Proceedings Paper:
Wang, S and Zhang, L orcid.org/0000-0002-4535-3200 (2022) A Multi-Criteria Handover Scheme for Distributed Antenna System Based High-Speed Rail Wireless Communications. In: 2021 24th International Symposium on Wireless Personal Multimedia Communications (WPMC). 2021 24th International Symposium on Wireless Personal Multimedia Communications (WPMC), 14-16 Dec 2021, Okayama, Japan. IEEE . ISBN 978-1-6654-2761-6

https://doi.org/10.1109/WPMC52694.2021.9700443

A Multi-Criteria Handover Scheme for Distributed Antenna System Based High-Speed Rail Wireless Communications

Siling Wang, Li Zhang
School of Electrical and Electronic Engineering
University of Leeds
Leeds, United Kingdom
Email: elswa@leeds.ac.uk, l.x.zhang@leeds.ac.uk

***Abstract*—High-speed railway (HSR) has become one of the most preferable modes of transportation. With increased train speed, the rail wireless communication faces lots of challenges. One of them is the handover problem. The high handover failure rate and frequent handover due to the fast moving speed can cause serious communication interruption. In order to achieve seamless handover for HSR system, this paper utilizes distributed antenna systems (DASs) along with dual-layer architecture and proposes an improved handover scheme based on multi-criteria. The proposed handover scheme improves both the handover triggering probability and handover success rate, demonstrated by both the theoretical analysis and simulation results. The simulation results also show that the proposed scheme outperforms the traditional handover trigger scheme.**

***Index Terms*—Distributed Antenna System, Handover, High-speed Railway, Train Relay Station, Dual-layer**

I. Introduction

In recent years, high-speed railway has been developed rapidly and considered as the most flourishing transportation mode. The maximum train moving speed has reached nearly 575 km/h. This brings multiple challenges to the high-speed railway (HSR) wireless communications, such as the handover scheme. In wireless communication of HSR, base stations (BSs) are deployed along the rail track and handover happens in the overlapping areas. The increased handover failure rate and frequent handover caused by high mobility results in serious communication interruption.

For instance, the train passes through the overlapping area so fast that the handover procedure can not be accomplished timely. Additionally, most of the high-speed trains have metal bodies with single or multi-layer glass windows which can cause penetration loss when signals go through the train carriages. This will degrade the received signal strength and lead to handover failure. Meanwhile, a handover will be triggered every 20s assuming a speed of 360km/h along an area with a coverage of 2km. In this case, it is hard to maintain the QoS and system performance is deteriorated. Moreover, when the minimum time required to process handover is larger than the time interval for the high-speed train (HST) takes to pass through an overlapping region, then call drops will occur and it causes packet loss. In addition, in HSR, there are a great number of handover requests from different users at the same time. However, because passengers congregate in the small areas on the train, simultaneous requests of handover from a large number of users result in "signaling storm", which will undoubtedly cause huge signaling overhead, and seriously deteriorate system performance [3]. For example, even only 30% of the 1000 User Equipments (UEs) in the train are active, there will be 300 simultaneous handover requests.

The above challenges have attracted intensive research interest. A communication system using dual-antenna and mobile relay station proposed in [4] can improve the quality of the received signal and provide reliable communication for train-to-ground network to enhance the handover performance. LTE-based HST mobile communication system is proposed in [5], which adopts a faster handover algorithm to reduce the failure probability by decreasing the handover latency with the target of providing reliable broadband services. Based on special features of railway architecture such as straight rail line and motion direction of train, a number of handover schemes based on distributed antenna system (DAS) are proposed [6] [7] [8]. The signal-to-interference-plus-noise ratio (SINR) can be increased especially for users near cell boundaries by DAS in a multicell environment [6]. Additionally, dual-antenna for HSR DAS is proposed in [7] to guarantee higher handover success rate and improve system throughput. A novel handover scheme based on DAS and mobile-relay-aided two-link network is introduced in [8] taking into account the effect of inter-carrier interference to reduce the handover failure rate and link outage probabilities. Furthermore, an expedited predictive handover scheme based on DAS is presented to lower the handover failure rate by starting handover preparation phase in advance via inferring the train position [9]. A handover optimization algorithm based on multi criteria is proposed in [13], considering joint RSRP and RSRQ to trigger handover in order to reduce the handover failure rate.

