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Alternative Reference Point Based Handover Algorithm for LTE High-speed Rail

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Abstract

A new fast handover algorithm for LTE high-speed rail networks is proposed in this paper. In railway environment, the motion direction and the GPS information of the train can be obtained at any time. Moreover, the neighbor cell that the UE will go through can be precognitive. The above information are utilized to bring forward a fast handover scheme in this paper, which can give a set of alternative reference points appropriate to trigger handover procedure instead of the measured information in A3 event based scheme. The proposed algorithm can evidently reduce time latency and accordingly shorten the necessary overlapping area of handover procedure, and the simulation results show that it has better performance than typical A3 event based handover algorithm in high-speed rail environment.

***Keywords**: LTE, handover, high-speed rail (HSR), radio link failure (RLF)*

1. Introduction

High-speed railways play an increasingly important part in people's lives recent years [1]. The current broadband wireless communication systems optimized for low mobility environments cannot maintain adequate performance for passengers traveling on the high speed trains (HST) any longer. Typical hard handover supported by LTE systems reduces the complexity of the system architecture but simultaneously brings about higher handover failure ratio and the decline of the user experience in high-speed mobility environment [2].

Handover becomes a great challenge in the systems designed for high-speed rail mainly due to the following reasons: 1) when the running speed of HST achieves 350km/h or even higher in the future, the time interval of every two handovers can be as short as 15s, given a size of about 1.5km which is typical in Macro cell [3], and it results in a high handover frequency; 2) classical event handover algorithm trigger a handover procedure basing on HO hysteresis and Time to Trigger, which increase the time latency of handover and meanwhile it may lead to Radio Link Failure (RLF) before the user terminals successfully access to the target eNodeB. Several papers have provided optimized schemes for LTE handover. Reference [4] analyzed the impact of propagation environment and velocity of UE on the handover performance. Reference [5, 6] also introduced algorithms for LTE systems to improve handover performance.

In order to solve the problems mentioned above, a novel handover algorithm is proposed in this paper. Due to the particularity of the railway environment, the trace and location information of the train and given position of the target eNodeB can be precognitive. The proposed scheme utilizes these to be the measurement information instead of reference signal received power (RSRP) and Reference signal received Quality (RSRQ) in typical event based HO algorithm. Simulation results show that the proposed algorithm has better performance than A3 event based algorithm.

The rest of this paper is organized as follows. Section 2 introduces the system model and problem formulation. Section 3 explains the selection of the location of the handover triggering and the proposed handover procedure. The simulation results are shown in section 4 and finally, conclusions are drawn in section 5.

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2. System Model and Problem Formulation
2.1. LTE System Model
LTE network architecture is constituted by three parts as shown in Figure 1: evolved-NodeB (eNodeB), Mobile Management Entity (MME), and Serving Gateway (S-GW) / Packet Data Network Gateway (P-GW). The eNodeB performs all radio interface related functions such as packet scheduling and handover mechanism. MME manages mobility, user equipment (UE) identity and security parameters. S-GW and P-GW are two nodes that terminate the interface towards E-UTRAN and Packet Data Network respectively [7]. This paper focuses on the high-speed railway scenario, which deploys the eNodeB consisting of Base Band Unit (BBU) and Radio Remote Unit (RRU) along railway line as shown in Figure 2 [8].

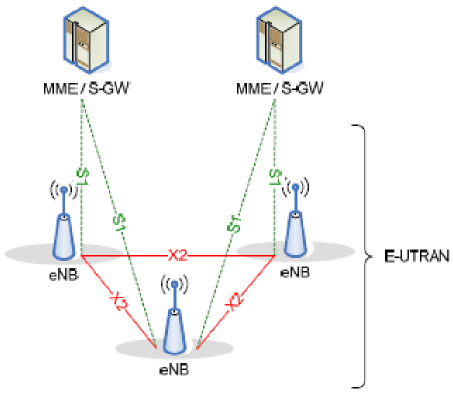

Figure 1. E-UTRAN Architecture

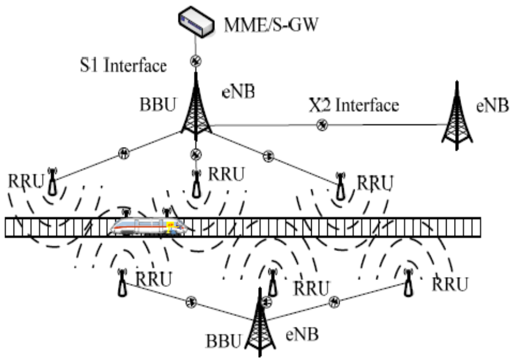

Figure 2. The eNodeB Deployment Along Railway Line

2.2. Measurement Model
Generally, handover procedure in LTE systems can be divided into following steps: the handover measurements, the handover decision and the handover execution [9].

