Handover Performance Improvement for Ultra Dense Network of High-Speed Railway

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***Abstract*—Nowadays the implementation of mobile Internet access services for high-speed railway (HSR) passengers are facing several challenges. In particular, the extra penetration loss of the train, frequent handovers, poor received signal and handover lag caused by fast time-varying fading channel may result in serious communication interruption. This paper investigates the mobility management of heterogeneous ultra dense network for HSR, in which macro base stations (BS) provide seamless coverage and millimeter-wave (mmWave) super micro BS provide high data rate services. With this network approach, a gray model (GM) prediction based handover algorithm is designed to prevent handover lag. To ensure service continuity for passengers, a combination factor is introduced into the handover decision to select target BS. Extensive simulation results prove the superiority of the proposed handover scheme in reducing handover failure probability and providing passengers with continuous services.**

***Index Terms*—Gray model prediction, heterogeneous ultra dense network, mobility management, high-speed railway mobile communications**

I. INTRODUCTION

With the rapid development of high-speed railway (HSR) systems, high demands on mobile Internet services are required by passengers. However, due to the extra penetration loss of the train, poor received signal and handover lag caused by fast time-varying fading channel, the quality of service (QoS) of mobile Internet services cannot meet the demands of the passengers. Therefore, how to provide users with high-speed mobile Internet services attracts increasing attention in the research of the fifth generation (5G) wireless communications.

Mobile Internet services for passengers are typically set as an ultra dense network (UDN) scenario in 5G wireless communications due to high density of passengers. In consideration of the limited spectrum resource of LTE system, millimeter-wave (mmWave) is strongly recommended as a promising technique for UDN in the future. However, under this circumstance, its limited coverage may lead to more frequent handovers and more severe handover lag.

Since heterogeneous networks was recommended to LTE-A Study Item in 3GPP to improve the overall system throughput [1], several enhancements of mobility management have been carried out from different perspectives to support mobile Internet services. Considering the hierarchical macro/femto-cell networks, J. M. Moon $et.\ al$ proposed a handoff decision algorithm which combines the values of received signal strength (RSS) from serving macro base stations (BS) and target femto BS [2]. However, this efficient RSS based algorithm did not highlight the untoward such as high speed and high density, and handover decision-making should be in early step to get low failure rate thus the application of prediction models such as gray theory emerge at a historic moment to achieve better mobility management for HSR [3]. Control/user (C/U) plane split technology is seen as a potential and promising technology of the 5G system in HSR and H. Song $et.\ al$ improved it as well as designed a matching handover trigger decision scheme based on gray model (GM) [4]. After that, imperfect network frame and key performance indicators caused extensive research. More concretely, L. Yan $et.\ al$ upgraded this decoupled architecture to a data-only carrier system which offers higher capacity for railway systems [5]. J. Zhang $et.\ al$ confirmed that such network has better mobility performance in UDN with much lower handover failure [6]. However, the handover lag and frequent handover problem have not been addressed in previous researches. Thus, how to guarantee QoS and the service continuity should be highly-regarded when considering the heterogeneous UDN of HSR.

In this paper, we propose a heterogeneous UDN scheme for HSR. Super cell technique is adopted in the radio remote unit (RRU) coverage with mmWave to provide high-speed data services for passengers. Macro BS are used to provide seamless coverage and low data rate services for passengers. In order to avoid signaling congest and extra penetration loss of the train, a mobile relay is deployed on the train and passengers can get access to the Internet via Wi-Fi or wired link. With this network approach, a GM prediction based handover decision algorithm is designed to address the handover lag problem, in which prediction with multiple outputs can efficiently reduce handover failure (HOF) probability and ping-pong (PP) handover probability. Meanwhile, a combination factor, which is the basis of ensuring service continuity, is introduced into the handover decision algorithm to help select suitable serving BS for passengers. Extensive simulation results show that our proposed handover scheme can improve the handover performance.

