An Improved Distributed Antenna System for High-Speed Railway

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Keywords: Railway digital mobile communication system, Distributed Antenna System (DAS), Handover, Fixed Handover Cell.

Abstract. Due to the rapid development of high-speed railways all over the world, Railway digital mobile communication system is one of the most important parts which bears various services. However, it has been a challenge to support high speed (e.g., above 350 km/h) mobile user with broadband communication in a challenging environment including rapidly fading radio channels, Doppler frequency shift and fast handover problem. An Improved Distribution Antennas System for High-Speed Railway is proposed in this paper to solve the problem of fast handover in the traditional cellular network. The overlap region of two adjacent Logical Cells is composed by a complete cell, which is named Fixed Handover Cell. Therefore, there is sufficient time to complete the handover. It can effectively avoid the occurrence of a ping-pong effect. Its advantages include seamless handover, simple handover, and cost-effective deployment to support high mobility.

Introduction

High-speed railway is now developing rapidly in China. Many Passenger dedicated high speed lines have been in safe operation, and the 'HeXie' High speed Rail Multiple Unit makes the railways running faster and faster [1]. With the development of high-speed railways, Railway digital mobile communication system is one of the most important parts, which bears various services, such as providing information and onboard entertainment services to passengers, train control, video surveillance. However, with the increasing speed of train, Doppler shift of radio signals will increase, and handover becomes more frequently [2]. An increasing handover rate is an important consequence of high mobility. Besides, handover process time and the cell overlap region is fixed, the train runs through the overlap region fast in shorter time and it results in the lower handover success rate and frequent handover [3]. Thus, in order to ensure the system robustness and effectiveness, it requires shorter handover time and higher handover success rate, which cannot be achieved by the most current wireless communication systems.

The future wireless communications networks construct would trend to be flat as the internet network structure, rather than the traditional hierarchical tree structure. Distributed wireless communication technologies have gradually become the important support for future distributed network structure [4]. Distributed Antenna is one of the exiting distributed wireless communication technologies, which can increase the supported data rate, optimize resource allocation procedure and improve the handling and management of handovers and interference between users. The distributed antenna that connected to a central unit by Radio over Fiber (RoF) links, is a simple-to-implement solution considered key to developing cost-efficient Distributed Antenna System (DAS) [5]. Compared to the traditional system without distributed antenna, DAS has more advantages in terms of outage, capacity, bit error rate, and so on [6].

Moreover, Distributed Antenna System (DAS) is very applicable to the high speed vehicles for continuous linear coverage along highways [7]. In [8], a radio over fiber network DAS for road vehicle communications is proposed. In [9], the authors analyzed the coverage efficiency of radio over fiber (RoF) network for high-speed railway, and demonstrated that the efficiency can be improved greatly compared with the conventional network. In [10], an on-vehicle dual-antenna based handover scheme in DAS for railway scenario is presented. The scheme transforms the hard-handover into macro diversity soft-handover, thereby improves the handover reliability. However, the related literatures are mainly using the traditional distributed antenna structure to solve the problem of fast handover in the traditional cellular network. It may result in smaller overlap, so there is no enough time available for handover when the train quickly moves through the overlap region. This paper presents an improved distributed antenna structure base on the traditional structure for high speed railway. In this novel DAS, the overlap region of two adjacent Logical Cells is composed by a complete cell which is namely Fixed Handover Cell.

The rest of this paper is organized as follows. In Section II Traditional Distributed Antenna System for High-Speed Railway is described. The improved Distributed Antenna System for high speed railway is described in Section III, and Fixed Handover Cell is proposed in the new Distributed Antenna System (DAS). In Section IV, the handover process in improved Distributed Antenna System and its advantages are described in detail. Finally, Section V summarizes the concluding remarks with future research plan.