The eNodeB controlled handover is based on the measurement taken by UE and execution taken by source eNodeB. Figure 3 shows the measurement model for handover.

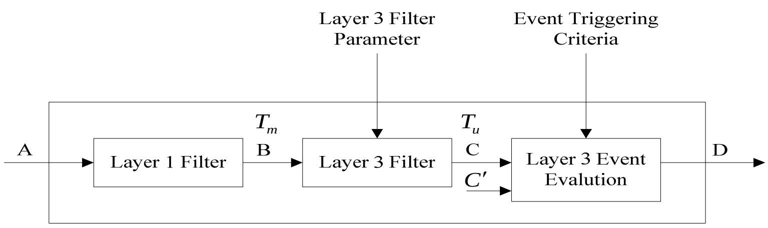

Figure 3. Measurement Model

Firstly, UE measures RSRP by adding reference symbols power within the sub-frame over the complete measurement bandwidth at point “A”, where RSRP is one important measured value that the user terminals have to achieve, and is defined as the average power value received from all the resource elements which load reference signals during one certain symbol. Then UE will sample the Layer 1 measurement periodically according to the requirement of the network side, and execute the Layer 1 filtering internal physical layer, aiming to linear average the sample values during one physical measurement period of T_m-ms. At the Radio Resource Control (RRC) Layer, Layer 3 filtering is executed under the control of the network side. RRC layer gives a weighting on the measurement RSS reported by physical layer according to Equation (1):

$$\overline{RSS}(nT_m) = (1-\alpha)\overline{RSS}((n-1)T_m) + \alpha RSS(nT_m)\,. \quad (1)$$

$$\alpha = T_m / T_u\,. \quad (2)$$

Where T_u is Layer 3 filtering report period. α named as "forgetting factor" is valued between 1/20 to 1. $\overline{RSS}(nT_m)$ is the received signal power after Layer 3 filtering at the time nT_m. . is the reference signal received power (RSRP) after Layer 1 filtering at the time nT_m.

Subscriber obtains signal to interference plus noise ratio (SINR) of each subcarrier from cell-specific reference signal. SINR value can be obtained as Equation (3):

$$SINR = RSRP_s - RSRP_{in}\,. \quad (3)$$

Where $RSRP_s$ indicates the RSRP of the eNodeB that currently serving and $RSRP_{in}$ is sum of the RSRP of the adjacent eNodeB and thermal noise.

The block error rate (BLER) is the rate of block per second having at least one incorrect bit. BLER of physical downlink control channel (PDCCH) can be a congruent indication of signal quality at physical downlink, and has close relation with the metewand of handover performance RLF. Thus, the BLER value of target eNodeB can be used to provide a scheme to find out the compatible location range in a certain running environment, and the method of obtaining it will be introduced in the following paragraphs.

Channel quality indicator (CQI) is the only feedback information in LTE single-input single-output (SISO) systems. Exponential effective SINR mapping (EESM) [10] provides a method to convert the SINRs at all subcarriers into an effective SINR value. Then it can be used to map to the BLER of corresponding RB based on AWGN link-level simulations.

According to EESM method, the effective SINR γ_{eff} is obtained by performing the following non-linear averaging of all the subcarrier SINRs for each RB as Equation (4).

$$\gamma_{\text{eff}} = -\beta \ln\left(\frac{1}{N_{sb}}\sum_{\text{n}=1}^{N_{sb}} \exp\left(\frac{\lambda_{\text{n}}}{\beta}\right)\right) \quad (4)$$

Where N_{sb} is the number of subcarriers to be averaged, λ_n is the SINR at the n*th* subcarrier, and β is an adjusting coefficient by means of link level simulations to fit the compression function to the AWGN BLER results [11].

Target BLER is defined as the upper limit value of BLER that can ensure the downlink data be received reliably. User terminal can select one CQI index according to the effective SINR and target BLER by using the method [10] as Equation (5) shows:

$$BLER = \frac{1}{2}\left[1\text{-}erf\left(\frac{\gamma_{\text{eff}}\text{-}b_m}{\sqrt{2}c_m}\right)\right] \quad (5)$$

Where b_m and c_m are the corresponding fitting parameters for a given MCS index m obtained from [13]. The CQI corresponding to the index m that satisfies the requirement $BLER \le 0.1$ will be chosen to feed back to the eNodeB. eNodeB will map the CQI index to one certain MCS. When UE receives the downlink data from eNodeB, it can obtain the current BLER through Equation (5).

2.3. Radio Link Failure (RLF)

RLF is one important evaluating indicator of the handover performance. Handover occurring at an improper location in the overlap region can cause a high probability of RLF triggering.

