Research on Handover Algorithm Based on Dynamic Beamforming in HSR Cutting Scene

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Abstract. High-speed train passes through the cutting terrain, signal propagation is significantly affected by the steep sides, resulting in a high probability of handover interruption. To solve this problem, this paper proposes a location-assisted dynamic beamforming handoff algorithm. This solution uses the vehicle-mounted GPS and the arrival angle of the incoming wave to determine the location of the Mobile Relay Node (MRN) and ensure the stability of signal transmission during the operation of the train in the overlapping area. According to the path loss of the High-speed Railway (HSR) cutting scene, calculate the Handover Interruption Probability (HIP), the Handover Trigger Probability (HTP) and the Handover Success Probability (HSP). The simulation results have showed that the proposed algorithm has lower HIP and higher HSP, compared with the traditional handover solution. It ensures the stability of handover in complex scenes, and has better performance in improving the handover efficiency of HSR communication systems.

1. Introduction

As a very important mode of transportation, railway transportation has the characteristics of large carrying capacity and fast transportation speed. However, with the speed increases, it brings more severe multipath fading and Doppler shift, and higher penetration loss. These lead to a high probability of interruption in complex scene [1-3]. Therefore, how to improve the handover performance of different scenes to enhance HSR service quality and user experience is the key technical issue in the design of HSR wireless communication system.

The environment experienced by HSR is complex, typical scenes such as plains, mountains, cutting, overhead, etc. Due to the complexity of the scene as well as high-speed trains, frequent handover will lead to a low HSP and affect driving safety [4]. In [5], it proposes some problems that will be faced in the future handover such as high handover failure rate, ping-pong effect and group handover. And gives solutions: The handover scheme based on geographical location information precisely controls the switching time, but will cause signaling overhead; Although the switching scheme based on the dual-cast mechanism can improve the communication interruption caused by frequent switching and hard switching, how to reduce the additional data overhead caused by dual-casting is an important issue of current research; The handover scheme based on beamforming is an effective mean to solve the frequent handover of the HSR communication system. In [6], based on genetic algorithm, the satisfactory communication probability and hysteresis tolerance are optimized to improve the HSP. A speed adaptive handover scheme based on beamforming is suggested in [7], which path loss using COST231-Hata model. Although the switching performance is improved, it is only effective in urban and suburban
environments. In [8], a seamless dual-link handover scheme based on beamforming is proposed, which improves the HSP through soft handover.

The existing handover algorithm does not consider the impact of different HSR operating scenarios on the quality of the received signal. This paper takes cutting as the main scenario, proposes a dynamic beamforming algorithm based on location assistance, and analyzes the performance of handover. The algorithm optimizes the HIP and the HSP while considering the terrain.

2. System model
The coverage mode of the eNodeB (eNB) in the HSR wireless communication system is linear coverage, as shown in Figure 1. For the convenience of research, this paper only draws the unilateral cutting slope in the figure. Assuming that the coverage radius of the eNB is \( r \) when working in the omnidirectional mode, the distance between two adjacent eNBs is \( D_{ab} \), and the width of the overlapping area is \( 2r - D_{ab} \). Suppose the eNB equipped with intelligent antenna, the communication between the train and the eNB is completed by the MRN, and the User Equipment (UE) connected to the MRN through fiber-optical.

![Figure 1. Relay communication model](image)

In the HSR operation scene, there are many cuttings which structure is complex. In order to ensure the accuracy of statistical analysis, this article analyzes the cutting structure firstly, as shown in Figure 2 [9]:

![Figure 2. (a) shallow cutting, (b) deep cutting structural parameters](image)

From Figure 2(b), due to the influence of the side slope and the height of the eNB, there is no direct signal path in some deep cuttings. Therefore, in these cutting scenarios, the traditional handover scheme is still used. This article only studies the topography of the deep cutting where the direct view path exists.

3. Beamforming strategy
The traditional beamforming technology completely covers the overlap area under constant gain [7-11], in Figure 3(a). This method does not take into account the variation of received signal power with distance.
In this paper, dynamic beamforming based on position assistance concentrates the power of the signal on the main lobe of the beam, and the signal strength of the side lobes is approximately zero. It improves efficiency while reducing energy loss and resource waste. And according to the arrival angle of the incoming wave, the direction of the main lobe points to MRN at all times, in Figure 3(b).

![Diagram](image)

**Figure 3.** (a) Traditional beam coverage, 3(b) Improved beam coverage

There are downtilt angles and central width angles of the beam main lobe in the beamforming mode, shown in Figure 3(b) and 4. When the MRN is at the x position at a certain moment:

\[ \alpha_x = \arcsin(H - h) \left( d^2 + x^2 + (H - h)^2 \right)^{-\frac{1}{2}} \]  

\[ \theta_x = \arcsin x \cdot \left( x^2 + d_{min}^2 \right)^{-\frac{1}{2}} \]  

Where \( H \) is the height of the top of the eNB from the ground, \( h \) is the height of the MRN, \( d \) is the horizontal distance between the eNB and the rail, and the distance between the top of the eNB and the rail is expressed as:

\[ d_{min} = \sqrt{d^2 + (H - h)^2} \]  

After the train enters the overlap area, both the eNBA and the eNBb turn on the beamforming mode, and the main lobe direction points to the MRN and moves with it. As shown in Figure 4, when the MRN is at position \( x \), the center width angles of the main lobe of the two eNBs are:

\[ \theta_a = \theta_{min} + \frac{(x+r-D_{ab})(\theta_{max}-\theta_{min})}{2r-D_{ab}} \quad x \in (D_{ab} - r, r) \]  

\[ \theta_b = \theta_{max} - \frac{(x+r-D_{ab})(\theta_{max}-\theta_{min})}{2r-D_{ab}} \quad x \in (D_{ab} - r, r) \]
Where $\theta_{\text{max}}$ and $\theta_{\text{min}}$ are the maximum and minimum center width angles of the beam main lobe respectively.

