Mobile relay based fast handover scheme in high-speed mobile environment

Qing Huang [1], Jianmei Zhou[1], Cheng Tao[1], Su Yi[2], Ming Lei[2]
[1]Institute of Broadband Wireless Mobile Communications, Beijing Jiaotong University, Beijing, China
[2] NEC laboratories, China

Abstract—**There are a lot of handovers failed in high-speed mobile environment because the handover can't be completed in time although the field strength values are sufficient availability along the tracks. A mobile relay based fast handover scheme is proposed which is suitable for high-speed mobile environment. Two reference points are introduced to ensure handover in time. Pre-preparation and packet bi-casting is introduced to reduce communication interruption time and realize seamless handover. The performance of the proposed scheme is analyzed in terms of handover delay, communication interruption time and bi-casting time.**

Keywords- handover, mobile relay, high-speed train

I. INTRODUCTION

As a fast and convenient public transportation system, high-speed railways have been developed rapidly in China and more and more people choose to travel by high-speed trains. In the long time traveling, various mobile wireless services not only voice and short messages but also multimedia services such as web browsing, videophone, online gaming and video conference etc. should be provided to passengers. Generally, these multimedia services with a high data rate are characterized with high level of Quality of Service (QoS) and low latency requirements, which can currently only be offered by broadband wireless access technologies in normal mobility. If deployed in high speed environment, the performance of these technologies will decrease severely because of fast fading, Doppler frequency shift, penetration loss, fast handover and so on. There is a technological gap regarding radio access techniques which could offer high transmission data rates in high mobility environments [1].

Third Generation Partnership Program (3GPP) has proposed LTE to meet the huge demand of wireless services. What's more, LTE-A is expected to provide more capacity, better coverage, higher throughput, reduced latency with less network complexity and low installation cost. In order to reduce the influence of penetration loss of the coaches and signaling overhead of handover, Mobile Relay Node (MRN) deployed in the trains is proposed in [2]. When UEs located in the coverage of the MRN they can be easily connected to their serving eNB in the moving environment. So a mobile-relay based LTE-A system is considered in this paper.

At present, by using improved handover algorithm such as rapid field intensity fading handover, synchronous/pre-synchronous handover [3], the success rate of handover can be improved and the handover time can be shortened in GSM-R systems. However, compared with the GSM-R, the cell radius in LTE-A shrinks because of high carrier frequency deployed. The handover rate will increase drastically when the speed of train is high or the cell size is reduced [1]. If the velocity is so high that the time across handover zone is less than the minimum handover delay, the handover process cannot be completed and calls will drop. Therefore a lot of handovers in this environment failed although the field strength values measured had indicated sufficient availability along the tracks.

In this paper, a Mobile Relay based Fast Handover Scheme (MR-FHS) in high-speed mobile environment is proposed to improve the performance of handover, which is one of the major challenges in high speed mobile communications. Two reference points are introduced and the handover procedure is proposed. Compared to the existing handover scheme, the proposed scheme can reduce handover delay, communication interruption time and bi-casting time.

The rest of the paper is organized as follows: In Section II, the mobile relay based LTE-A system architecture is introduced and some terminologies are defined. Following by describing the mobile relay based fast handover scheme in high-speed mobile environment in Section III. Simulation results are given and discussed in section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM ARCHITECTURE AND TERMINOLOGY

A. System Architecture

A typical LTE-A system architecture with MRN mounted in the train is shown in Fig.1. It is a dual-layer system architecture [4]. Passengers communicate directly with the Access Points (AP) inside the train while MRN is in charge of the communication between the train and the roadside. All of the APs are controlled by the MRN.

We deploy the LTE-A network with straight line pattern without any crossings, namely that each cell only has two neighbor cells — forward cell and backward cell. This is reasonable for high-speed mobile environment because in case of intersection of several lines scenario, we can avoid multi-forward cells or backward cells by putting the eNB at the intersection site [5].

Assuming the network knows the position and speed information of high-speed trains. There are two ways to obtain this information. One is from GPS system on high-speed trains. According to the longitude, latitude and measurement interval information from GPS system we can get the position and velocity information. The other is from Time Advance (TA).

This work is supported in part by the National Natural Science Foundation of China (No.61032002 and 61101138), the National Science and Technology Major Project under grant 2011ZX03001-007-01 and NEC Research Fund.