The rest of the paper is organized as follows. Section II introduces the heterogeneous UDN scheme and its channel model. Section III proposes a novel gray prediction based handover decision algorithm and then introduces handover performance metrics in the proposed network scheme. In

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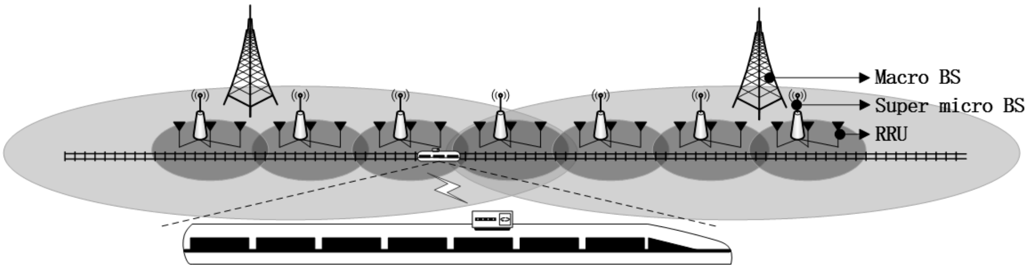

Fig. 1. Heterogeneous UDN of HSR

Section IV, the handover algorithm performance is evaluated by simulation, and the effects of key parameters on performance are also investigated. Finally, conclusions are summarized in Section V.

II. SYSTEM MODEL

A. HSR Communication System

In this work, the high-speed line is covered by the heterogeneous UDN, which is illustrated in Fig. 1. The first layer of the network is covered with macro BS with carrier frequency 900MHz, providing seamless coverage. The second layer of the network is covered with micro BS with mmWave frequency, providing high-speed data services for passengers due to the rich bandwidth resource. However, serious propagation attenuation of mmWave leads to limited coverage. In this case, more and more micro BS need to be densely deployed in HSR scenario and this undoubtedly aggravates the current problem with handover frequency. To solve this problem, several RRUs, which are linked to one baseband unit, construct one super micro BS by means of radio over wires/fibers. Thus super micro BS extend their coverage and help passengers reduce the handover frequency. Although the second layer increases reuse distance, rich bandwidth resource of mmWave makes up for system capacity.

To avoid penetration loss caused by the train, one relay is deployed on the roof of the train to help passengers connect to the super micro BS or macro BS on the track side. The passengers can get access to the Internet via Wi-Fi or access points which are connected to the relay by wired link. In this way, we can consider all passengers as a whole and mobility management of all mobile terminals can also be simplified. Details can be found in [7], which will not be discussed in this article.

B. Channel Model

The linear radio coverage topology is adopted in HSR. M RRUs connect together to construct a super micro BS.

The path loss model of a macro BS is proposed in [8], which is applicable to HSR scenario. As line-of-sight (LOS) path exists in this scenario, the received signal is modeled as a Rician channel model. Note that the received power from macro BS used in this paper is based on the narrowband 900MHz measurements taken along the “Zhengzhou-Xi’an” HSR in China.

The path loss (in decibels) of the mth RRU in the jth super micro BS can be expressed as

$$PL_m[dB] = PL(d_0) + 10\theta\log(d_m/d_0), d_m \geq d_0, \tag{1}$$

where $d_m, m = 1, 2, \cdots, M$, is the distance between the mth RRU and the mobile terminal, θ is the path loss exponent for the mmWave frequency band, $d_0 = 1$m is close-in free space reference distance thus $PL(d_0) = 10\theta\log(4\pi d_0/\lambda)^2$, λ is the wave length.

Based on the path loss model, the received power from the mth RRU in the jth super micro BS is calculated as

$$Pr_m[dBm] = Pt_m - PL_m - X_\sigma - 10\log_{10} h, m \in j, \tag{2}$$

where X_σ denotes shadow fading (in decibels) and obey Gaussian distribution with zero mean and standard deviation σ. h denotes the multipath fast fading, which can be modeled as Rician distribution with K-factor, Pt_m is the transmitted power of the mth RRU. Set all RRUs have the same transmitted power.