Figure 4 shows the diagrammatic sketch of RLF procedure. The first phase begins with radio problem detection. That is the detection of radio link quality threshold Q_{out}, which is the threshold of trigging RLF procedure. If the radio link quality can recovery to a proper level of threshold Q_{in}, the RLF procedure will be cancelled. Here Q_{out} corresponds to 10% BLER on the PDCCH, and Q_{in} corresponds to 2%BLER [14].

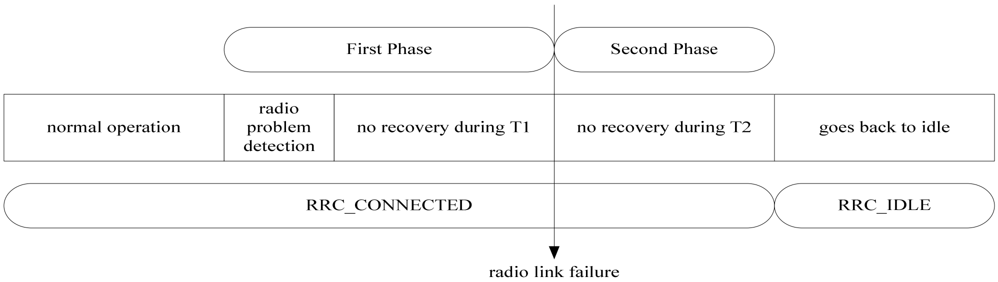

Figure 4. Diagrammatic Sketch of RLF Procedure

3. Location Based Handover Algorithm

The triggering of RLF can lead to interruption in communication service or a cell-reselection in all probability. Handover at unsuitable location in the overlap region will bring about RLF before or after handover. Hence, for a certain scene between two adjacent cells in high-speed rail network, there exists a small range of distance that can be the suitable location to execute handover, which can be caught handover reference point.

3.1. Handover Reference Point Selection

For the location information based handover scheme, selecting an accurate handover reference point is of paramount importance. Handover reference point is a statistic result of repeated measurement.

Firstly, several handover hysteresis thresholds should be restricted, for instance three, and here we express them as sets U_1, U_2 and U_3, satisfying $U_1 \cup U_2 \cup U_3 = [0dB, 3dB]$.

Secondly, test user terminal moves across over the overlap region of two adjacent cells. Its measurements include $\overline{RSS}$ from both source eNodeB ($\overline{RSS_s}$) and target eNodeB ($\overline{RSS_t}$), along with longitude and latitude information from GPS as well. Meanwhile, user side should make statistic of BLER value from source eNodeB ($BLER_s$) and target eNodeB ($BLER_t$). For one certain hysteresis threshold set U_1 with the lower limit and upper limit set to T_1 and T_2 respectively, it should record the points meeting the following conditions as Equation (6) and Equation (7):

$$T_1 \le \overline{RSS_t} - \overline{RSS_s} \le T_2 . \quad (6)$$

$$BLER_s < Q_{in} \ \& \ BLER_t < Q_{in} . \quad (7)$$

Where Q_{in} is the same as the one in part Radio Link Failure. Through this step, test result can provide several points satisfy the equations above. Most of them will concentrate congregate in one fixed range for a certain scene. Repeat the process above for enough times, we will find that the location of the selected points accords with normal distribution. At present, the mean value of the distribution can be chosen to be an alternative handover reference point indicated as P_1 .

Then, for sets U_2 and U_3, the second step should be repeated to obtain the handover reference points P_2 and P_3 respectively. Here, there points P_1, P_2 and P_3 corresponding to the three hysteresis threshold sets have been get already.

Finally, let test user terminal move across the overlap region along the rail repeatedly for several times. Handover procedure should be triggered each time it passes the predesigned point. Count up the RLF ratio when handover triggered at P_1, P_2 and P_3, then the most appropriated handover reference point can be obtained for current environment.

3.2. Location-based Handover Procedure

The followings show the steps of the location-based handover procedure, and Figure 5 can visually show the steps:

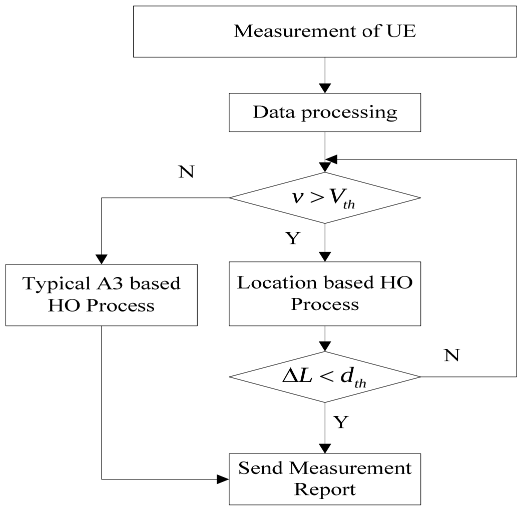

Figure 5. The Flowchart of the Location-based Fast Handover Algorithm

When the UE enters the overlap region, it sends measurement reports periodically to the source eNodeB, including the speed and location information get from GPS. The handover scheme is chosen according to the speed information. When the speed is higher than a certain threshold V_{th} , the proposed scheme will be chosen, or otherwise typical A3 event based scheme should be used. The source eNodeB makes the HO decision if the location information indicates that the distance between the train and the predesigned HO point is closer than a threshold of d_{th} , the HO request is sent from source eNodeB to the target one. The target eNodeB saves the context; prepare L1/L2 for HO and response to the source with a HO request ACK which prepare information for the establishment of the new radio link. The source eNodeB transfers all the necessary information to the UE in the HO command.