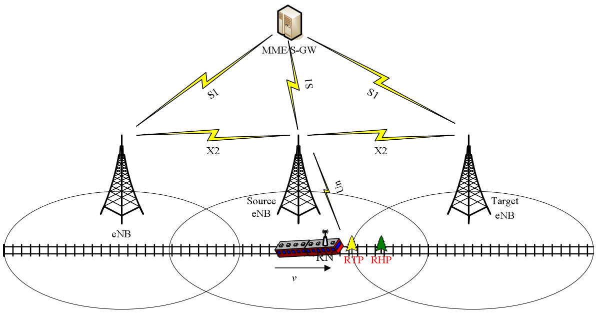

Figure 1. Handover architecture in high-speed mobile environment

For example, when TA_{t1} - $TA_{t0} < 0$, we can know that the train approaches the eNB, otherwise just the opposite. Then based on the directional antenna we can know train's approaching or going away from the eNB in which side.

Assuming the height of eNB antenna is H, the height of relay node antenna on trains is h, the value of TA is Ta, the speed of light is c, then the horizontal distance D between relay node and eNB is

$$D = \sqrt{(T_a \times 3.69 \times 10^{-6} \times c)^2 - (H-h)^2} \tag{1}$$

The velocity of the train is

$$V = (D_1 - D_0) / \Delta T \tag{2}$$

Where D_1 and D_0 is the distance between relay node and eNB. ΔT is report interval.

B. *Terminology*

In order to facilitate the MR-FHS, some parameters are defined as follows.

Reference Trigger Point (RTP). RTP is the point that measurement result starts to report periodically. This point is significant for handover preparation and data bi-casting.

Reference Handover Point (RHP). RHP is the point that handover execution process starts.

Handover Time Threshold (HTT): If the time that the train runs to RHP is equal or shorter than HTT, the handover preparation process will start. Assuming reporting period is P, handover preparation time and signaling exchange time for establishing data bi-casting is T, then HTT is P+T.

Speed threshold (ST): If the speed of train is higher than ST, MR-FHS is executed; else execute the conventional handover process.

Both of the reference points are updated by data collected from the handover. The initial value of RHP can be simply set as the center point of two neighbor eNBs .The initial value of RTP is $(P+T)\times V_{max}$ far from RHP ahead, where V_{max} is the max velocity of high-speed trains.

All of the above parameters are saved in the database established in eNB and can be broadcast in the cell. Besides, the ID of neighbor eNB, measurement reports, train speed etc. is saved in database too.

III. FAST HANDOVER SCHEME

A. *Detail of the Process*

When the train arrives at RTP or satisfies other event-triggered reporting criteria, MRN begins to report the measurement result periodically and eNB extracts the position and velocity information from the measurement report. If $V >$ ST, the MR-FHS is executed, otherwise execute the normal handover algorithm instead.

In MR-FHS, eNB will calculate time t that how long the MRN will reach RHP when it receives measurement report. The computation formula is

$$L = \sqrt{(X - Ar)^2 + (Y - Br)^2} \tag{3}$$

$$t = L/V \tag{4}$$

Where (Ar, Br) is the coordinate of RHP, (X, Y) is the position of MRN, L is the distance between the RHP and MRN.

When $t \leq$ HTT, the source eNB will send "*Resource Configuration Request Message*" to target eNB. The target eNB will respond a "*Resource Configuration Request ACK Message*" when it completes the resource configuration procedure. Otherwise the source eNB will wait for the next measurement report.

The source eNB will deal with other measurement items at the same time. If the MRN arrives at RHP or satisfies other handover condition and the source eNB receives the "*resource configuration request ACK message*", it sends "*Handover Command Message*" to MRN immediately. MRN will start connection procedure to target eNB.

Figure 2 shows the handover mechanism of MR-FHS in high-speed mobile environment. The more specific flow is as follows.

