Performance Evaluation and Analysis on Group Mobility of Mobile Relay for LTE Advanced System

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Abstract*—High Speed Railway(HSR) scenario was currently agreed as the main scenario in the 3GPP Rel.11 study item, Mobile Relay for E-UTRA. Usually, communications of high-speed railway systems suffer from problems such as Doppler spread, radio condition abrupt change and handover failure. Mobile relay is a promising scheme to solve these problems, but the quantitative performance improvement to HSR has not been fully evaluated and analyzed. In this paper, a high speed scenario with mobile relay integrated is presented to analyze these issues for LTE Advanced system. The proposed mobile relay solution with group mobility is evaluated by a series of system simulation which witnesses an improvement in train user throughput as well as system throughput, and higher handover success ratio with a decrease in radio link failure ratio.

Key words- Long Term Evolution-Advanced；high speed rail; mobile relay; system throughput；group mobility

I. INTRODUCTION

With the increasing demand and rapid development of wireless communication quality during the past thirty years, the initial 1G have run into 4G with a higher data rate and a better mobility support. The 4G technique-International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile broadband communication systems include new capabilities that go significantly beyond those of the IMT-2000. The key requirements of IMT-Advanced systems include increased spectral efficiency and bandwidth, improved cell edge performance and mobility support, reduced Control and User plane latency, reduced handover interruption time [1]. 3GPP LTE-Advanced, with advanced features such as carrier aggregation, coordinated multipoint processing (CoMP), relays as potential solutions is considered to be one of the top candidates towards achieving IMT-Advanced requirements, and thus becomes the main trend in future wireless communications.

In 3GPP, high speed train scenario was agreed as the main scenario in the Rel11. study item, Mobile Relay for E-UTRA. In this scenario, when the train moves at high speed, the channel characteristics will change rapidly and result in obvious Doppler spread. Also the vehicles are more crowded than other areas and the passengers have higher probability to use high data rate services, e.g. watching videos, browsing, playing game, for killing time [2]. High-data-rate transmission systems require strong received signal strengths and high throughput, as well as better mobility management, so mobile relay stations for large vehicles are proposed for Broadband Wireless Access (BWA) system.

Mobile relay station is a dedicated network node equipped on the vehicles, e.g. buses and trains, to provide a fixed access link to passengers riding on vehicles. Therefore, mobile relay is very suitable to solve the capacity gain of high speed vehicles if it is well deployed.

The aim of this paper is to investigate the capacity and handover performance gain of mobile relay in high speed scenario. Two kinds of scenarios will be discussed in this paper: one is vehicle without relay; the other is vehicle implemented with mobile relay, also called as group mobility. Both of them are dedicated network devices, not the case where mobile terminal serves as relay.

The rest of this paper is organized as follows. Firstly, the overview of mobile relay is given in Section II. In Section III, the capacity and handover analysis for different scenarios are proposed. Section IV presents a system level simulation of vehicle with or without relay in high speed scenario and compares the results. The paper is brought to a conclusion in section V.

II. MOBILE RELAY OVERVIEW

A. *Background of Relay in the LTE-Advance Network*

Generally speaking, relay is identified as an enhancement for the traditional cellular architecture. Relay Station (RS) can be regarded as a key node in the network and it is intelligently capable of relaying data between the base station (BS) and mobile stations (MS) wirelessly. Under normal condition, relay is likely to provide the following functions: wireless connection service to mobile stations in the cell; wireless backhaul connection to on-land network. The BS-RS link and RS-MS link are respectively called backhaul link and access link [3].

There are several advantages provided by relay station which have been approved already. Firstly, RS is usually expected to be settled in the edge of the cell to cover shadowing area. Due to the BS cannot provide sufficient coverage for edge users, RS will improve radio link quality for them with unremarkable interference to other users. Secondly, in some hot spot area where may burst high data traffic for a certain period, RS can help to offer service for some users to avoid network overload. At last, with less deployment cost and smaller size against BS, RS is easy to deploy and maintain.

