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Seamless Handover Scheme in Broadband Wireless Communication Systems for High- Speed Rail

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Abstract: Due to frequent handovers in broadband wireless-communications in communication interruption, high-speed rail during handover could seriously degrade the experiences of passengers on the train. Intending to reduce the interruption time, a seamless handover scheme based on a dual-layer and dual-link system architecture has proposed in this paper, where a Train Relay Station is employed to execute handover for all users in a train and two antennas are mounted at the front and rear of a train. The front antenna executes handover while the rear antenna is still communicating with Base Station (BS), so that the communication can keep non-interruptive throughout the handover. Additional, bi-casting is adopted to eliminate the data forwarding delay between the serving BS and target BS in the prospective scheme. A exhaustive handover protocol is designed and the performance of the proposed scheme is examined. It can be seen from analytical results that the handover failure probability decreases as cell overlap increases and the communication interruption probability decreases with the decrease of train handover location and the increase of cell overlap. The communication interruption probability is smaller than 1% when the handover and the simulation results show that in the proposed scheme. Location is properly selected and the system throughput is not affected by handover is shown. In conclusion, both theoretical and simulation results show that the proposed scheme can efficiently perform seamless handover for high-speed rail with low implementation overhead.

KeyWords—High-Speed Rail, Handover and Seamless.

1. INTRODUCTION

LTE-based HST mobile communication system is proposed in [1][2], which adopts the flat access network architecture to achieve the lower control plane latency comparing to GSM-R networks, so that the handover processing time can be reduced further. Moreover, a two-layer cellular architecture is presented to optimize the handoff blocking probability of high-speed moving terminals and dynamic antennas systems are deployed to reduce the handover frequency. Based on special features of railways such as the predictable speed and motion direction a number of handoff decision algorithms are proposed in [3]. The unnecessary handovers can be reduced by the fuzzy logic based handoff decision algorithm or random direction-lock based algorithm to lighten handover implementation overhead. Furthermore, key parameters of handoff decision algorithms are optimized to increase the decision accuracy. A predictive handover method is introduced with channel borrowing to reduce the connection blocking probability and handover dropping probability. There is limited work on how to design a seamless handover scheme where the communication interruption time is almost zero and transmitted data is lossless with low implementation overhead High handover frequency. With the drastically increase of train speeds, the handover will occur more and more frequently Group handover QoS guarantees [4]. The Quality of Service (QoS) of various mobile services of High Speed Trains(HST) will be degraded because of frequent handover, especially QoS of real-time services including passenger entertainment services and train control services which are critical for the traffic safety. In proposed system a seamless handover scheme based on the dual-layer and dual-link system architecture for HST. Two antennas are employed in this scheme one at the front of the train and the other at the rear. The rear antenna keeps connected to the serving Base Station (BS) when the front antenna carries out handover to the target BS and it switches to the working frequency of the target BS after the handover of the front antenna is refined. As a result communication will not be interrupted during handover. Secondly, the proposed scheme in [5] adopts the idea of bi-casting to eliminate the delay and overhead of data forwarding from the serving BS to target BS. Moreover it is Train Relay Station (TRS) not each user in a train to implement the handover procedure, which reduces the signaling overhead to about half of LTE handover scheme's. The performance of the proposed scheme is analyzed in terms of handover probability, communication interruption probability and handover failure probability.

Advantages: Theoretical and simulation results show that comparing with LTE handover scheme, the proposed scheme can reduce communication interruption probability Reduces handover failure probability drastically with only half of LTE scheme's signaling overhead. Moreover, simulation results show that the throughput of the proposed scheme is not affected by handover.