The received power from the jth super micro BS which contains M RRUs can be calculated as

$$Pr_j[dBm] = 10\log(\sum_{m=1, m\in j}^{M} 10^{Pr_m[dBm]}/10). \tag{3}$$

Since the radio resource is multiplexed by frequency reuse, the interference cannot be ignored. For macro BS, we adopt the interference model of GSM-R and only the inter-cell interference caused by the two nearest neighboring BS with same frequency is considered. For super micro BS, we use intra-frequency network and the interference in which the two nearest neighboring super micro BS are considered can be denoted as

$$I_j[mW] = \sum_{k=1, k\neq j}^{N_{nei.j}} 10^{Pr_k[dBm]}/10, \tag{4}$$

where $N_{nei.j}$ denotes the number of the nearest neighboring super micro BS of the jth super micro BS. Then, the signal to interference plus noise ratio (SINR) of the jth super micro BS can be computed as

$$SINR_j[dB] = 10\log\left[\frac{10^{Pr_j[dBm]}/10)}{I_j[mW] + N_0[mW]}\right], \tag{5}$$

where N_0 is the noise power.

III. PROPOSED HANDOVER SCHEME

In this section, a GM prediction based handover algorithm is designed to solve the handover lag problem. To avoid PP handover, a GM with multiple outputs is drawn into the handover decision. To enhance service continuity for passengers, a combination factor is introduced into the handover algorithm to determine target BS.

A. Gray Prediction based Handover Algorithm

Since it has been analyzed that the characteristics of HSR obey the input requirement of the GM$(1, N)$ model [4], gray theory is applied to mobile terminal measurements as follows. N means the number of BS participating in measuring channel quality. Set S as the length of the collected measurements from a BS reported by the mobile terminal, then the sequence of the collected measurements can be expressed as

$$x_n^{(0)} = \{x_n^{(0)}(1), x_n^{(0)}(2), \cdots, x_n^{(0)}(S)\},\ n = 1, 2, \cdots, N, \quad (6)$$

where the index 0 denotes the original measurements sequence.

According to gray theory, the first-order accumulated generating operation (AGO) with the original sequence $x_n^{(0)}$ is

$$x_n^{(1)} = \{x_n^{(1)}(1), x_n^{(1)}(2), \cdots, x_n^{(1)}(S)\},\ n = 1, 2, \cdots, N, \quad (7)$$

where $x_n^{(1)}(s) = \sum_{q=1}^{s} x_n^{(0)}(q),\ s = 1, 2, \cdots, S,\ n = 1, 2, \cdots, N$.

Gray theory can be expressed as

$$x_1^{(0)}(s) + a x_1^{(1)}(s) = b_2 x_2^{(1)}(s) + \cdots + b_N x_N^{(1)}(s), \quad (8)$$

where $x_1^{(1)}(s) = (x_1^{(1)}(s) + x_1^{(1)}(s-1))/2,\ s = 2, 3, \cdots, S$.

Take the first sequence as an example

$$\begin{cases} x_1^{(0)}(2) + a x_1^{(1)}(2) = b_2 x_2^{(1)}(2) + \cdots + b_N x_N^{(1)}(2) \\ x_1^{(0)}(3) + a x_1^{(1)}(3) = b_2 x_2^{(1)}(3) + \cdots + b_N x_N^{(1)}(3) \\ \vdots \\ x_1^{(0)}(S) + a x_1^{(1)}(S) = b_2 x_2^{(1)}(S) + \cdots + b_N x_N^{(1)}(S) \end{cases} \quad (9)$$