Although the handover problems for high-speed railway have been widely investigated, most of them consider only A3 event method to trigger handover in the DAS architecture. A3 is triggered when a neighbouring cell becomes better than the serving cell by an offset. In fact, other criteria

978-1-6654-2760-9/21/$31.00 ©2021 Crown

can also affect the handover performance such as speed, reference signal received quality (RSRQ), and position etc. Thus, we propose an improved handover scheme based on dual-layer DAS architecture for HST. The scheme jointly considers multi-criteria including speed, location, Reference signal received power (RSRP), and RSRQ, in order to have more precise handover decisions. In this paper, the received signal strength and SINR obtained from the measurement report are used as the RSRP and RSRQ respectively. Table 1 summarizes the criteria used by existing works and our proposed scheme that are based on DAS architecture.

TABLE I
HANDOVER TRIGGER CONDITION in DAS

References	Criteria used
[4][7][8]	RSS
[5][6]	SINR
[9]	RSS, Location
[13]	RSRP, RSRQ
Proposed scheme	RSRP, RSRQ, Speed, Location

The rest of this paper is organized as follows: In section 2, the network architecture model and usage scenarios are introduced. Section 3 is devoted to present the proposed handover scheme. Section 4 analyzes the performance of the proposed scheme. Simulation results are presented and dicussed in section 5. Finally, Section 6 concludes this paper.

II. System Architecture

Considering that the train is running at relatively constant speed and direction on a straight railway line, we take the advantage of the specialized DAS network architecture to meet the requirement of high quality wireless communication service. In addtion, dual-layer configuration which is similar to the two-hop model [3] is also used to reduce penetration loss and avoid the group handover problem.

A. *Dual-layer configuration*

The dual-layer configuration has been well recognized in the broadband wireless communication for HST [4] [10]. As shown in Fig.1,

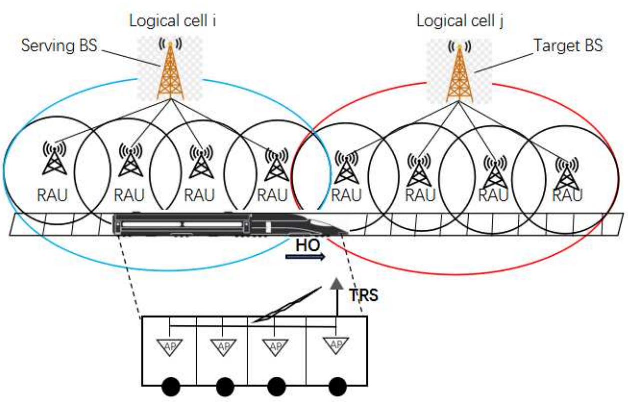

Fig. 1. System architecture.

The users communicate directly with the access points (AP) which are located inside each carriage of the train. All access points are able to support various types of wireless access technologies such as 3G,4G and WLAN, and are controlled by train relay station (TRS). All information collected by the TRS will be sent to BS. Actually, in dual-layer configuration, the TRS acts as a single big user to execute handover from the serving BS to the target BS, which substantially reduces the handover signaling overhead. However, for conventional handover scheme, all the active mobile terminals in a train will request a handover at the same time which can result in “signaling storm”.