According to the moving state, the relay station can be sorted into two kinds: fix relay station (FRS) and mobile relay

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station (MRS). The advantages mentioned above have raised interest of network operators, equipment manufactures and academies. More fascinating is the fact that mobile relays can achieve better handover performance and user seamless mobility experience. So in this article, we mainly focus on the study of mobile relays in fast-moving environments.

B. Mobile Relay

Mobile relays are generally mounted on a vehicle, such as the bus and train. Vehicles with well shield carriages can cause higher penetration loss of the radio signals to/from UEs inside the carriage. In order to reduce penetration loss and decrease interference, it is recommended mobile relay utilize individual transceiver inside and outside vehicle separately. The donor antenna is located on the top of vehicle and the antenna of MRS to UE is placed inside the vehicle and down tilted to decrease the interference to the area outside of vehicle.

Compared to FRS, MRS may have some additional new features resulting in lower equipment cost and more flexible deployment options. Given the fact that the MRS has better antennas to obtain diversity gain, the backhaul link will be better than the direct radio link between BS and MS, so one of the main contributions of MRS is that it can effectively improve the system capacity. As a serving BS for UEs in vehicle, mobile relay should at least support the following BS functions: radio resource management, routing of user plane data towards serving gateway, measurement and measurement reporting configuration for mobility and scheduling[4]. It seems that MRS can have the ability to perform group handover instead of UE individual mobility procedures. This is another major contribution of MRS. With group mobility, it can be seen that UE will achieve better handover performance and lower radio link failure.

Fig.1 shows an application scenario of high speed railway downlink transmission from a BS to a UE via a MRS.

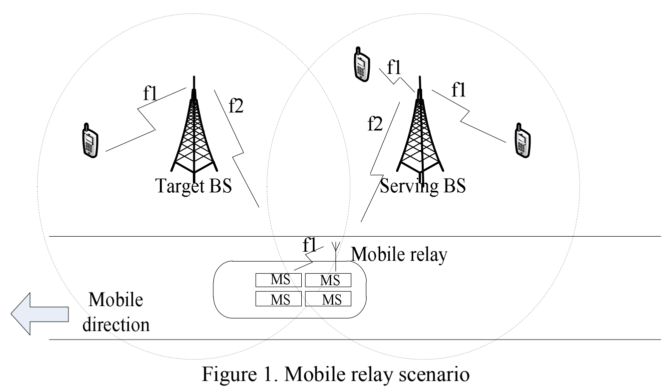

Figure 1. Mobile relay scenario

III. CAPACITY AND HANDOVER ANALYSIS IN HIGH SPEED SCENARIO

In the high-speed rail(HSR) systems, the received signal may have a Doppler shift due to the mobility of UE relative to the serving BS as:

$$f_D = v\cos\theta / \lambda \tag{1}$$

Where θ is the arrival angle of the received signal relative to the direction of motion, v is the receiver velocity towards the transmitter in the direction of motion, and $\lambda = c / f_c$ is the signal wavelength (c is the speed of light, f_c is the carrier frequency) [5]. Then the channel would be more complex to estimate as the frequency deviation and fast fading. In order to eliminate or weaken the impact of Doppler shift, the receiver of BS must provide frequency correction to compensate for performance degradation. Secondly, the vehicles are more crowded than rural areas passing by and the passengers have higher probability to use high data rate services such as watching video, browsing, playing games for killing time. So high-data-rate transmission systems require high system throughput. Thirdly, in the HSR system, UEs moving as a group are highly possible to handoff at the same time, causing higher call drop rate and signaling overhead.

Considering the characteristics of wireless cellular networks along the railway described above synthetically, MRSs are suitable to improve the communication quality of UEs on the train. We assume that MRS can support the functionality of Doppler frequency shift correction. The concrete mobile relay-assisted scenario is given in Fig.1. Since a wireless device cannot simultaneously transmit and receive signals at the same frequency channel, we consider the TDM scheme as the multiplex mode for BS-to-MRS link and MRS-to-MS link, as well as frequency division case that RS uses two orthogonal frequencies to transmit and receive, as shown in Fig.1. In the analysis, we mainly consider Amplify and Forward (AF) mode, i.e. RS simply amplifies the received signals and forwards it to the destination node with same frequency.