Then, transform the equation into matrix form

$$Y = X\beta, \quad (10)$$

where

$$Y = \begin{pmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(S) \end{pmatrix}, \beta = \begin{pmatrix} a \\ b_2 \\ \vdots \\ b_P \end{pmatrix},$$

$$X = \begin{pmatrix} -\frac{x_1^{(1)}(1)+x_1^{(1)}(2)}{2} & x_2^{(1)}(2) & \ldots & x_N^{(1)}(2) \\ -\frac{x_1^{(1)}(2)+x_1^{(1)}(3)}{2} & x_2^{(1)}(3) & \ldots & x_N^{(1)}(3) \\ \vdots & & & \\ -\frac{x_1^{(1)}(S-1)+x_1^{(1)}(S)}{2} & x_2^{(1)}(S) & \ldots & x_N^{(1)}(S) \end{pmatrix}.$$

Then we use the least square method to find matrix β

$$\hat{\beta} = (X^T X)^{-1} X^T Y. \quad (11)$$

Substitude $\hat{\beta}$ into (8), the first value to be predicted can be calculated as

$$\begin{aligned} \hat{x_1^{(1)}}(S+1) =& [x_1^{(0)}(1) - \frac{1}{\hat{a}} \sum_{n=2}^{N} \hat{b_n} \hat{x}_n^{(1)}(S+1)] e^{-\hat{a}S} \\ &+ \frac{1}{\hat{a}} \sum_{n=2}^{N} \hat{b_n} \hat{x}_n^{(1)}(S+1). \end{aligned} \quad (12)$$

$$\hat{x_1}^{(0)}(S+1) = \hat{x_1}^{(1)}(S+1) - \hat{x_1}^{(1)}(S). \quad (13)$$

Through these derivation processes, we can obtain $\hat{x}^{(0)}(S+1) = \{\hat{x_1}^{(0)}(S+1), \hat{x_2}^{(0)}(S+1), \cdots, \hat{x_N}^{(0)}(S+1)\}^T$, where $\hat{x_n}^{(0)}(S+1)$, $n = 1, 2, \cdots, N$, represents the first predicted value of the nth BS from the previous S measurements.

On this basis, we can predict more values for each sequence in chronological order, which can be obtained by the recursion formula mentioned in (12) and (13). We put the original S measurement values into GM$(1, N)$ model to predict the $(S+1)$th data and use the fitting coefficient to predict the rest. Set the number of predicted received power values to k. Multi-variable GM with multiple outputs is illustrated in Fig. 2.

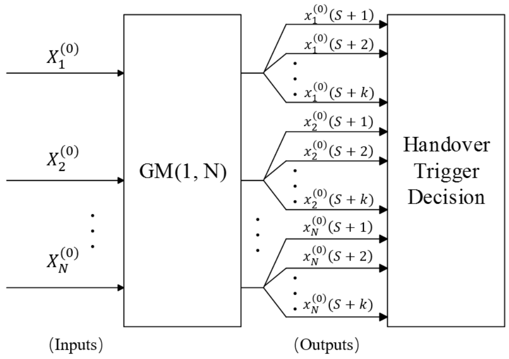

Fig. 2. Multi-variable GM with multiple outputs

Since the heterogeneous UDN is adopted in this work, the handover signaling procedure is different from conventional LTE system. The macro BS have two main tasks, one is to help mobile terminals determine the best target super micro BS or macro BS according to the predicted results; the other is to carry voice and data services when micro BS cannot guarantee QoS. This highlights the main differences from the conventional handover process. Therefore, conventional handover procedure does not fit the heterogeneous UDN scenario and handover signaling procedure in the proposed network scheme is similar with that in C/U decoupled wireless network [5]. As to the page limitations, details are omitted here.