1. The source eNB configures the measurement procedure of the MRN according to the area restriction information;
2. If the train arrives at RTP or satisfies other event-triggered reporting criteria (such as A3 in [7]), MRN will send measurement report to source eNB periodically;
3. When HTT is satisfied (and the train speed is higher than ST), the source eNB will send "*Resource Configuration Request Message*" to target eNB. This message contains the resource that the MRN needs, UE context information, position and velocity information and so on.
4. After receiving the "*Resource Configuration Request Message*" from source eNB, the target eNB will prepare for the incoming handover and configure resource in advance.
5. After completing the resource configuration procedure, the target eNB will send "*Bi-cast Start Request Message*" to S-GW through MME. Then the S-GW will bi-cast the data packet to both source eNB and target eNB through S1 interface at the same time.
6. The S-GW sends "*Bi-cast Start Request ACK Message*" containing the first bi-cast packet ID to target eNB through MME, informing that packets bi-cast has started.
7. After receiving "*Bi-cast Start Request ACK Message*", the target eNB will respond a "*Resource Configuration Request ACK Message*" to source eNB. This message is a RRC message which contains the "*MobilityControlInfo*" that MRN needs in handover

and other access parameters. For example C-RNTI, target eNB security algorithm identifiers, dedicated RACH preamble etc. The first bi-cast packet ID is also contained.

8. When the MRN arrives at RHP or satisfies other handover conditions and source eNB receives the "*Resource Configuration Request ACK Message*", the source eNB sends "*HO Command Message*" to relay node immediately. This message contains the same information as "*Resource Configuration Request ACK Message*". The source eNB sends the "*SN Status Transfer Message*" to target eNB. Then the source eNB sends the buffered packets which have not sent to target eNB by bi-cast to target eNB through X2 interface. (S-GW would send the packet ID that has bi-casted to source eNB so that source eNB can forward fewer packets).
9. The source eNB sends the "*SN Status Transfer Message*" to target eNB to convey uplink PDCP SN receiver status and downlink PDCP SN transmitter status. Source eNB sends the packet IDs to target eNB through X2 interface when it receives the ACK from the MRN and the target eNB will delete the relevant packets. The target eNB will send remaining packets to MRN once the MRN accesses to target eNB.
10. At the moment that handover is starting, the MRN performs synchronization to target eNB and accesses to the target eNB via RACH.
11. The target eNB responds with UL allocation and timing advance.
12. After MRN successfully accesses to target eNB, the MRN will send "*Handover Confirm Message*" to the target eNB. From now on, the MRN established normal communication link with target eNB and then the data packets stored in target eNB starts to transmit.
13. The target eNB sends a "*Source Path Release Request Message*" to MME to inform that the MRN has changed cell.
14. The MME sends a "*Source User Plane Release Request Message*" to the S-GW.
15. The S-GW releases the downlink data path of source eNB.
16. S-GW sends a "*Source User Plane Release Request ACK Message*" to MME.
17. The MME confirms the "*Source Path Release Request Message*" with the "*Source Path Release Request ACK Message*".
18. After sending "*UE Context Release Message*", the target eNB informs success of handover to the source eNB and triggers the release of resources of the source eNB. The target eNB sends the message after the "Source Path Release Request ACK Message" is received from the MME.
19. Upon reception of "UE Context Release Message", the source eNB releases radio and C-plane resources associated to the UE context.

B. Features of the Scheme

Compared with the handover scheme in [6], MR-FHS has four main features.

The first one is the setup of RTP and RHP. RTP can ensure measurement results be reported in time and RHP ensure the handover be executed in time. The location of RTP and RHP are based on both the measurement result and the location of RTP and RHP before. Namely that if the MRN has not arrived at RTP but certain event-triggered reporting criteria is satisfied, the measurement report will start in advance and the location will be used to update the RTP. In addition, RTP also provides reference for starting of data bi-casting. The update method of RHP is similar to RTP.

The second feature is that after measurement report starting, if t<=HTT, the target eNB will prepare for the incoming handover and configure resource in advance. So once the handover execution conditions are satisfied, MRN can synchronize to target eNB rapidly. This method can eliminate the handover preparation time.

The third feature is data bi-casting with minimum network consumption. The bi-casting scheme we proposed is right after the completion of resource configuration in target eNB, which is much closer to the handover execution time. So not only communication interruption time is reduced but seamless handover is realized. Besides, the bi-casting time is minimized so that the consumption of network resources is decreased.

The fourth is that a database was established in eNB or relay node to save the reference point and measurement results information etc. The information has update mechanism based on long-term statistical measurement results to ensure that RTP and RHP are accurate.

In addition, The target cell can be decided according to the database since the train moving direction is fixed and the position and speed can be known. This not only reduces the number of eNBs to be measured but the resource can be prepared in target eNB in advance. By this, the handover preparation delay is reduced.

IV. PERFORMANCE ANALYSIS

In order to evaluate the performance improvement of the proposed scheme, handover time delay, communication interruption time and bi-casting time will be analyzed next.

