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Review

Handover schemes and algorithms of high-speed mobile environment: A survey

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ABSTRACT

With lower energy consumption, less environmental pollution, larger capacity, and higher safety, the high-speed railway is playing an important role in mass transportations. The development of high-speed railways makes people's life more and more convenient. Meanwhile, it puts forward much higher demands on high-speed railway communications. Therefore, new solutions are desired to keep up with this unprecedented growth. However, communications in high-speed environment have particular characteristics such as fast and frequent handover, high penetration loss, and high Doppler frequency shift. Current researches mainly focus on providing broadband wireless network access for high-speed mobile terminals. This article presents an overview of the latest technical developments on handover schemes and handover algorithms targeting high-speed mobile scenarios. In addition, this paper suggests the most appropriate techniques which can efficiently communicate in high-speed mobile scenarios. Finally, we discuss future trends of handover researches in high-speed mobile environments.

Currently, Cyber-Physical System (CPS) is emerging on the basis of environmental perception and deep integration of computing, communications, and control (3Cs) technologies. CPS is a device-networking system which is controllable, trusted, and scalable. Through interactions and integrations between the calculation process and the physical process, the system can increase or extend its functionalities. Therefore, it can monitor or control physical entities via much more safe, reliable, efficient and real-time ways [1–7]. China Train Control System Level 3 (CTCS-3) is designed for high-speed mobile environments. As one of the CPS subsystems, CTCS-3 shall meet the CPS characteristics which include reliability, heterogeneous, autonomous, real-time performance, green energy, large capacity, and safety. The high-speed railway (HSR) is playing an important role in mass transportations not only in China, but also in other parts of the world. The development of high-speed railways makes people' life and work more and more convenient. Meanwhile, this development puts forward various higher service requirements for high-speed (i.e. above 300 km/h) users.

For the purpose of ensuring system reliability and real-time performance, underlying technologies must be reliable and real-time in the first place. In addition, the reliability and real-time performance of communication technologies are mainly determined by the handover performances. Therefore, in order to provide Quality of Service (QoS) for high-speed users, the handover is a key element in wireless cellular networks. In addition, it is also a main carrier of the CPS performance metrics (e.g. delay). As illustrated in [8–10], according to future consumers' requirements, broadband high-speed mobile communication is an unavoidable trend. Innovative technology solutions are desired to keep up with this unprecedented demand growth.

The scope of this paper is to provide a state-of-the-art overview of different types of handover schemes and handover algorithms on broadband high-speed mobile scenarios, to classify them and to discuss them accordingly. The rest of this paper is organized as follows: Section 1 analyzes the problems caused by high-speed mobility. Basic handover concepts are presented in Section 2. Various handover schemes are discussed in Section 3. Section 4 summarizes different handover algorithms. Besides, comparisons are also made in Sections 3 and 4, respectively. Finally, Section 5 concludes this paper.

1. Effects of high-speed mobility

The wireless connection between the high-speed train (HST) and the ground network is the bottleneck of improving the QoS of train passengers [11,12]. The wireless access problems in high-speed mobile scenarios are as follows: (1) Frequent handover, which causes frequent cell re-selection, call quality decline, and

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data service unavailability; (2) Doppler frequency shift and fast fading, which causes intolerably low communication connection rate, difficulty in handover initiation, and numerous handover failures; (3) Large car body loss and multipath loss, which makes the intra-train to be a signal weak field. In this section, these effects will be discussed in detail.

1.1. Fast handover

An important factor which affects the broadband wireless access for HSTs is the fast and frequent handover. The frequent handover is caused by the high-speed mobility of mobile terminals. For a given cell size, the higher of the HST speed, the shorter the time it spends to pass through the overlapping region. When the minimum handover processing delay is larger than the time interval of the HST passing through the overlapping area, the handover process fails to complete, resulting in call drops. For example, the cell of a Remote Antenna Unit (RAU) typically has a diameter of 100 m. Then for the HST at a speed of 100 m/s, handovers will occur once every second. So, traditional handover times of 0.1–1 s are definitely unacceptable [10]. Frequent handover also brings the problem of packet loss and packet reordering [13]. Therefore, a main difficulty that the high-speed railway broadband wireless access faces is how to achieve fast handovers.

In order to meet the requirement of fast handovers, on the one hand, increasing cell radius can reduce the handover rate (i.e. the number of handover events per unit time). However, according to [14], expanding cell coverage will sacrifice part of the system capacity. In the special HSR scenario, improving handover mechanisms and optimizing handover decision conditions and procedures will help to reduce the handover time. In this way, stability and reliability of the network performance are guaranteed. On the other hand, reducing the cell radius (e.g. 100–500 m) and applying both the optical switching and the millimeter wave technologies can achieve fast handovers. Millimeter wave, e.g. 60 GHz RF signal, has a good line of sight (LOS) characteristic in free space, and its transmission distance is around 100 m. All these properties will help eliminate the multipath effect. However, this solution increases the number of handover events. The handover rate will be too high in a high-speed mobile environment.