B. *DAS configuration*

DAS system has been certified as a promising system for HST communication through shortening the distance between transmitter and receiver to provide better communication services [1]. Unlike the conventional collocated antenna system, DAS is divided into several sectors including BSs and remote antenna units (RAUs). Several RAUs in the DAS system are geographically distributed in the cell and all RAUs are connected to a central unit or base station via cable or optical fiber in a cell (see Fig.1). The left four RAUs constitute a logical cell i which are centrally controlled by the serving station i. Similarly, the right four RAUs constitute a logical cell j which are centrally controlled by the target station j. RAUs are only considered as the antenna units, and their aim is to transmit and receive radio signals for their BSs. Because all RAUs are connected to one BS in a cell, spatial diversity technology can be utilized to improve spectral efficiency. Moreover, several RAUs are controlled by the same BS, which can be considered as repeaters for the same signal to form spatial diversity and there is no need to handover when train moves from one RAU to the next one in the same cell. Handover between RAUs in the coverage of the same BS can be avoided via moving frequency concept. This concept can be achieved by using optical switching technology. Since there is usually more data transmission in downlink than uplink, this paper will mainly concentrate on the downlink scenario.

III. Handover Scheme

According to [6], several transmission schemes such as RAU selection transmission scheme and blanket transmission scheme can be adopted for data transmission in a DAS cell. In the blanket transmission scheme, each BS allocates its available power to its RAUs equally, even during the handover process. [10] shows that the RAU selection transmission is more appropriate for wireless HSR and hence it is adopted in our paper. In this paper, we concern about the handover between the last RAU of source cell and the first RAU of the target cell, namely the handover between two adjacent logical cells.

A. *Proposed Handover Decision Scheme*

In this section, a handover trigger scheme is proposed considering four parameters, i.e., speed, location, RSRP, and RSRQ. The handover decision algorithm determines whether to trigger a handover according to the measurement reports sent by the UE. A good handover decision algorithm can guarantee the success probability, avoid the occurrence of ping-pong effect, and ensure good quality of service and experience of passengers.

RSRP and RSRQ are the key parameters of physical layer measurement. RSRP is a key measurement of signal level for modern LTE networks. When a mobile device moves from one cell to another, it must measure the signal strength of the neighboring cells. In a low-speed environment, the RSRP received by the UE fluctuates smoothly and the received signal strength is more acccurate, so the RSRP handover decision algorithm is widely used. However, the RSRP measurement values for the two adjacent cells are close and if channel conditions are not good, RSRP based scheme may not trigger a handover in time, causing a waste of channel resources. In addition, in a high-speed environment, because the channel environment changes very quickly, considering RSRP only to trigger a handover easily results in ping-pong effect.

The received signal strength indicator(RSSI) is the average power of the received signals of the UE in the measurement bandwidth and it is used to indicate the interference condition of channel. RSRQ is defined as the ratio of RSRP to RSSI, expressed as

$$RSRQ = N \times \frac{RSRP}{RSSI} \tag{1}$$

where, *N* is the number of resource blocks within measurement bandwidth. RSRQ is determined by reference signals, interference singals and noise signals, which is similar to the signal-to-interference-plus-noise ratio of the link. Thus, RSRQ can effectively reflect the channel quality. During the handover, RSRQ is seriously affected by the system load and measurement strategy. Considering RSRQ only may lead to increased drop rate. Therefore, a handover decision algorithm that considers RSRP and RSRQ jointly can enhance suitable triggering of handover. The proposed handover decision algorithm, first checks the RSRP. When the RSRP of the target BS is higher than that of the source BS by a certain threshold, handover can be triggered. Otherwise, the algorithm then checks RSRQ of the target BS. If it is higher than that of the source BS by a certrain threshold, handover can be triggered.

Additionally, speed can also have a big impact on handover performance [11]. In a given measurement period T, with higher train speed, the train moves further during time to trigger (TTT), then the handover trigger position can be further away from the right point which will cause higher handover failure probability. For this reason, speed is also used as one of the parameters to make handover decision. Conventional A3 event-based handover algorithm is very prevalent. However, it is mainly designed for the low speed scenarios such as speed less than 120 km/h [11]. Thus, when the velocity is higher than 120km/h, the effect of speed on handover performance should be considered. In the proposed handover scheme, if the speed is higher than 120km/h, then the algorithm checks the location of users. Otherwise, traditional A3 trigger event will be adopted to determine a handover. Another criteria, location is also used to check if the train reach the midpoint of the overlapping area. Specifically, when the train does not reach near the midpoint of the overlapping area, A3 trigger event with considering TTT is used to avoid false triggers and ping-pong effect caused by signal fluctuations in high-speed scenario, and to ensure the stability of handover triggers. When the train reaches the midpoint of overlapping area, checking the RSRP without considering TTT to decrease the handover delay. According to the analysis of [14], A3 event has the best behavior in terms of defined indicators such as HO probability or HO success rate when compared with A4 and A5 events for high-speed railway scenario. In terms of A4 event, it is triggered when strength of the signals from the neighbouring cell becomes better than a threshold. For A5 event, it is a relatively complex event with two thresholds. That is triggered when strength of the signals from the serving cell becomes worse than threshold-1 and while strength of the signals from the neighbouring cell becomes better than threshold-2.