Traditional Distributed Antenna System for High-Speed Railway

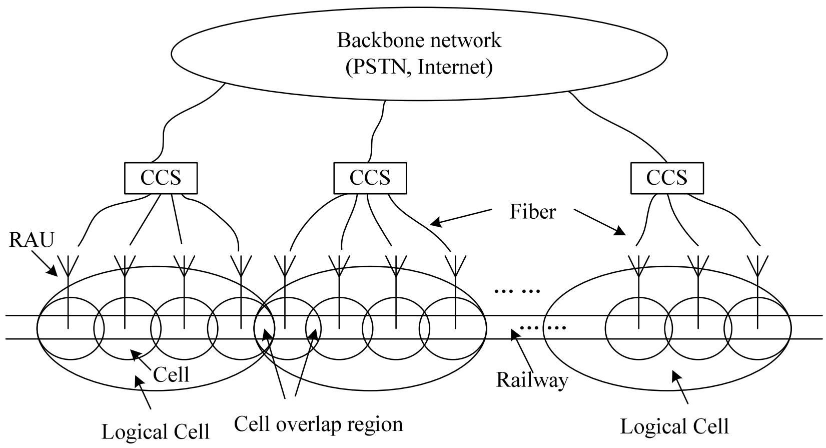

Fig. 1 Traditional Distributed Antenna System via high-data-rate radio over fiber (RoF) links

Normally, in high speed railway scenario, traditional Distributed Antenna System via high-data-rate Radio over Fiber (RoF) links is configured by linear arrangement as shown in Fig. 1. A Central Control Station (CCS) is interconnected with multiple Remote Antenna Units (RAUs) via optical fibers, and RAUs are deployed along the railway to support wireless communications link to the train. A Central Control Station (CCS) is in turn connected to backbone networks such as public switched telephone network (PSTN) or the Internet. Each Remote antenna Unit (RAU) covers an area called 'cell' and there is cell overlapping area between two adjacent cells. A Logical Cell is made up of multiple cells with one Central Control Station (CCS). In a Logic Cell, all the RAUs send same signals to the train and only part of the antennas receive signals from the train. A CCS of the Logical Cell deals with the data transmission. According to the feature of DAS, handover between the RAUs in the same Logical Cell can be considered as the Intra-CCS handover, which weakly impacts the overall performance of the system. The handover between two adjacent Logical Cells would be more complex with much handover delay, which is one of the main problems as mentioned above. So the train would have the handover problem between two adjacent Logical Cells. In that case the frequency of handover would be reduced, because the Logical Cell is much bigger than the traditional cell. However, the cell overlap region between the RAUs in adjacent Logical Cells is also the overlap region of the Logical Cell. So the smaller overlap region would also result in that, there is no enough time available for handover when the trains quickly move through the overlap region. In this paper, the improved Distributed Antenna System for High-Speed Railway is proposed to solve this handover problem between two adjacent Logical Cells.

Improved Distributed Antenna System

In order to solve the handover problem between two adjacent Logical Cells, an improved Distributed Antenna System for High-Speed Railway is proposed as shown in Fig. 2, which has a Fixed Handover Cell with two remote antenna units. The major different of the two systems can be found is the overlap region of two adjacent Logical Cells. In this novel DAS, the overlap region of two adjacent Logical Cells is composed by a complete cell which is namely Fixed Handover Cell in this paper. The Fixed Handover Cell is covered by two RAUs, and the two RAUs are connected to two adjacent CCSs respectively in different Logical Cells.