In the subsequent analysis, the important parameter for channel capacity is characterized as the SINR [6]. Assuming transmit power is known as P_{tx} , in order to gain SINR parameter, radio propagation should be analyzed including path loss and shadowing.

The pass loss model (in dB) we used in our scenario is the WINNER II rural channel model [7]. Propagation scenario D1 in [7] represents radio propagation in large areas (radii up to 10 km) with low building density. Consequently, LOS conditions can be expected to exist in most of the coverage area. In case the UE is located inside a building or vehicle, an additional penetration loss is experienced which can possibly be modeled as a (frequency-dependent) constant value, which is shown as follows.

In BS-to-MRS link, the pass loss is denoted as PL_1, which is calculated according to the comparison between the actual distance d with a threshold d_{bp}.

$$PL_1 = \begin{Bmatrix} 44.2 + 21.5\lg(d[m]) + 20\lg(f[GHz])/5), 10m < d < d_{bp} \\ 10.5 + 40\lg(d) - 18.5\lg(h_{BS}) \\ -18.5\lg(h_{\text{Train}}) + 1.5\lg(f[GHz])/5), d_{bp} < d < 10km \end{Bmatrix} \tag{2}$$

Where h_{BS}=32m, h_{Train}=2.5m, d is distance between BS and the train carriage, f is the centre-frequency (GHz), and d_{bp} is described as (3).

$$d_{bp} = 4 h_{BS} h_{\text{Train}} f_c / c \tag{3}$$

where h_{BS} is the height of the base station, h_{Train} is the height of the train carriage, c is the velocity of light and f_c is the centre-frequency.

In MRS-to-MS link, the transmit process is in the carriage, so radio propagation environment can be simplified as indoor LOS scenario. The MRS-to-MS link path loss, PL_2, can be described as (4), [7].

$$PL_2 = 46.4 + 18.7\lg(d[m]) + 20\lg(f[GHz])/5 \qquad (4)$$

Where d is the distance between MRS (the top of carriage) and MS and f is the centre-frequency. Then the overall pass loss PL_{B-R-M} with MRSs involved is denoted as:

$$PL_{B-R-M} = PL_1 + PL_2 \qquad (5)$$

Additionally, BS-to-MS link without mobile relay should be given in order to compare with mobile relay scenario. The path loss of BS-to-MS link, PL_{B-M}, can be described as follows.

$$PL_{B-M} = PL_1 + PL_2 + We + WGe(1-\cos(\theta))^2 \qquad (6)$$

Where We is the Loss through wall for the perpendicular penetration, WGe is Loss through wall for the parallel penetration and θ is angle between the normal of the wall and outgoing (incoming) ray. Usually, We is equal to 20dB and WGe is equal to 12dB [8].

For shadow fading value σ, most empirical studies for outdoor channels support a table of values to be chosen according to different SINR.

Models for path loss and shadowing are typically superimposed to capture power falloff versus distance along with the random attenuation about this path loss from shadowing. For this combined model the SINR gain is denoted as:

$$SINR = \frac{P_{tx} - PL - \sigma}{I + N_0 \cdot B} = \frac{P_{tx} - PL - \sigma}{I + N} \qquad (7)$$

Where Ptx is the transmit power, PL is the pass loss value， PLB-R-M or PLB-M according to whether there are mobile relays implemented or not (as discussed earlier). I is the overall interference from the macro cell and mobile relay signal. N0 is Gaussian noise coefficient and B is the bandwidth.

After the deriving of these basic indexes, we can discuss whether mobile relay is an effective solution to facilitate higher throughput and lower call drop rate for the passengers in the following section.