B. Handover Trigger Decision

To guarantee service continuity, mobile terminals should be served by macro BS when the channel quality of a super micro BS is poor. Therefore, a combination factor is introduced into the handover algorithm to select super micro BS or macro BS as a service provider [2]. The handover strategy including both priority handover in the same layer and cross layer handover. $S_{nei.S}$ and S_M denote the vector of predicted received power from adjacent super micro BS and macro BS, respectively. $S_{cur.S}$ denotes the predicted received power vector of current serving super micro BS. Handover will be triggered when $S_{nei.S}$ or S_M becomes better than $S_{cur.S}$ even after considering the hysteresis ($Hyst$) value, which avoids the unnecessary trials.

1) Handover in the same layer: Considering the mobile terminal is currently served by a super micro BS, if $S_{nei.S} - S_{cur.S} > Hyst$, handover between two super micro BS is triggered.

2) Cross-layer handover: Although the super micro BS is used to provide the high data rate services, the mobile terminal should be served by a macro BS when channel quality of the super micro BS is poor. Thus, we introduce a combination factor into the handover algorithm to guarantee the service continuity. We define a combination factor α by considering the large asymmetry in the transmitted power between the super micro BS and macro BS.

When the mobile terminal is currently served by a super micro BS, if $(1+\alpha)*S_M - S_{cur.S} > Hyst$, where $\alpha \in [0, 1]$, handover between the current super micro BS and target macro BS is triggered.

When the mobile terminal is currently served by a macro BS, if $\{S_{cur.S} - (1+\alpha)*S_M > Hyst \;\&\&\; S_{cur.S} > S_{th}\}$ or $\{S_{cur.S} - S_M > Hyst \;\&\&\; S_{cur.S} < S_{th}\}$, where S_{th} is a threshold to guarantee a certain level of QoS during the handover [2], handover between the current macro BS and target super micro BS is triggered, where && means logical "AND". Otherwise, mobile terminal will keep communicating with the current macro BS.

C. Mobility Performance

In this paper, two key metrics, HOF probability and PP probability, are used for performance evaluation.

In general, handover failure is defined as that the received SINR is less than the required SINR threshold in following different handover phases: 1) before the trigger decision; 2) during the handover trigger decision; 3) during the handover execution; and 4) after handover execution. In the fourth case, the SINR of target BS is less than the threshold. Then, the handover failure probability is calculated as the handover failure in all situations.

A handover is considered as PP handover if the following two phases both happen: 1)the target BS at present is the same as the source BS in the previous handover; 2) the residence time in the current BS is less than the threshold. In this work, the PP probability is specified to the handover in the same layer.

TABLE I
SYSTEM PARAMETERS IN SIMULATION

Parameter	Value	Parameter	Value
f_{micro}	28GHz	TTT	160ms
Pt_{micro}	46dBm	$Hyst$	1dB
r_{micro}	600m	σ_{micro}	3.6dB
h_{micro}	7m	Q_{in}	-6dB
$h_{terminal}$	1.5m	Q_{out}	-8dB
n	2.1	S_{th}	-60dBm

IV. SIMULATION RESULTS AND DISCUSSION

In this section, extensive simulations are conducted to evaluate the handover performance in the heterogeneous UDN for HSR, in which the traditional handover scheme of LTE system is selected as the baseline [9]. In the traditional handover scheme, the handover decision is trigged if $S_{target} - S_{cur.S} > Hyst$, where S_{target} and $S_{cur.S}$ are the received power from the target BS and the current serving BS, respectively. Furthermore, handover between the two neighboring BS is executed when the criteria of handover is met during time-to-trigger (TTT) time period. Thus, $Hyst$ and TTT duration are two key parameters for the handover optimization in the conventional trigger decision [6].

A. Simulation Setup

In this paper, since the data traces of the received power from macro BS are based on the narrowband 900MHz measurements taken along the "Zhengzhou-Xi'an" HSR (300km/h) in China, we will not explore the exact channel model of macro BS in this article. The major simulation parameters of super micro BS are set according to [10] and simulation parameters are listed in Table I. Overlapped coverage of heterogeneous UDN in HSR scenario is shown in Fig. 3.