We define the handover delay, denoted by T_{ho_delay}, from the time that handover condition is satisfied to the time that user equipments receive packets from S-GW through target eNB. Though in control plane, it's normally thought that handover is completed when user equipments respond an HO Confirm massage. The time consumption of every part is defined in [8].

Considering that only hard handover scheme is supported in LTE, the handover leads to communication interruption in the user plane. Communication interruption time is known as the period that user equipments cannot exchange user plane packets with any of the eNBs.

System level simulations within a typical suburb propagation environment is been performed. The network is assumed as a linear coverage along the railway. Each eNB only has a backward and a forward eNBs. Table I summarizes the general environment simulation parameters. Handover and mobility related parameter is assumed in table II.

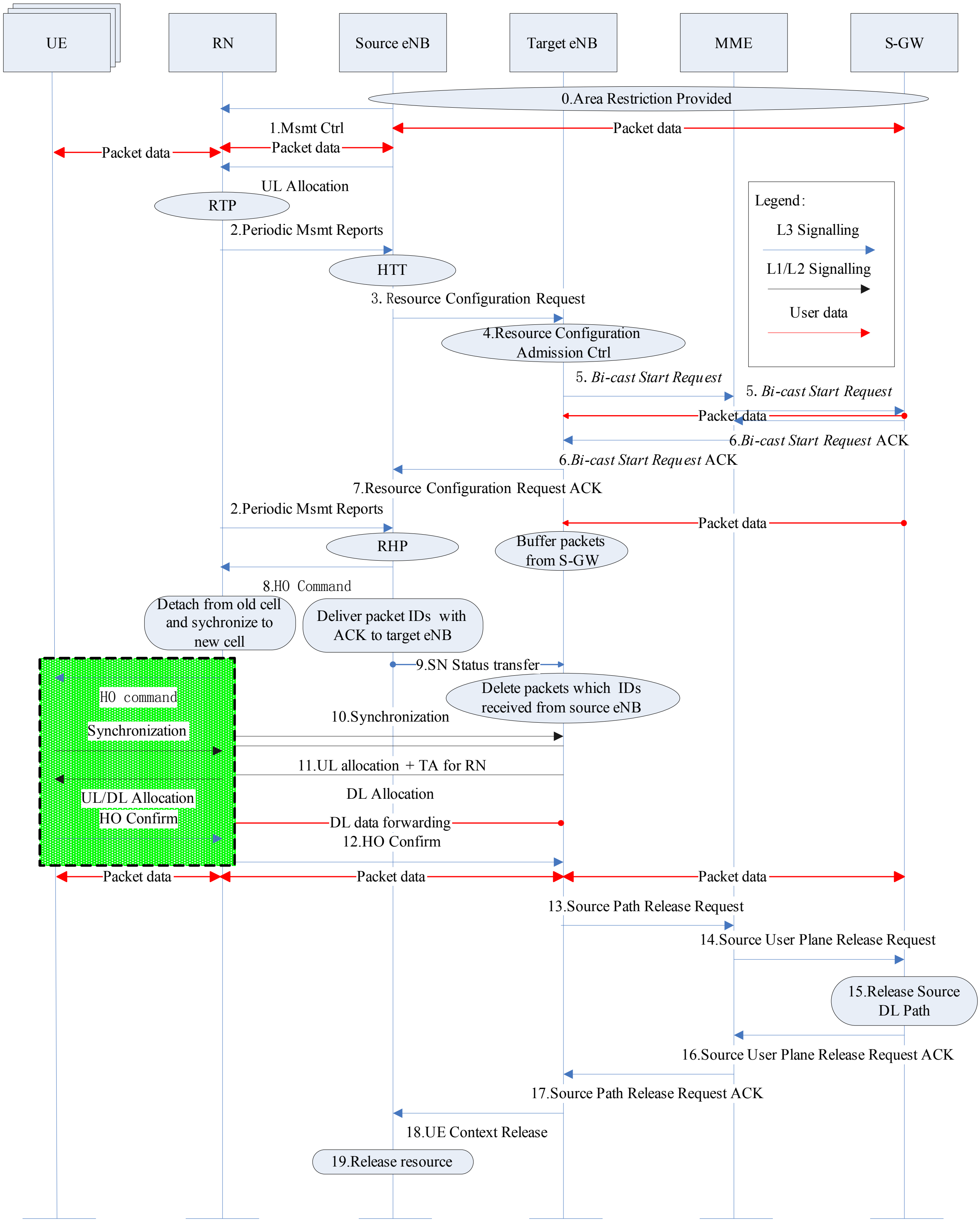

Figure 2. Handover mechanism of MR-FHS

TABLE I. ENVIRONMENT PARAMETERS

Parameter	Assumption/Explanation
Inter-Site Distance(ISD)	2000m
Distance between eNB and Railways	10m
eNB Antenna Height	30m
RN Antenna Height	5m
Carrier Frequency	2GHz
System Bandwidth	10MHz
eNB Tx Power	46dBm
eNB Antenna Gain	14dBi
Propagation Model	Path Loss(dB) = 128.1 + 37.6 * log10 (R in km), where R is distance from eNB to RN
Shadowing Standard Deviation	8dB
Shadowing Correlation distance	50m
Small-scale Fading	Rice Fading, K=20
RN Antenna Gain	5dBi
Thermal Noise Level	-174dBm/Hz