A. System Throughput

In High-speed railway scenario with MRSs integrated into the cellular systems, the carriage is a good shield and the wireless condition in the train is relative stable and easy to control. So the capacity of BS-to-MRS link is likely to be the bottleneck. Although the quality of BS-to-MRS link is not always good when the mobile relay is moving with the train across the cells，we can conclude without doubt that in any given moment, the SINR of BS-to-MRS link is always better than the BS-MS link where there is no relay at all because of the shielding of carriage. So if the system gives the relay enough radio resources, HSR system with mobile relay integrated would has a better system throughput than traditional one.

B. Handover and Group Mobility

When the train travels along the railway with very high speed (300~350km/h), there will be excessive frequent handovers happening in a relative short period. UE has very limited time(<2s) to measure and execute one handover procedure, which typically includes cell measurement and report, RRC connection reconfiguration, random access in new cell when passing the overlap area between two adjacent cells.

Because each mobile station in the same carriage performs handover almost at the same time, this will certainly aggravate system signaling burden, cause channel congestion and result in handover failure. So how to ensure handover successful rate of HSR becomes a remarkable issue.

Given the fact that large number of users' handover at the same time risks highly possibility of block up and call drop, the users moving as a group in the train should have a new way to connect to the BS, i.e. regarding the passengers connecting with MRS as a whole to execute handover, thus decreasing the management cost and resource allocation complexity of the entire system compared with the cellular system without relay. As the handover of MRS is transparent to the MSs, this procedure is feasible and practical. MSs could re-establish the connection with MRS after the handover and at the same time with the Target BS, thus realizing group mobility without much signal overhead as well as radio link failure. This is exactly a solution to the important issue in high speed railway system named mobility management.

IV. Simulation and Results

System-level simulations for a TDD-LTE cellular network are carried out to evaluate the performance of the MRS in terms of system capacity and handover performance. There are two cases to be compared which are high speed train with MRS and without MRS.

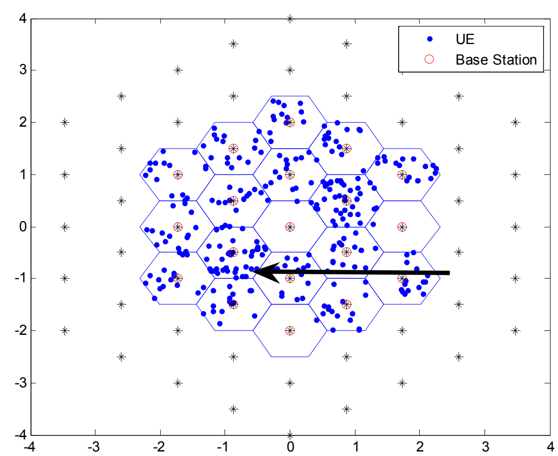

Figure 2. Network model with wrap-around technique

A. Layout, scenarios, parameters

In the simulation, a regular hexagonal 19 cell layout with an inter site distance of 1732m is deployed. Wrap around technique is used to avoid boundary effects (shown in Fig. 2). The bandwidth is set to be 20MHz. Each cell has one base station situated in the center with no sectors divided. There are

15 UEs randomly distributed in every cell with a velocity of 3km/h. A train with 350km/h starts in one cell and travel in line direction (The arrow direction in Fig. 2 shows the direction the train moves). We only consider one carriage of 224 meters long and 4 meters wide with 50 UEs and one MRS on it in this simulation. We assume that each user requests a constant bit rate of 0.5Mbps. It is supposed that the MRS can correct Doppler frequency shift. The rest parameters are shown in Table I and II.

Here in the case of train without MRS, each user communicates with BS directly and there is 22dB penetration loss of the carriages. While in the case of train with MRS, all users connect with MRS in access link and then MRS relays the signals to BS in backhaul link.