2. RELATED WORK

This examination epitomize the different elements of HST operation with the aim of characterizing HST operation and putting in contexts its impact in terms of what it is best designed for and what it can deliver. The review concludes that the HST is best designed to substitute conventional railway services on routes to substitute conventional railway services on routes where much higher capacity is required and to reduce travel time [6], further improving the railway facility, as well against other modes, therefore leading to mode substitution. Algorithm Shinkansen model. on the other hand, the high investment in HST infrastructure could not be justified based on its economic development benefits since these are not certain. Reduced-order robust controllers for tilting trains were proposed to improve the curving performance of high-speed trains. Linear Quadratic Gaussian (LQG) control with loop transfer recovery was already applied to active suspension designs, where model reduction on high-order controllers were used to achieve desirable closed loop performances. Algorithm Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) algorithm.

The main advantages of ATC include making possible use of automatic signaling instead of track side signaling and possible use of smooth deceleration patterns in lieu of the rigid and rough stops encountered by the old train stopping technology.

However, most of the above-mentioned research works were concerned with the ATO system only for traditional trains. Energy-saving is another main concern for the high-speed train systems.

Based on the relationship between speed and transmission interference [7], the scheme based on Distributed Antennas System (DAS) is proposed to improve transmission interference of RDMCS. The collision probability between data transmission and handover with the improved performance of transmission interference can reduce by the proposed scheme. Algorithm Distributed Antennas System (DAS) can not only improve the signal-to-noise ratio in tunnels bit also expand cell coverage area. Therefore, we can resort to DAS technology to improve transmission interference. The increasing speed of train, Doppler shift of radio signals will enhance, and handover will become more frequently. These changes will cause negative impacts on transmission interference performance of RDMCS. This paper derives an information theoretic lower bound on the Medium Access Control (MAC) layer overhead associated with re-associations caused due to mobility of node. An efficient MAC protocol is then proposed that reduces the handoff deferment. Simulations are used to demonstrate the superior performance of the proposed protocol in[8] terms of the throughput and packet latency Algorithm MAC protocol.

Advantages: Reduces the handoff delays. Disadvantages: However, these techniques only reduce the time required to locate a new access point and not the MAC layer delay required to a access the channel for transmitting the handoff related packets.

Handover is one of the key components in cellular network mobility management and has the most stringent latency requirement on service interruption time since the end-user experience is majorly determined by it. This article presents the state-of-the-art handover schemes considering various deployment scenarios in IMT Advanced candidate systems with a focus on IEEE 802.16m1 based 3GPP LTE-Advanced Algorithm Packet Data Convergence Protocol (PDCP) and next-generation WiMAX networks. In the design of IMT-Advanced systems, flexibility and the scalability to support various 4G deployments is also very crucial while meeting the latency requirement on handover.

Advanced features of handover interruption time and less of a coverage hole due to new system deployment Disadvantages However, if there is no direct link between the eNodeBs, for the serving eNodeB to direct the UE to handover to a specific target eNodeB, the handover could happen over SI.

3. SYSTEM ARCHITECTURE

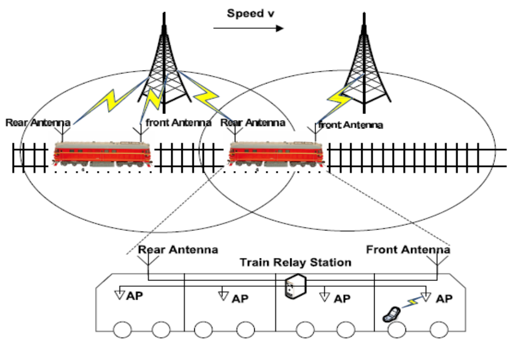

Fig-1: System Architecture

The dual-layer system architecture has been well recognized in the broadband wireless communications for HST [4]. As shown in the Fig-1 the users communicate directly with the Access Points (AP) located inside each carriage. All AP's which could support different types of wireless access technologies (e.g. WLAN, 2G and 3G) are controlled by a TRS. The data collected by AP's will be forwarded to a ground BS via the TRS. In the dual-layer architecture, the TRS can act as a single user to execute handover from the serving BS to target BS, which greatly reduces the handover overhead comparing to the conventional scheme where all the active mobile users in a train should execute handover simultaneously.