Generally, a handover will take place between two neighboring base stations when the criteria of handover is met. We assume that the handover criteria is met when the RSRP of the target station is larger than that of the serving station by a certain threshold for a certain period of time called TTT. If the TTT is too long, the probability of radio link failure might increase before handover is finished. This is mainly because the time interval available to execute the handover decreases as the train velocity increases based on constant overlapping area. Similarly, in case of 5G system, the time available to perform handover successfully between base stations also decreases substantially as the cell size smaller. Thus, in the proposed scheme, when the train enters the overlapping area between two neighboring BSs, the handover decision will occur at the predefined location where the handover criteria is met without considering the waiting time TTT. So, the time for performing HO is decreased by omitting the time delay caused by TTT which results in radio link failure especially in the high-speed railway scenario. Specifically, the handover will be triggered at one location where the RSRP or RSRQ of the target BS is larger than that of the serving BS by a certain threshold. The flow chart of the proposed handover decision algorithm is shown in Fig.2.

B. Analytical model

In this section, only the main path signal will be considered since high-speed train runs through rural or viaduct areas most times, so multi-path effect can be ignored. At time *t*, let a high-speed train be located at *x* in the *i*-th cell (original logic cell). The received signal power from the cell *i* is:

$$R(i,x)[\mathrm{dBm}] = Pt[\mathrm{dBm}] - PL\left(i,d_i\right)[\mathrm{dB}] - \varepsilon\left(0,\sigma_i\right)[\mathrm{dB}] \tag{2}$$

where *Pt* is the transmission power of the *i*-th cell. $PL(d) = A \cdot d^{-\gamma}$ is the path loss, where *A* is a constant, *d* is the distance, γ is the path loss exponent. $\varepsilon\left(0,\sigma_i\right)$ is a Gaussian distributed random variable with a zero mean and a standard

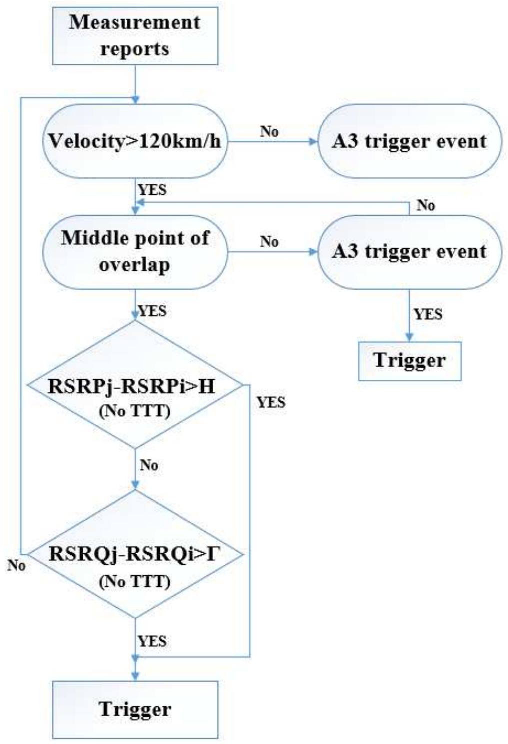

Fig. 2. The flow chart of the proposed handover decision algorithm.

deviation to describe the shadow fading.
Similarly, the received signal from target logical cell *j* is:

$$R(j,x)[\text{dBm}] = Pt[\text{dBm}] - PL\left(j,d_j\right)[\text{dB}] - \varepsilon\left(0,\sigma_j\right)[\text{dB}] \quad (3)$$