TABLE II. HANDOVER AND MOBILITY RELATED PARAMETERS

Parameter	Assumption/Explanation
Hysteresis	2~4 dB
Time to Trigger(TTT)	64ms
Speed State Scale Factors	sf-Medium: 0.75, 1.0; sf-High: 0.25, 0.5.
Back-haul Delay	Truncated-exponential with mean 20ms, (min, max) of (10, 100)ms[8]
Radio Synchronization	1ms[9]
RACH Waiting	2ms[9]
Preamble	1ms[9]
eNB Processing and Grant	7ms[9]
UE/RN Processing Delay	2ms[9]
Packets Delay	5ms
Radio Link Failure(RLF) Delay	Truncated-exponential with mean 60ms, (min, max) of (10, 500)ms
RLC declaration of RLF	T310=500ms
Speed Threshold	60m/s

Figure 3 illustrates the numerical results of handover delay with different MRN velocity. The handover time threshold is determined by propagation environment and velocity of MRN[10]. When velocity is higher than 60m/s, the T_{ho_delay} reduces to about 50 ms in MR-FHS while the normal handover procedure time remains 230ms. So the proposed handover procedure delay can well satisfied the handover time threshold.

Figure 4 shows the numerical results of bi-casting time with different MRN velocity. We compare the MS-FHS with the SINR based scheme and the velocity based scheme [11]. From the results we can know that the handover scheme we proposed is more efficient in reducing bi-casting time during handover than the SINR based bi-casting and Velocity based bi-casting.

Figure 5 shows the communication interruption time in normal handover and proposed handover. From the numerical result in figure 5, we can know that the communication interruption time reduced about 27%.