![Figure 4. Beamforming arrival angle model](image)

With reference to Figure 1, after the train enters the overlap area, in order to ensure that the communication connection is quickly and stably switches to the eNBb, the eNBa does not generate beam gain when the train is running between P and Q, and the beam gain in the second half of the overlap area is G1. The eNBb maintains the G2 beam gain throughout the overlap area. The adjustment plan is shown in Table 1 [10]:

| eNB | Interval             | Power | Gain |
|-----|----------------------|-------|------|
| a   | $(D_{ab}-r, 0.5D_{ab})$ | $P_t$ | 0    |
| a   | $(0.5D_{ab}, r)$     | $P_t$ | $G_1$|
| b   | $(D_{ab}-r, r)$      | $P_t$ | $G_2$|

4. Handover performance analysis

Path loss can provide a basis for the quality of train received signals. Combining the measured path loss index and log shadow fading variance of the cutting scene, the large-scale fading model used in this paper is [11]:

$$PL(d_x) = -7.19 + 36.1 \log (d_x) + X_\sigma \quad \sigma = 4$$

(6)

Where $d_x$ is the distance between the eNB and the MRN, and $X_\sigma$ is the shadow fading. Assuming that the transmission power of the eNB is $P_t$, and $PL$ is the path loss, when the train passes through the overlap area, the eNBa and the eNBb will produce different beam gains. Therefore, the received signal powers from two eNBs are expressed as:

$$P_{r_a}(d_x) = \begin{cases} 
Pt_a - PL_a(d_x) & d_x \in (D_{ab} - r, 0.5D_{ab}) \\
Pt_a - PL_a(d_x) + G_1 & d_x \in (0.5D_{ab}, r) 
\end{cases}$$

(7)

$$P_{r_b}(d_x) = Pt_b - PL_b(d_x) + G_2 \quad d_x \in (D_{ab} - r, r)$$

(8)

Therefore, in this article, the HIP of the eNBa and the eNBb in the proposed scheme are respectively [11]:

$$P_{out}(d_x)_a = \begin{cases} 
Q \left( \frac{Pt_a - PL_a(d_x) - \lambda}{\sigma} \right) & d_x \in (D_{ab} - r, 0.5D_{ab}) \\
Q \left( \frac{Pt_a - PL_a(d_x) + G_1 - \lambda}{\sigma} \right) & d_x \in (0.5D_{ab}, r) 
\end{cases}$$

(9)

$$P_{out}(d_x)_b = Q \left( \frac{Pt_b - PL_b(d_x) + G_2 - \lambda}{\sigma} \right) \quad d_x \in (D_{ab} - r, r)$$

(10)

Where $Q(x)$ is the Q function, and $\lambda$ is the minimum signal strength that satisfies normal communication.
When the switching condition is satisfied, the HTP may be represented as [11]:

\[ P_{tri} = \begin{cases} 
Q \left( \frac{P_L a(d_x) + P_L b(d_x) - G_2}{\sigma} \right) & d_x \in (D_{ab} - r, 0.5D_{ab}) \\
Q \left( \frac{P_L a(d_x) + P_L b(d_x) - G_2 + G_1}{\sigma} \right) & d_x \in (0.5D_{ab}, r) 
\end{cases} \]  

(11)

Combining (9) ~ (11), the HSP should be expressed as:

\[ P_{suc} = (1 - P_{out}(d_x)_a) \cdot P_{tri} \cdot (1 - P_{out}(d_x)_b) \]  

(12)

The relevant parameters are obtained at a frequency of 2.6GHz, a bandwidth of 20MHz, and the train speed of 360km/h. The values of the simulation parameters are provided in Table 2[7].

| Parameters | Values | $d$(m) | $\lambda$(dBm) | $\sigma$(dB) |
|------------|--------|--------|----------------|--------------|
| $P_t$(dBm) | 38     | 3000   | -100           | 4            |
| $r$(m)     | 3000   | 10 (dB) | 2.5            | -3           |
| $D_{ab}$(m)| 4800   | 4      | 4              |              |
| $H_1$(m)   | 30     | 5      | 2              |              |
| $G_1$(dB)  | -3     | 4      | 4              |              |

Table 2. Parameters and values

Figure 5 shows the received signal power changes of two eNBs during the operation of the HSR in the overlapping area.

Figure 6 compares the changes of the HIP of the eNBb in the traditional scheme and the handover scheme proposed in this paper.

Figure 7 compares the changes of HSP between the traditional handover scheme and the handover scheme proposed in this article.

Figure 8 compares the changes of the HTP between the proposed scheme and the traditional scheme. As shown in the figure, the trigger probability increases significantly at the beginning of the overlap area. After the end of the overlap area, the trigger probability of the proposed scheme decreases because the train leaves the overlap area and the eNB resumes the omnidirectional mode. At this time, the trigger probability is numerically consistent with the traditional scheme.
Figure 6. The change curve of HIP of different schemes

Figure 7. The change curve of HSP of different schemes

Figure 8. The change curve of HTP of different schemes
5. Conclusion
In the HSR cutting scene, the steep walls on both sides have a great influence on signal propagation, resulting in a low HSP and affecting driving safety. This paper proposes a dynamic beamforming technology applied to the cutting scene to overcome the problem of poor signal quality in the overlapping area of the base station. Compared with traditional algorithms, the proposed algorithm has significantly improved the HSP and HTP; the HIP has further been decreased.

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