The co-frequency interference for the serving cell can be given by:

$$I(i,x) = \sum_{n=1}^{N_{cell}} R(n_i,x) \quad (4)$$

Similarly, the co-frequency interference for the target cell can be given by:

$$I(j,x) = \sum_{n=1}^{N_{cell}} R(n_j,x) \quad (5)$$

Where N_{cell} is the number of co-frequency interference cells. $R(n_i,x)$ means interference signal power from the co-frequency cells.
Thus, at location *x*, we can express the singal-to-interference-plus-noise ratio (SINR) from source BS and target BS respectively as follows:

$$SINR(i,x) = 10 \cdot \log_{10} \frac{R(i,x)}{I(i,x) + B \cdot N_0} \quad (6)$$

$$SINR(j,x) = 10 \cdot \log_{10} \frac{R(j,x)}{I(j,x) + B \cdot N_0} \quad (7)$$

Where N_0 is the noise power spectral density (dB/HZ). *B* is signal bandwidth (HZ).

IV. Performance Analysis

The performance of the proposed handover trigger scheme is evaluated in terms of handover trigger probability, handover success probability and the outage probability.

A. Handover trigger probability

Handover trigger probability is defined in this paper as the probability that handover occurs at position *x*. According to the proposed handover decision algorithm in DAS cell, the handover trigger probability of HST can be written as:

$$\begin{aligned} P(x)_{\text{trigger}} &= P[R(j,x) - R(i,x) \geq H] \\ &+ P[R(j,x) - R(i,x) < H] \cdot P[SINR(j,x) - SINR(i,x) \geq \Gamma] \end{aligned} \quad (8)$$

Based on equations from (2) to (7), we can obtain the following equations:

$$\begin{aligned} &P[R(j,x) - R(i,x) \geq H] \\ &= P\left[-PL\left(j,d_j\right) + PL\left(i,d_i\right) - \varepsilon\left(0,\sigma_j\right) + \varepsilon\left(0,\sigma_i\right) \geq H\right] \\ &= P\left[\varepsilon\left(0,\sigma_i\right) \geq H + PL\left(j,d_j\right) - PL\left(i,d_i\right) + \varepsilon\left(0,\sigma_j\right)\right] \\ &= P\left[\varepsilon\left(0,\sigma_i\right) \geq H + PL\left(j,d_j\right) - PL\left(i,d_i\right) + \varepsilon_0 \mid \varepsilon\left(0,\sigma_j\right) = \varepsilon_0\right] \\ &\cdot P\left[\varepsilon\left(0,\sigma_j\right) = \varepsilon_0\right] \\ &= \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_j^2}} Q\left(\frac{H + PL\left(j,d_j\right) - PL\left(i,d_i\right) + \varepsilon_0}{\sigma_i}\right) \\ &\exp\left(-\frac{\varepsilon_0^2}{2\sigma_j^2}\right) d\varepsilon_0 \end{aligned} \quad (9)$$

$$\begin{aligned} &P[R(j,x) - R(i,x) < H] \\ &= \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_j^2}} \left[1 - Q\left(\frac{H + PL\left(j,d_j\right) - PL\left(i,d_i\right) + \varepsilon_0}{\sigma_i}\right)\right] \\ &\exp\left(-\frac{\varepsilon_0^2}{2\sigma_j^2}\right) d\varepsilon_0 \end{aligned} \quad (10)$$

$$\begin{aligned} &P[SINR(j,x) - SINR(i,x) \geq \Gamma] \\ &= \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_j^2}} \\ &Q\left(\frac{\Gamma + PL\left(j,d_j\right) - PL\left(i,d_i\right) + I(j,x) - I(i,x) + \varepsilon_0}{\sigma_i}\right) \\ &\exp\left(-\frac{\varepsilon_0^2}{2\sigma_j^2}\right) d\varepsilon_0 \end{aligned} \quad (11)$$

Where, *Q(x)* is defined as follows:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\left(-\frac{t^2}{2}\right) dt \quad (12)$$