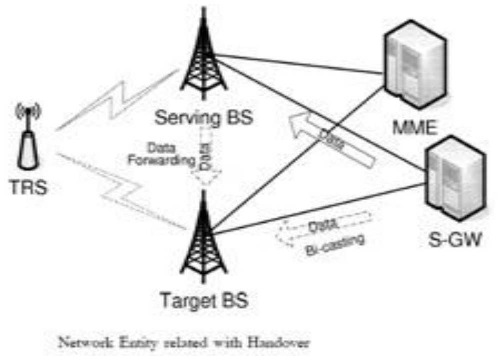

Fig-2: Network Entity related with Handover

As shown in Fig-2, the network entities include the Mobility Management Entity (MME) and Serving Gateway (S-GW). MME holds the functions of non-access stratum signaling tracking, TRS mobility management, air-interface security control, authentication, S-GW selection, etc. The downlink packets routing path and forward the packets to the target BS after a handover procedure is successfully executed. In the proposed scheme, there are two major modifications to the above entities: 1) MME needs to maintain two different sets of the connection context information about a TRS at the same time since the TRS may connect with both the serving BS and target BS during handover. 2) S-GW should keep two forwarding path within its routing table to support bi-casting, that is, the service packets are forwarded to both of the serving BS and target BS. Although the proposed scheme introduces some special functions in the design of BS, MME and S-GW entities of LTE, it will not affect mobile terminals of LTE because the TRS entity represents mobile terminals to implement handover.

4. PERFORMANCE ANALYSIS

By means of simulation, the performance of the proposed handover scheme based on the dual-layer and dual-link system are investigated in the high-speed scenario. The speed range of the train is assumed from 180km/h to 540km/h. Suppose there are totally 1000 users in a train and ten percent of them are active. According to the HST channel model recommended by 3GPP a single-path fading channel is considered in the simulation.

a. Handover Probability

Firstly, the handover probabilities with the different hysteresis level 'U' are plotted as a function of the train location. It can be seen that the handover probability with U=1db will exceed 50% when the train location is larger than 1300m. Moreover, it also can be seen that the theoretical results are close to the simulation results. If the measurement period of the received signal strength is 400ms in the proposed scheme, the handover decision will occur six times at most with the train location from 1300m to 1500m. Therefore, the handover probability is defined in this paper as the probability that handoff occurs at position *x*, which can be expressed as,

$$\begin{aligned} P_{ho} &= P\{R_{f,j} - R_{f,i} \geq U\} \\ &= P\{-10\gamma \log_{10} D_{f,j} + 10\log_{10} sh^2{}_{f,j} \\ &\quad + 10\gamma \log_{10} D_{f,i} - 10\log_{10} sh^2{}_{f,i} \geq U\} \end{aligned}$$

Let $SD_{f,j} = 10\log_{10} sh^2_{f,j}$ and $SD_{f,j} = 10\log_{10} sh^2_{f,i}$.

Then $SD_{f,j}$ and $SD_{f,i}$ are both zero mean Gaussian distributed with the standard deviation $\sigma_{f,j}$ and $\sigma_{f,i}$ respectively.

b. Handover Occurrence Probability

The handover occurrence probability is defined to describe the probability that handover is triggered before a certain position, which is calculated based on the handover probability. Therefore, the handover occurrence probability between 1300m and 1500m is larger than 1-(0.5)^3(0.6)^3=99.2% with U=1db and speed = 360km/h. The handover occurrence probability with the different train speeds. In the same train location, the handover occurrence probability decreases with the increase of train speed should be shortened to reach the same probability when the speed is increasing.

c. Handover Failure Probability

The handover failure probability as a function of handover locations, where the front antenna begins to handover. Both simulation and analytical results are shown. It can be seen that the analytical results match well the simulation results. The handover failure probability of the proposed scheme is smaller than 0.0001 while that of the single antenna scheme is about 0.05. Moreover, the handover failure probability decreases with the handover location increasing because the received signal by the front antenna from the target BS becomes better when the handover location is nearer to the target BS.