TABLE I Simulation Parameters

System bandwidth	20MHz
Cell layout	Hexagonal grid, 19 cell sites, with wrap-around technique
Inter-site distance	1732m
Pass loss	See equation (1), [7]
Shadow fading	Log-normal with standard deviation 4dB
Shadow fading correlation distance	10m
BS Tx Antenna gain	14dBi
RN Tx Antenna gain	2dB
BS Tx antennas	1 per cell
UE Rx antennas	2
BS Tx power	46dBm
RN Tx power	20dBm
Traffic model	CBR 0.5Mbps full buffer traffic

TABLE II UE Distribution Parameters

Number of background users unit	285
Number of users in one high-speed carriage	50
Distribution in each cell	Uniform distribution
Cell capacity	30UE
UE speed	3km/h
high-speed train speed	350km/h

B. Simulation Results and Analysis

To evaluate the performance of MRS, we focus on the system capacity and group mobility and carry out a series of comparative trial of simulations.

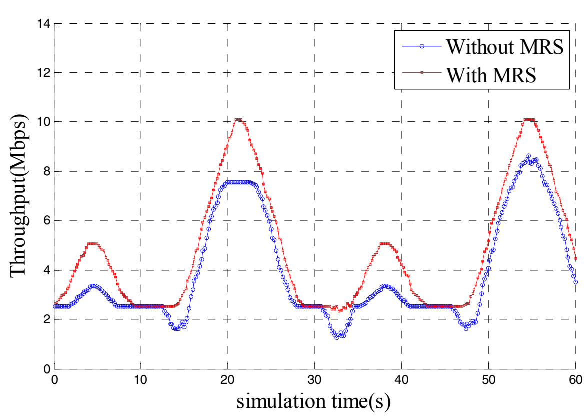

Figure 3. Train Throughput Comparison

Fig. 3 shows the timeline for train users' throughput versus the simulation time (60 seconds). In the simulation scenario a train carriage of 50 users is moving across the network on a predefined path, and the throughput would fluctuate when the train is moving into the cell center or moving out to the cell edge. According to Fig. 3, we can see that the average total throughput of 50 train users reach 8.03Mbps in the mobile relay scenario, while only reach 6.47Mbps in the traditional scenario, which means a 24.12% increase in high speed moving users' throughput. Furthermore, mobile relay gives the better throughput performance than traditional scenario in 73.6% simulation time. This illustrates that MRS can significantly and stably improve the capacity of users in the high speed vehicle, thus providing the possibility to support high data rate services.

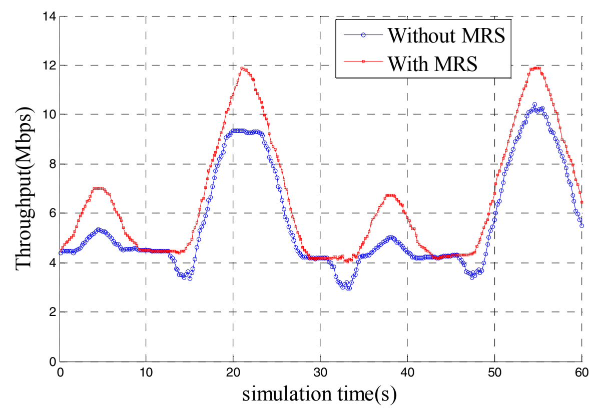

Figure 4. The overall system throughput

Figure 4 is the curve of overall system throughput including high speed users and background users for a whole simulation runtime. In the simulation scenario there are 15 UEs randomly distributed in every cell with a velocity of 3km/h as the background users. It is visible from the figure that the cell throughput of 50 in-car users and 15 users when the train passes reach 11 Mbps in the mobile relay scenario，while only reach 9.44 Mbps in the traditional scenario. It is a 16.53% improvement for the whole cell capacity. And mobile relay gives the better throughput performance than traditional scenario in 72.6% simulation time.

We can then safely conclude that the MRS would give good performance to the whole cell system when increasing the in-train user performance. It can even improve the capacity of the cell which the high speed train goes through at the same time.