Based on the above analysis, the handover trigger probability of proposed scheme can be expressed as (13)

B. Outage probability

Another important criteria to evaluate the handover performance is outage probability. Communication outage happens if the received SINR of the TRS is less than a threshold. The outage probability is:

$$P(i,x)_{\text{outage}} = P[SINR(i,x) < \Upsilon] \quad (14)$$

$$P(j,x)_{\text{outage}} = P[SINR(j,x) < \Upsilon] \quad (15)$$

$$
\begin{aligned}
P(x)_{\text{trigger}} &= \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_j^2}} Q\left(\frac{H + PL\,(j, d_j) - PL\,(i, d_i) + \varepsilon_0}{\sigma_i}\right) \exp\left(-\frac{\varepsilon_0^2}{2\sigma_j^2}\right) d\varepsilon_0 \\
&+ \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_j^2}} \left[1 - Q\left(\frac{H + PL\,(j, d_j) - PL\,(i, d_i) + \varepsilon_0}{\sigma_i}\right)\right] \exp\left(-\frac{\varepsilon_0^2}{2\sigma_j^2}\right) d\varepsilon_0 \\
&\cdot \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_j^2}} Q\left(\frac{\Gamma + PL\,(j, d_j) - PL\,(i, d_i) + I(j, x) - I(i, x) + \varepsilon_0}{\sigma_i}\right) \exp\left(-\frac{\varepsilon_0^2}{2\sigma_j^2}\right) d\varepsilon_0
\end{aligned} \tag{13}
$$

Where Υ is the minimum SINR required for normal communication.
Substituting equations (6)(7) into equations (14)(15), then:

$$
\begin{aligned}
&P(i, x)_{\text{outage}} \\
&= P\left[\varepsilon(0, \sigma_i) > (Pt - PL(i, d_i) - (I(i, x) + B \cdot N_0) \cdot 10^{\frac{\Upsilon}{10}})\right] \\
&= Q\left(\frac{Pt - PL\,(i, d_i) - (I(i, x) + B \cdot N_0) \cdot 10^{\frac{\Upsilon}{10}}}{\sigma_i}\right)
\end{aligned} \tag{16}
$$

$$
\begin{aligned}
&P(j, x)_{\text{outage}} \\
&= P\left[\varepsilon(0, \sigma_j) > (Pt - PL(j, d_j) - (I(j, x) + B \cdot N_0) \cdot 10^{\frac{\Upsilon}{10}})\right] \\
&= Q\left(\frac{Pt - PL\,(j, d_j) - (I(j, x) + B \cdot N_0) \cdot 10^{\frac{\Upsilon}{10}}}{\sigma_j}\right)
\end{aligned} \tag{17}
$$

C. Handover success probability

In our proposed scheme, the handover success probability can be defined as the probability when the following three conditions are met simultaneously. At first, there is no communication interruption before the handover is triggered. Then, the handover is triggered at appropriate position and successfully executed. Finally, there is no communication interruption after the handover is completed. Thus, when the train is at location *x*, the probability of successful handover can be expressed as:

$$
\begin{aligned}
&P(x)_{\text{success}} \\
&= [1 - P(i, x)_{\text{outage}}] \cdot P(x)_{\text{trigger}} \cdot [1 - P(j, x)_{\text{outage}}]
\end{aligned} \tag{18}
$$

V. Simulation Results and Discussion

The performance of our proposed handover scheme is also evaluated by simulation based on dual-layer DAS cell architecture. The speed of the train is assumed to be 360km/h. Based on the HST channel model recommended by 3GPP [12], a single-path fading channel is used in the simulation. In the obtained simulation results, each point of the curves was obtained as the average of over 1000 channel realisations. The parameters used in the simulation are listed in Table II.