Therefore, handover failure probability of the proposed scheme can be expressed as,

$$P_{ho\_fail} = P^{f}_{ho\_fail} \cdot \frac{1}{R_d + L_t - x_r} \int_{x_r}^{R_d + L_t} P^{\tau}_{ho\_fail} dx$$

Where $P^{f}_{ho\_fail}$ and $P^{\tau}_{ho\_fail}$ represent the handover failure probabilities of the front antenna and rear antenna respectively, x_r is the location where the rear antenna has entered the overlap region and the front antenna has completed handover. If there is only one antenna,. Based on the above analysis, $P^{f}_{ho\_fail}$ can be obtained by

$$P^{f}_{ho\_fail} = P\{R_{f,j} \leq T \mid R_{f,j} - R_{f,i} \geq U\}$$

$$= \frac{P\{R_{f,j} \leq T, R_{f,j} - R_{f,i} \geq U\}}{P\{R_{f,j} - R_{f,i} \geq U\}}$$

$$= \frac{1}{P_{ho}} \int_{-\infty}^{\alpha_f} P\{SD_{f,i} \leq 10\gamma \log_{10} D_{f,i} / D_{f,j} + \psi - U / SD_{f,j} = \psi\}$$

$$P\{SD_{f,j} = \psi\} d\psi$$

$$= \frac{1}{P_{ho}} \int_{-\infty}^{\alpha f} (1 - Q(\frac{10\gamma \log_{10} D_{f,i} / D_{f,j} + \psi - U}{\sigma_{f,i}}))$$

$$\cdot \frac{1}{\sqrt{2\pi\sigma_{f,j}}} . e^{\frac{-\psi^2}{2\sigma^2_{f,j} d\psi}}$$

As a function of the overlap, according with the theoretical analysis, the handover failure probability decreases as the overlap increases. This is because that, at the same location, the received signal from the target BS becomes stronger with the overlap increasing.

d. Communication Interruption Probability

In communication interruption probability of the proposed scheme is plotted with the different handover locations. Again the analytical results are close to the simulated ones. Although the handover location is on the edge of the serving BS, Communication Interruption Probability is only about 0.2. Comparing with the conventional scheme such as LTE handover scheme of which Communication Interruption Probability is 1 all the time during the handover procedure, the proposed scheme decreases the probability of Communication Interruption drastically. It also shown that the Communication Interruption Probability is no more than 0.1 when the handover location is within 1300m.

Based on the definition, P_{ho_out} of the proposed scheme can be given by,

$$| P_{ho\_out} = (1 - P^{f}_{ho\_fail}) . P^{f}_{ho\_out} + P^{f}_{ho\_fail} . P^{r}_{ho\_out} |$$

Where $P^{f}_{ho\_out}$ represents the outage probability of the link between the rear antenna and the serving BS when the front antenna is accessing to the target BS, and $P^{r}_{ho\_out}$ is 1 because the communication is interrupted when the rear antenna executes handover if handover of the front antenna fails.

Therefore the proposed scheme can achieve a seamless handover when the handover location is properly selected. Moreover Communication Interruption Probability with different overlap are shown. At the same train location, Communication Interruption Probability decreases with the overlap increasing. Therefore, we can configure the overlap for network deployment by taking the handover performance such as handover failure probability and Communication Interruption Probability into consideration. In [9] the system capacity of the proposed scheme and single antenna as a function pf the train location are plotted. The throughput of single antenna scheme is 0 while that of the proposed scheme is not changed much during handover(about 1300m-1310m) because single antenna scheme when the train camps on a cell because the TRS can select the antenna with better signal qualities to communicate with BS. For Example in [10] the throughput of the proposed scheme is decreasing when the location is from 0 to 100m for the front antenna moving farther away from the serving BS, and the throughput starts increasing again when the location reaches about 100m because the rear antenna is selected to communicate with BS from 100m and this antenna gradually approaches the serving BS.