Fig. 5 shows the comparison of radio link failure (RLF) ratio in the case of MRS and non-MRS versus the simulation time. The radio link failure mainly happens during user handover, which is a key performance indicator of system mobility and user experience. When handover occurs, the radio link condition of traditional non-MRS case would become much worse than MRS case. Its RLF ratio would reach between 30% and 60% during the process of handover. In MRS case the time of RLF duration is shorter than that of UE case and the RLF ratio is about 10%. Furthermore the maximum instantaneous value of RLF ratio in mobile relay scenario almost does not exceed 15%, which is a great improvement for high speed railway handover performance, providing a lower call drop rate as well as a better wireless communication quality and user experience.

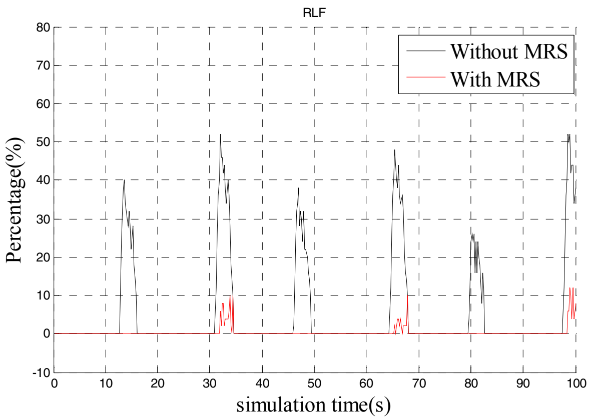

Figure 5. The radio link failure ratio over the simulation time

V. CONCLUSION

In this paper, a high speed scenario with mobile relay integrated is presented. The introduction of mobile relay increases the throughput by 24.12% for train users. As for the overall system throughput, mobile relay provides performance gains of more than 16.53%. The radio link failure ratio is also decreased greatly compared with the scenario without relay, improving the communication quality and user experience. However, there are still situations to be discussed in the future. For example, the resource allocation and interference in the mobile relays when trains are moving from opposite directions; the deployment and handover decisions of users in platform where there are usually more than one train arrive or depart, stop or pass by; the different decision for real time traffic and non-real time traffic passengers, and so on.

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REFERENCES

[1]. ITU-R-M.2134, "Requirements related to technical system performance for IMT-advanced radio interface(s) [IMT.tech]," ITU, Tech. Rep., 2008.

[2]. Huang Lin, Daqing Gu, Wenbo Wang, Hongwen Yang, "Capacity Analysis of Dedicated Fixed and Mobile Relay in LTE-Advanced Cellular Networks", Proceedings of ICCTA2009.

[3]. R.Balakrishnan, X.Yang, M. Venkatachalam, Ian F. Akyildiz, "Mobile Relay and Group Mobility for 4G WiMAX Networks", IEEE WCNC 2011.

[4]. 3GPP TSG RAN WG3#74, R3-112821, "Analysis on mobile relay functionalities".

[5]. Andrea Goldsmith, Wireless Communications, California: Stanford University, 2004.

[6]. T. M. Cover and J. A. Thomas. Elements of Information Theory. New York: Wiley, 1991.

[7]. IST-WINNER II Deliverable 1.1.2 v.1.2, "WINNER II Channel Models", IST-WINNER2, Tech. Rep, 2007.

[8]. Farrokh Abrishamkar, JamesIrvine, "Comparison of Current Solutions for the Provision of Voice Services to Passengers on High Speed Trains". IEEE VTC-Fall, VTC 2000. 24 -28 Sept. 2000.

[9]. Yunxiang Jiang, Gang Zhu, Zhenghao Wang, "a specific mobule relay with doppler diversity in OFDM system for high-speed railway scenario", Proceedings of ICNIDC2010.

[10]. Nourizadeh, H.; Nourizadeh, S.; Tafazolli, R.; "Performance evaluation of cellular networks with mobile and fixed relay station", VTC-2006 Fall. 2006 IEEE 64, 25-28 Sept. 2006 Page(s):1-5.

[11]. 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.