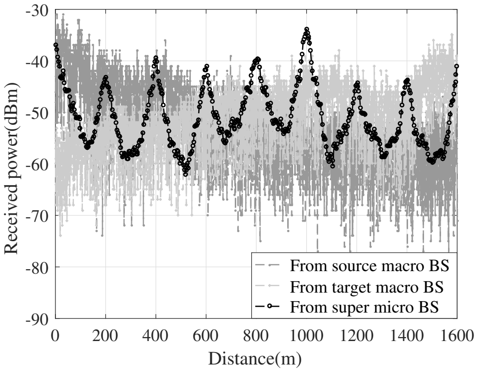

Fig. 3. Overlapped coverage of heterogeneous UDN in HSR scenario

B. Performance Evaluation

In Fig. 4, we compare the HOF probability of the proposed handover scheme with the traditional scheme. Note that in GMk, k means the number of the predicted values. We can see that the proposed scheme achieves lower HOF

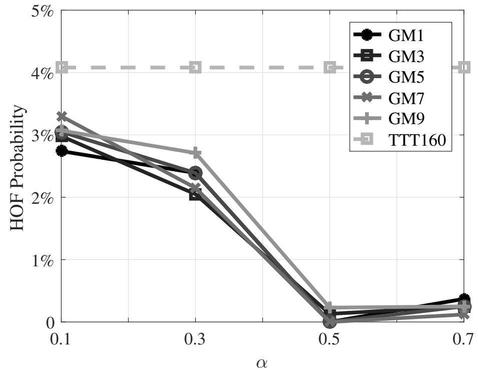

Fig. 4. HOF probability of different handover schemes

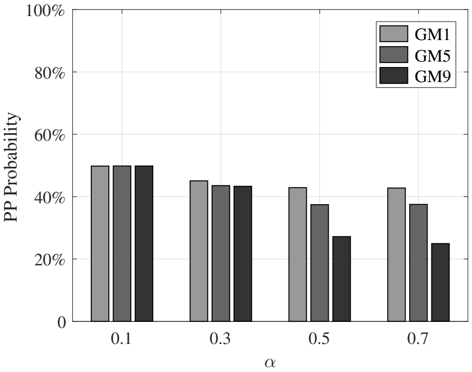

Fig. 5. PP probability of different handover schemes

probability performance than the conventional scheme. In traditional scheme, TTT results in handover lag and high HOF probability in HSR scenario. Instead, in the proposed scheme, HOF probability falls dramatically with the increasing number of predicted outputs due to the enhancement of prediction accuracy. In other words, multi-variable GM with multiple outputs avoids handover lag efficiently. On the other hand, HOF probability drops with the increase of α, because it is easier to execute cross layer handover with larger α when the channel quality of super micro BS falls sharply.

Generally, the reduction of HOF probability may result in the increase of PP probability. The evaluation results of PP probability which are illustrated in Fig. 5 show that PP probability decreases with the growing number of predicted outputs, so it is clear that GM with multiple outputs also helps prevent frequent PP handover because it helps improve the handover steady. Furthermore, the higher the value of α is, the lower the PP probability is, because α compensates the large asymmetry in the transmitted power between macro BS and super micro BS. When α varies from 0.1 to 0.7 with GM9 model, PP probability reduces 40%.

V. CONCLUSION

In this paper, a heterogeneous UDN scheme has been designed for HSR communication systems and a GM prediction based handover algorithm has also been proposed to enhance mobility management. The results show that the proposed handover scheme achieves better handover performance than the conventional handover scheme. Furthermore, the combination factor and GM with multiple outputs can improve the prediction accuracy and avoid handover lag effectively. For the future work, we are likely to use real-field measurements of heterogeneous UDN scheme to verify the proposed algorithm, and optimize the scheme to further improve the handover performance in HSR scenario.

ACKNOWLEDGMENTS

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