5. SIMULATION RESULTS

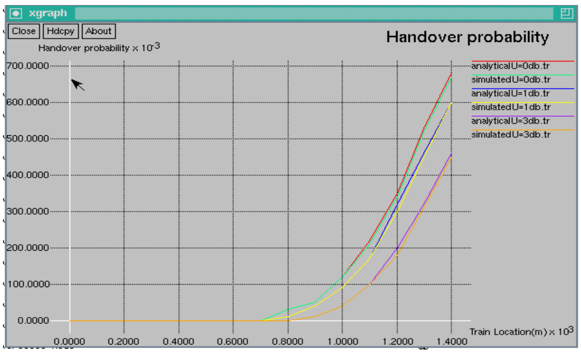

Fig-3: Handover Probability of proposed scheme (Speed=360km/h)

Fig-3 shows that the handover probability with U = 1dB will exceed 50% when the train location is larger than 1300m. Moreover, it also can be seen that the theoretical results are close to the simulation results. If the measurement period of the received signal strength is 400ms in the proposed scheme, the handover decision will occur six times at most with the train location from 1300m to 1500m. The handover occurrence probability is defined to describe the probability that handover is triggered before a certain position, which is calculated based on the handover probability. Therefore, the handover occurrence probability between 1300m and 1500m is larger than 1 – (0.5)3(0.6)3 = 99.2% with U = 1dB and $Speed$ = 360km/h.

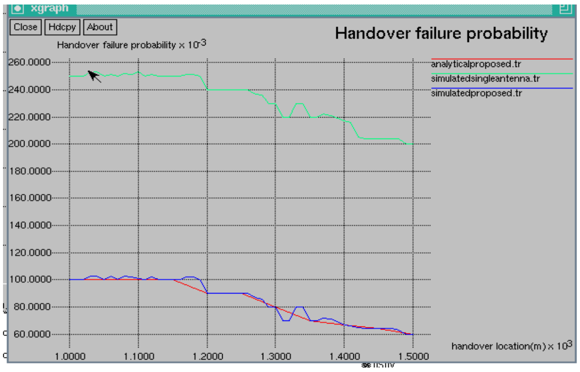

Fig-4: Handover Failure Probability (Speed = 360km/h)

Fig-4 shows that the handover failure probability as a function of handover locations where the front antenna begins to handover. Both simulation and analytical results are shown. It can be seen that the analytical results match well the simulation results. The handover failure probability of the proposed scheme is smaller than 0.001 while that of the single antenna scheme is about 0.05. Moreover, the handover failure probability decreases with the handover location increasing because the received signal by the front antenna from the target BS becomes better when the handover location is nearer to the target BS.

Fig-5: Handover Occurrence Probability of proposed scheme

In Fig-5 shows the handover occurrence probability with the different train speeds. In the same train location, the handover occurrence probability decreases with the increase of train speed. Therefore, the measurement period should be shortened to reach the same probability when the speed is increasing.

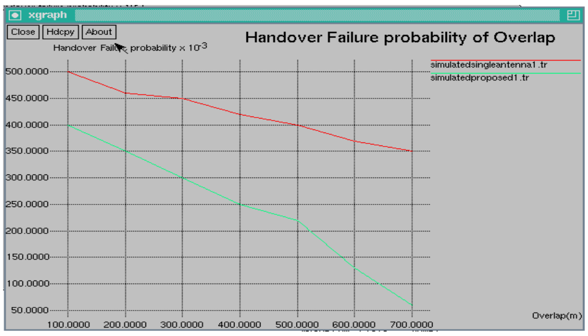

Fig-6: Handover Failure Probability as a function of overlap (Speed = 360km/h)

Fig-6 shows the handover failure probability as a function of the overlap. According with the theoretical analysis, the handover failure probability decreases as the overlap increases. This is because that, at the same location, the received signal from the target BS becomes stronger with the overlap increasing.

