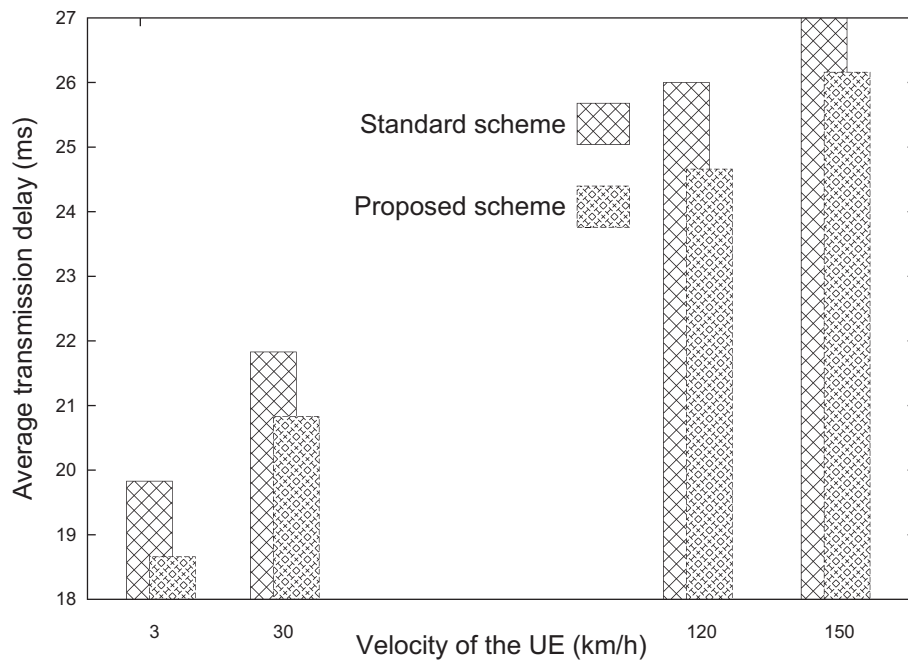
Figure 7 The number of packet loss for different handover schemes. By selecting a proper target eNB for handover with our proposed scheme, packet loss is reduced.

Figure 8 The average transmission delay for different handover schemes. Extra signal overhead is able to be saved with our proposed scheme, since UEs are able to connect with a proper target eNB, which results in lower transmission delay than that in the standard scheme.

M and H represent the number of measurement report and handover, respectively, that the number of N UEs counted within a T (minutes) simulation time. P_s and P_r are the number of transmitted and received packets, respectively. T_i^r and T_i^s indicate the time the ith packet received and send, respectively.

Simulation results

The simulation results are shown from Figures 5, 6, 7, and 8. Figure 5 shows the average number of measurement reports. It is observed that the velocity of UEs will not affect the number of measurement report with a standard scheme, because it adopts a fix-duration report strategy. However, our proposed scheme has a very low number of measurement report than the standard scheme. The main reason for this is due to the fact that UE only reports its current position to its serving eNB periodically in our scheme. The serving eNB then executes our proposed direction-assisted handover procedure to select one target eNB for the UE. UE periodically measures the single strength of serving and target eNBs, instead of measuring all its neighbor eNBs.

Figures 6, 7, and 8 shows the average number of handover, number of packet loss, and average transmission delay, when UEs move with various velocities. It is observed that the average number of handovers in high velocity is higher than that in low velocity. This is because the higher the velocities of UEs, the longer the distance that UEs move, thereby increasing the number of handovers. By selecting a proper target eNB for handover, unnecessary handovers and packet loss are reduced as shown in Figures 6 and 7, since UEs are able to connect with a proper target eNB, avoiding the ping-pong effect, in which UEs move out/in its serving eNB in a short time. Extra signal overhead is able to be saved with our proposed scheme, which results in lower transmission delay than that in the standard scheme as shown in Figure 8. Therefore, our proposed scheme has outperformed than the standard scheme.

Conclusions

There is a risk of the handover fail which may result in a radio link failure in LTE networks, because it adopts a hard handover scheme. System performance is being aggravated by unnecessary handovers. It leads to transmission delay, packet loss, and signal overhead, which may seriously affect the performance of a real-time application.

In this paper, a direction prediction mechanism for LTE networks has been proposed in order to lower the unnecessary handover. We first proposed a direction prediction scheme with a simple cosine function to predict the moving direction of UEs. The eNBs, in front of the moving direction of UEs, are designated candidate eNBs for handover. Then, a target eNB is selected from the candidate eNBs for handover through an angle-based dynamic weight adjustment scheme. Simulation results revealed that under various velocities of UEs, our proposed handover scheme apparently outperforms the standard scheme from the aspect of average handover times, number of packet loss, and average transmission delay. Average handover times (17%) can be reduced through a proper target eNB selection; hereby, 12% average number of packet loss and 5% average packet delay time are able to be reduced. The number of measurement reports with our proposed scheme which approaches 73% can be reduced. It reflects that more power engine of UEs can be saved.

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