From then on, source eNodeB begins to forward downlink data to the target eNodeB. Simultaneously, UE detaches from source eNodeB and synchronizes to the target one. At last, UE sends HO confirmation to target eNodeB about the success of radio handover.

Finally, target eNodeB begins to send its buffered data received from the source one and sends HO complete message to initiate data path switching. After MME/S-GW confirms the path switching, target eNodeB will notice the source one to flush its forward downlink data buffer and release resource.

4. Simulation Results

The simulation parameters are shown in Table 1. The propagation model of Cost231-Hata is used [15], and it can be expressed as Equation (8):

$$L = 46.3 + 33.9\lg f_c - 13.82\lg H_b - \alpha(H_m) + (44.9 - 6.55\lg H_b)\lg d + C_m. \quad (8)$$

The channel model of this scene is mountain environment. The estimated C_m can be obtained from project experience as Equation (9):

$$C_m = -10.03. \quad (9)$$

The system operates at frequency $f_c = 2600\text{MHz}$. The attenna effective height of base station and mobile terminal are $H_b = 35\text{m}$ and $H_m = 1.5\text{m}$ respectively. $\alpha(H_m)$ is modifying factor of mobile terminal effective height. Thus, the equations above can be simplified as Equation (10):

$$L = 140.729 + 34.786\log d - 10.03. \quad (10)$$

Table 1. Handover Simulation Parameter

Network nodes	Number of VoIP	5, 10,..., 100
	Number of eNodeB	2
	Number of UE	1
Network Topology	Cell Radius	1.6km
	Handover Area Length	300m
	Distance between eNodeB and Railway Line	100m
	Transmitting Power	46dBm
Wireless Channel	Noise	-148.95dB/sub-channel
	Number of Multi-path	8
	Path Loss	Refer to Eq. (6)
	Log-normal Shadow Fading	Standard Deviation=8dB Mean=0
System Parameter	Carrier Frequency	2.6GHz
	System Bandwidth	10MHz
	Transmission Time Interval(TTI)	1ms

Figure 6 shows the contrastive analysis of each points belonging to different hysteresis regions. It can be seen that the point of the middle set provides lowest RLF ratio. In this area, it can reduce both RLF before and after HO evidently.

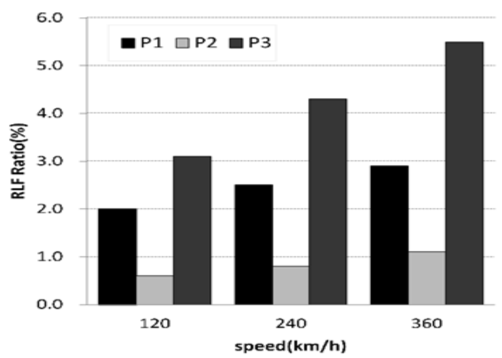

Figure 6. Performance Comparison of Three Hysteresis Ranges

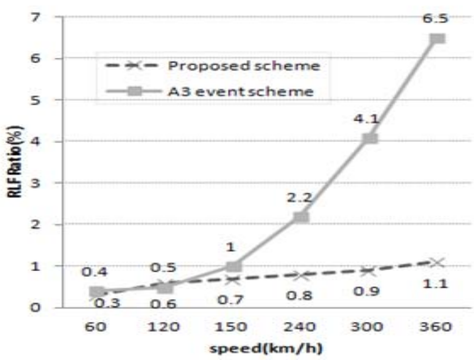

Figure 7. RLF Ratio of Proposed Scheme and A3 Event Scheme at Different Movement Speed

In Figure 7, comparison between the proposed scheme and the typical A3 event based scheme is shown. In low mobility environment, they have similar performance. However, when the user terminal runs at a high speed, A3 event based scheme displays a performance of serious decline.

4. Conclusion

A novel handover scheme based on location information for LTE high-speed rail networks is proposed. A method of selecting handover reference point is provided for certain environments. Simulation results show that the accurate handover region can be found through this method. The proposed scheme can adapt to the high-speed rail environment better than typical event based scheme, because it can eliminate ping-pong HO and achieve preferable RLF ratio.

Acknowledgements

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