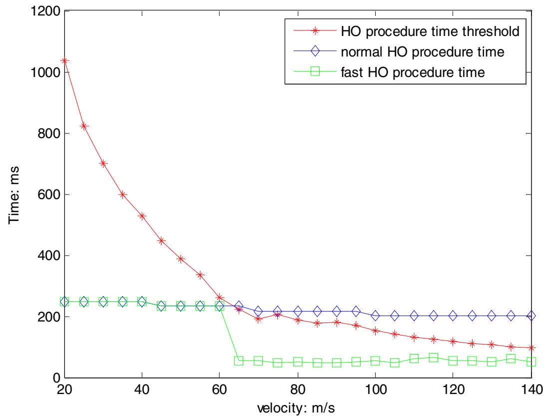

Figure 3. Handover Delay

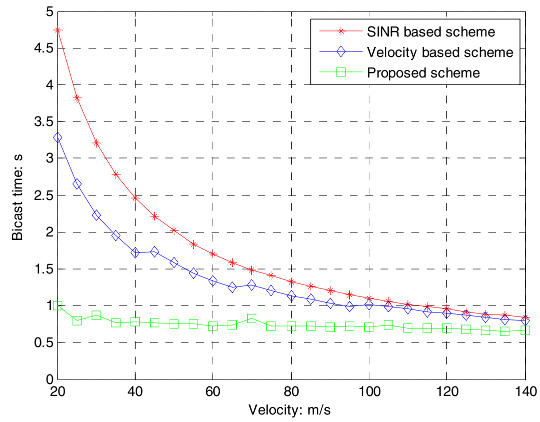

Figure 4. Bi-casting Time

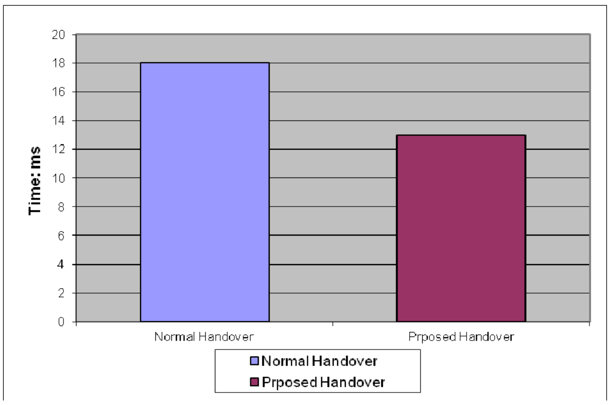

Figure 5. Communication Interruption Time

V. CONCLUSION

This paper mainly focuses on the handover problem for high-speed trains. Based on the environment characteristics of high-speed trains, a mobile relay base fast handover scheme is proposed and discussed in detail. The main goal of this scheme is triggering handover in time, reducing handover execution time and minimizing the interruption time with minimum network consumption. The proposed scheme includes three main features: 1) Two reference points are set to ensure handover in time. Furthermore, the position of the reference points is updated by both measurement results and the location of reference points before. 2) Pre-preparation and packet transmission to target eNB before handover is introduced to reduce the handover time. With the assistance of RTP and HTT, the network consumption can be minimized. 3) A MRN is utilized to combat the high penetration loss of coaches and the group mobility challenge. The simulation results show that in high-speed environment, the proposed scheme performs better in handover delay, communication interruption time and bi-casting time compared to conventional handover scheme.

REFERENCES

[1] Jia-Yi Zhang, Zhen-Hui Tan; Zhang-Dui Zhong, Yong Kong, "A Multi-Mode Multi-Band and Multi-System-Based Access Architecture for High-Speed Railways," Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd , pp.1-5

[2] Lianhai Shan, Fuqiang Liu, Liping Wang, Yusheng Ji, "Predictive Group Handover Scheme with Channel Borrowing for Mobile Relay Systems," Wireless Communications and Mobile Computing Conference, 2008. IWCMC '08. International , vol., no., pp.153-158

[3] CHEN Chen, LI Chang-le. High speed rail communication system: A survey. Computer Engineering and Applications, 2010. 46(34), P24-26.

[4] Lin Tain, Yiqing Zhou, Juan Li, Yi Huang, Jinglin Shi, Jihua Zhou, "A novel handover scheme for seamless wireless connectivity in high-speed rail," Wireless and Mobile Computing, Networking and Communications (WiMob), 2011 IEEE 7th International Conference on , vol., no., pp.230-236, 10-12 Oct. 2011

[5] Kastell, K., "Challenges and improvements in communication with vehicles and devices moving with high-speed," Transparent Optical Networks (ICTON), 2011 13th International Conference on , vol., no., pp.1-4, 26-30.

[6] Oumer Teyeb, Vinh Van Phan, Bernhard Raaf, and Simone Redana, "Dynamic Relaying in 3GPP LTE-Advanced Networks," EURASIP Journal onWireless Communications and Networking, Volume 2009,P1-11

[7] 3GPP TS 36.331, “Radio Resource Control (RRC)”, V10.3.0, 2011-09.

[8] Farajidana, A., Wanshi Chen, Damnjanovic, A., Taesang Yoo, Malladi, D., Lott, C., "3GPP LTE Downlink System Performance," Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE , pp.1-6.

[9] Singhal, D., Kunapareddy, M., Chetlapalli, V., James, V.B., Akhtar, N., "LTE-Advanced: Handover interruption time analysis for IMT-A Evaluation," Signal Processing, Communication, Computing and Networking Technologies (ICSCCN), 2011 International Conference on , vol., no., pp.81-85, 21-22 July 2011

[10] Qureshi, S.-U.-R., Nawaz, S.J., Patwary, M., Abdel-Maguid, M., Kamar, A., "The impact of propagation environment and velocity on the handover performance of LTE systems," Wireless Communications and Signal Processing (WCSP), 2010 International Conference on , pp.1-5,

[11] Dongwook Kim, Sawhney, M., Hanjin Lee, Hyunsoo Yoon, Namgi Kim, "A Velocity-Based Bicasting Handover Scheme for 4G Mobile Systems," Wireless Communications and Mobile Computing Conference, 2008. IWCMC '08. International , vol., no., pp.147-152