1.2. Doppler frequency shift

The signal frequency shift at the receiver due to the movement is known as the Doppler frequency shift. During the train traveling, Doppler frequency shift can be calculated by $f_d = \frac{v}{c} f_c \cos\theta$, where v is the train speed, c is the speed of the electromagnetic wave, f_c is the central carrier frequency, and θ is the angle formed by the signal and the train direction (Fig. 1). The center frequency of the wireless signal (e.g. uplink f_0, downlink f_1) shifts dramatically because of the Doppler Effect in high-speed mobile scenarios. When the train is crossing the handover zone, the downlink frequency shift is jumping from $+f_d$ to $-f_d$, with a total change of $2f_d$. For instance, a central carrier frequency of TD-SCDMA (Time Division-Synchronous Code Division Multiple Access) is 2025 MHz, and if the train speed is 350 km/h, the Doppler frequency shift at the receiver is about ±656 Hz, which will destroy the orthogonality of subcarriers in the OFDM (Orthogonal Frequency Division Multiplexing) system. This will induce Inter Channel Interference (ICI), which further deteriorates wireless channels, causes significant impacts on bit error rate (BER), and increases the synchronization difficulty.

In order to reduce the Doppler frequency shift, base station (BS) sites should be deployed far away from the tracks in the initial network planning. In this way, the angle θ of the multipath waves arrived at the receiver is large enough to mitigate the Doppler frequency shift. However, in practical network deployment, for the penetration ability enhancement of the wireless signal, there is usually a short distance between the base station and the track. Therefore, another technical difficulty of the high-speed railway broadband wireless access network is the Doppler frequency shift compensation.

1.3. Penetration loss

Another major factor in the high-speed railway broadband wireless access system is the penetration loss. The signal suffers this loss when it goes through train compartments. Most kinds of high-speed trains are metal bodies with large windows of a single layer or multilayer glasses. The entire train compartment is like a Faraday cage which increases the penetration loss. For example, penetration loss of the CRH (China Railways High-speed) series HST is 10 dB larger than ordinary trains. In addition, with the increase of frequency, signals that go through the compartments will suffer greater attenuation. Meanwhile, the smaller the wireless signal incidence is, the higher the loss it bears.

In order to overcome the penetration loss, various methods such as reinforcing the trackside base station transmitter power, upgrading the base station receiver sensitivity, and enhancing the transmission power of the user terminal, can be applied. However, none of these methods corresponds to the Green Communication concept. A much different approach is using the two-hop model [10] which introduces a dedicated multi-band and multimode base station (acts as a relay station) for the HST. The first hop is from the BS to the HST, and the second hop is from the HST to the user terminals (Fig. 2). This model architecture will be

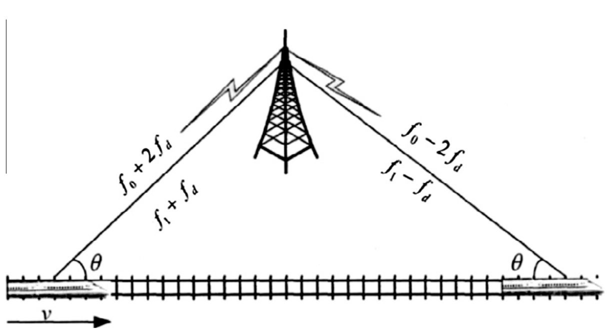

Fig. 1. Doppler Effect on high-speed rail.

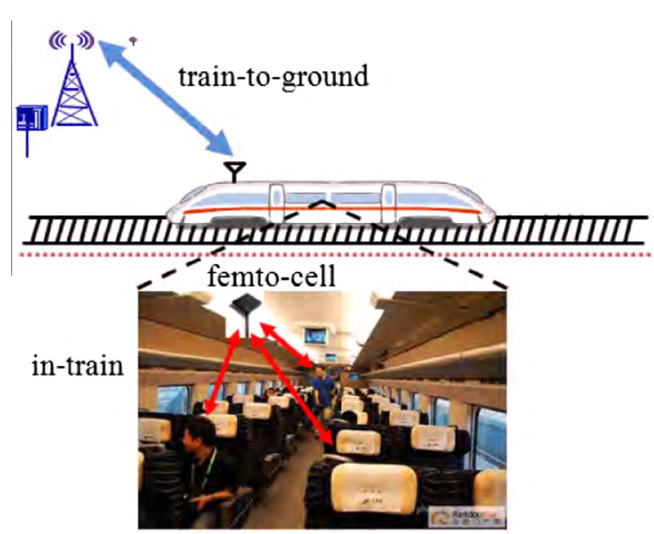

Fig. 2. Two-hop architecture.