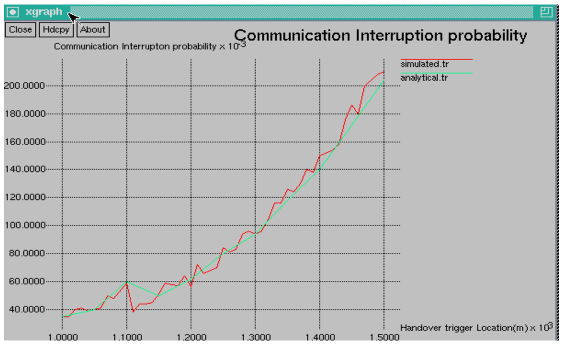

Fig-7: Communication Interruption Probability of proposed scheme (Speed= 360km/h)

In Fig-7, communication interruption probability of the proposed scheme is plotted with the different handover locations. Again, the analytical results are close to the simulated ones. Although the handover location is on the edge of the serving BS, Com Interrupt Probability is only about 0.2. Comparing with the conventional scheme such as LTE handover scheme of which Com Interrupt Probability is 1 all the time during the handover procedure, the proposed scheme decreases the probability of communication interruption drastically. It also can be seen from Fig.9 that Com Interrupt Probability is no more than 0.1 when the handover location is within 1300m. Therefore, the proposed scheme can achieve a seamless handover when the handover location is properly selected.

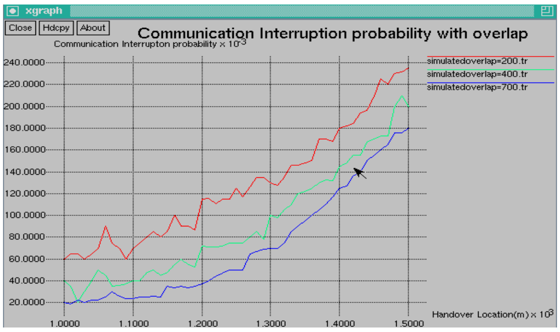

Fig-8: Communication Interruption Probability with different overlap (Speed = 360km/h)

Moreover, Communication Interrupt Probability with different overlap are shown in Fig-8. At the same train location, Com Interrupt Probability decreases with the overlap increasing. Therefore, we can configure the overlap for network deployment by taking the handover performance such as handover failure probability and Communication Interrupt Probability into consideration.

In Fig-9, the system capacity of the proposed scheme and single antenna scheme as a function of the train location are plotted. As shown in Fig-9, the throughput of single antenna scheme is 0 while that of the proposed scheme is not changed much during handover (about 1300m-1310m) because single antenna scheme can not support the seamless handover.

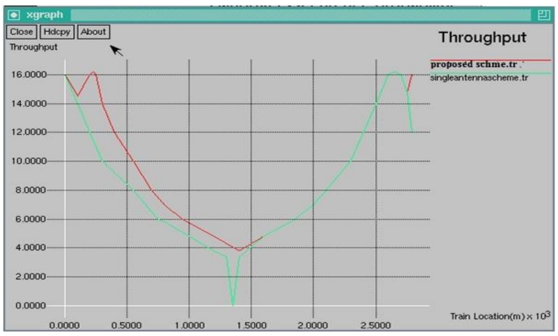

Fig-9: Throughput of proposed scheme and single antenna scheme (Speed= 360km/h).

Moreover, the average throughput of the proposed scheme is higher than that of single antenna scheme when the train camps on a cell because the TRS can select the antenna with better signal qualities to communicate with BS. For example, the throughput of the proposed scheme is decreasing when the location is from 0 to 100m for the front antenna moving farther away from the serving BS, and the throughput starts increasing again when the location reaches about 100m because the rear antenna is selected to communicate with BS from 100m and this antenna gradually approaches the serving BS.

7. CONCLUSION

Focusing on the design and performance analysis of the proposed handover process, a relatively ideal model with perfect channel estimation is assumed in this paper. However it is well known that accurate channel information is difficult to obtain in broadband wireless systems for HST. Theoretical and simulation results show that comparing with LTE handover scheme, the proposed scheme can reduce communication interruption probability. Reduces handover failure probability drastically with only half of LTE scheme's signaling overhead. Moreover, simulation results show that the throughput of the proposed scheme is not affected by handover.

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