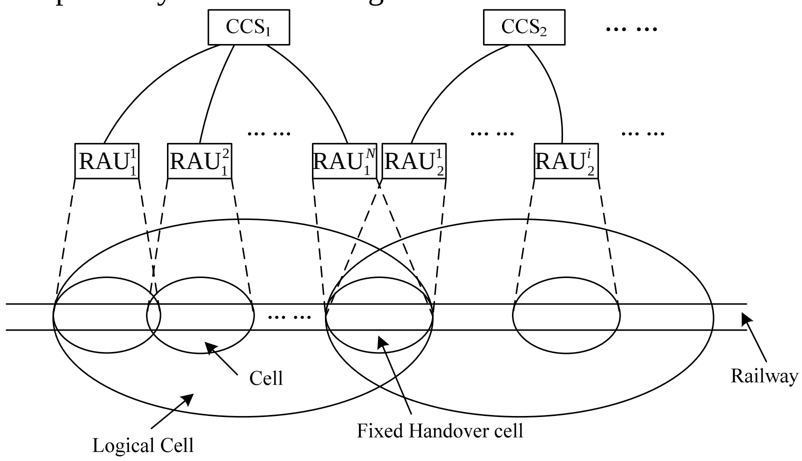

Fig. 2 Improved Distributed Antenna System architecture for high speed railway

In Fig. 2, the RAU_j^i represents the i th RAU in the Logical Cell j. The $RAU_1^{1\text{-}N}$ constitute a Logical Cell 1 which are centralized controlled by the Central Control Station 1 (CCS_1). Similarly, the RAU_2^1 and RAU_2^i are connected to the Central Control Station 2 (CCS_2), and belong to the Logical Cell 2. Suppose there are M Central Control Stations (CCSs), i.e., M Logical Cells. A CCS is connected to N RAUs based on the RoF architecture, and the RAUs are deployed along the one-dimensional railway. The RF channel in a same Logical Cell is the same, and adjacent Logical Cells must not use the same RF channel to avoid co-channel interference. Therefore, while a train is running within a Logical Cell it does not have to change RF channels, called Intra-CCS handover. It must change RF channels only when it enters a new Logical Cell, which means the handover between two adjacent logical cells happens, that is called the Inter-CCS handover.

Handover Process

The handover process in the novel Distributed Antenna System is introduced in this part. Suppose the train runs from left to right in Fig. 2, let see the handover between Logical Cell 1 and Logical Cell 2 for example.

At first, the train runs from RAU_1^1 to RAU_1^2 till to RAU_1^N in Logical Cell 1. When it runs from one cell to its adjacent cell which is called intra-CCS handover, CCS_1 would mark the current communication RAU number. Fixed Handover Cell between the Logical Cell 1 and Logical Cell 2 contains RAU_1^N and RAU_2^1 which connect to CCS_1 and CCS_2 respectively. When it runs from $RAU_1^{N\text{-}1}$ to RAU_1^N, the Inter-CCS handover starts in the Fixed Handover Cell. CCS_1 marks the current communication $RAU_1^{N\text{-}1}$ to RAU_1^N, then CCS_1 communicates with the target CCS_2 through the backbone. CCS_2 would allocation resources in the new Logical Cell then it have successfully accessed to the target logical cell 2. Two RAUs work independently at different frequency bands $f1$ and $f2$, but the two antennas receive and transmit the same data. When it runs out of Fixed Handover Cell, there is no RAU_1^N signals, and CCS_2 would easily handover from RAU_2^1 to RAU_2^2

in the Logical Cell 2. So far, the whole handover process between two adjacent Logical Cells has been finished.

In this case, the frequency of the Inter-CCS handover is reduced because the Logical Cell coverage radius becomes much bigger than traditional cell by using the Distributed Antenna System (DAS). With the Fixed Handover Cell, the occurrence time of handover can be accurately determined. The overlap region of the two adjacent Logical Cells expands to the Fixed Handover Cell to ensure that there is sufficient time to complete the handover. Once one handover finished, there is no more handovers in the Fixed Handover Cell because of the one-dimensional movement characteristics of the train. In this way it can effectively avoid the occurrence of a ping-pong effect. The coverage area expands multiple times compared with no distributed antennas.

Conclusion

In this paper, an improved Distribution Antennas System for High-Speed Railway is proposed to solve the handover problem caused by the high speed train. There is sufficient time to complete the handover. It can effectively avoid the occurrence of a ping-pong effect. Its advantages include seamless handover, simple handover, and cost-effective deployment to support high mobility. Besides, when each RAU has multiple antennas, there would be cooperated diversity based on the partial Channel State Information (CSI) sharing between the adjacent RAUs. Collaboration of the dual antennas and resource management in this multiuser MIMO wireless system will be studied in depth in the future.

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Published by Atlantis Press, Paris, France.