TABLE II
SIMULATION PARAMETERS

Parameters	Value
Bandwidth of System	10MHz
Carrier Frequency	2.5GHz
Total Transmit Power Pt	86dBm
Path Loss Model	31.5+35log10(d)
Shadow Fading Deviation	4dB
Noise Density	-145dBm/Hz
Signal Threshold	-30dB
Distance from BS to Rail	Dbs,rail=100m
Distance from RAU to Rail	Drau,rail=60m
Distance between two cells	ds=3000m
Number of RAU in one cell	N=4
Hysteresis Threshold	1dB

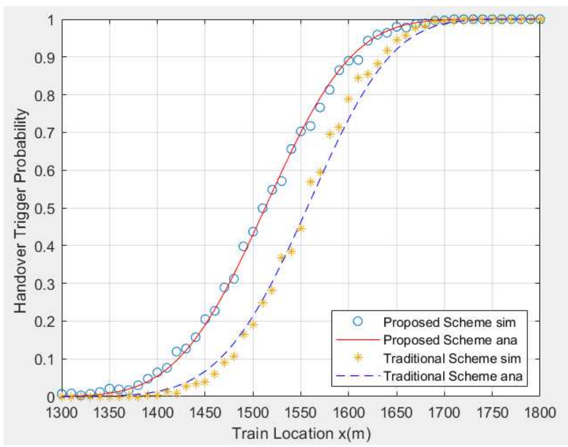

Fig. 3. Handover trigger probability during the overlap

Fig.3 presents the handover trigger probability versus the train location *x*. To verify the analysis in Section IV, both analytical results and simulation results are presented, and it is clear that the simulation results based on real pamaraters match very well with results from theoretical analysis. The curve with yellow star indicates the cumulative distribution probability of conventional handover which only considers RSS as the triggering metric. For example, when the train location is at 1500m, the TRS has 20% handover triggering probability. The curve with blue circle indicates the cumulative distribution probability of the poposed handover triggering method. As shown in the figure, the handover triggering probability of proposed scheme is 22% higher than that of the traditional scheme when the train locates at 1500m.

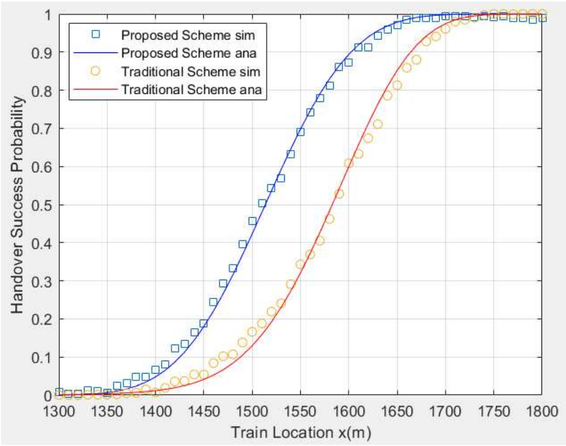

Fig. 4. Handover success probability of proposed scheme

Fig.4 is the probability of handover success. It can be clearly seen that proposed scheme can substantially enhance the handover performance. At distance 1600m, the successful handover probability rises from 60% to 91%.

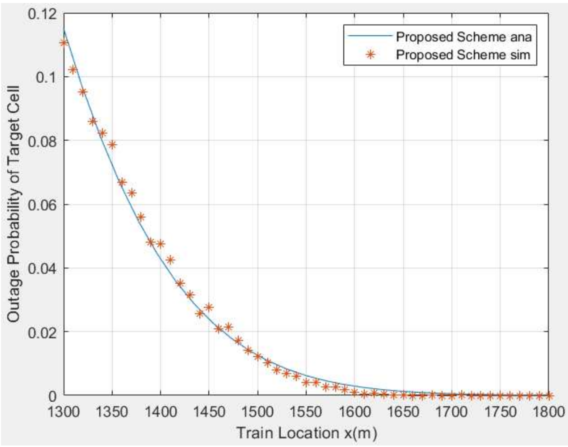

Fig. 5. The outage probability of proposed scheme

Fig.5 illustrates the outage probability of the target cell vs. train location. Again, the simulation result (red star) matches with the analysis (blue curve) closely. With the high-speed train moving towards the target cell, its outage probability is gradually reduced. In addition, it is close to 0 when the handover location exceeds 1600m. This clearly indicates that the proposed scheme can achieve a seamless handover when the handover location is properly selected.

VI. Conclusion

This paper has investigated the handover problem in wireless communication systems for HST scenario. Based on dual-layer and DAS architecture, an improved handover scheme employing multi-criteria is proposed to achieve better handover performance, which is analyzed in terms of handover trigger probability, handover success probability and outage probability. The simulation results coincide with theoretical analysis perfectly and they both show that the proposed scheme can not only reduce the handover implementation overhead but also improve the handover success probability compared with the conventional RSRP-based handover decision algorithm in DAS cell.

References

[1] J. Wang, H. Zhu and N. Gomes, ”Distributed Antenna Systems for Mobile Communications in High Speed Trains”, IEEE Journal on Selected Areas in Communications, vol. 30, no. 4, pp. 675-683, 2012.

[2] Y. Liu, ”Research on Handover Technology in High-Speed Railway Scenario”, ResearchGate, 2017.

[3] L. Tian, J. Li, Y. Huang, J. Shi and J. Zhou, ”Seamless Dual-Link Handover Scheme in Broadband Wireless Communication Systems for High-Speed Rail”, IEEE Journal on Selected Areas in Communications, vol. 30, no. 4, pp. 708-718, 2012.

[4] X. Qian, H. Wu and J. Meng, ”A Dual-Antenna and Mobile Relay Station Based Handover in Distributed Antenna System for High-Speed Railway,” 2013 Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing, Taichung, Taiwan, 2013, pp. 585-590.

[5] W. Ali, J. Wang, H. Zhu and J. Wang, ”An Optimized Fast Handover Scheme Based on Distributed Antenna System for High-Speed Railway,” 2017 IEEE 86th Vehicular Technology Conference (VTC-Fall), Toronto, ON, Canada, 2017, pp. 1-5.

[6] W. Choi and J. G. Andrews, ”Downlink performance and capacity of distributed antenna systems in a multicell environment,” in IEEE Transactions on Wireless Communications, vol. 6, no. 1, pp. 69-73, Jan. 2007.

[7] C. Yang, L. Lu, C. Di and X. Fang, ”An On-Vehicle Dual-Antenna Handover Scheme for High-Speed Railway Distributed Antenna System,” 2010 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), Chengdu, China, 2010, pp. 1-5.

[8] Z. Liu and P. Fan, ”An Effective Handover Scheme Based on Antenna Selection in Ground–Train Distributed Antenna Systems,” in IEEE Transactions on Vehicular Technology, vol. 63, no. 7, pp. 3342-3350, Sept. 2014.

[9] W. Ali, J. Wang, H. Zhu and J. Wang, ”An Expedited Predictive Distributed Antenna System Based Handover Scheme for High-Speed Railway,” GLOBECOM 2017 - 2017 IEEE Global Communications Conference, Singapore, 2017, pp. 1-6.

[10] Y. Lu, K. Xiong, Z. Zhao, P. Fan and Z. Zhong, ”Remote Antenna Unit Selection Assisted Seamless Handover for High-Speed Railway Communications with Distributed Antennas,” 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring), Nanjing, China, 2016, pp. 1-6.

[11] J. Li, L. Tian, Y. Zhou and J. Shi, ”An adaptive handover trigger scheme for wireless communications on high speed rail,” 2012 IEEE International Conference on Communications (ICC), Ottawa, ON, Canada, 2012, pp. 5185-5189.

[12] 3GPP TS 36.521: Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) conformance specification Radio transmission and reception Part 1: Conformance Testing, v9.3.0, Dec.2010.

[13] F. Yang, H. Deng, F. Jiang, and X. Deng, “Handover optimization algorithm in LTE high-speed Railway environment,” Wireless Personal Communications, vol. 84, no. 2, pp. 1577–1589, 2015.

[14] Amin Sadrabadi, H., Ardalani, N., Bakhshi, H, “Performance analysis of the LTE handover decision events for the high speed railway application,” Journal of Communication Engineering, vol. 9, no. 2, Dec.2021.