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# Localization of a high-speed train using a speed model based on the gradient descent algorithm

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## HIGHLIGHTS

- The High-speed railway user information extracted rule is proposed.
- The High-speed railway user information of one HST is modified.
- The High-speed railway line is fitted based on base station information.
- Speed model for locating high speed train is proposed.

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## ABSTRACT

Owing to the problem of weak coverage of private network in the high-speed rail (HSR) environment, the users' internet perception will be seriously affected by abnormal connection to the ordinary public network. Radio remote unit(RRU) that works abnormally is an important reason for the weak coverage of HSR private network. To address this problem, first, in contrast with the traditional positioning system, such as the global system for mobile communications-railway(GSM-R), we proposed a method that just use HSR user's information collected by base stations and base station information provided by the telecom operators of China to locate a high-speed train(HST) off-line. Second, an abnormal RRU was detected by using the established speed models based on the gradient descent algorithm. The experimental results showed that the probability of accurately locating the HST was up to 87.17%.



## 1. Introduction

The HSR system in China is more than 22,000 kilometers in length, accounting for more than half of the globe's HSR mileage [1]. Because of the strong technology, safe and reliable service, and the low construction cost, China's railways are recognized by many countries. According to Zhang Haitao [2], deputy to the National People's Congress and Party Committee Secretary and Chairman of the Shenyang railway group, in 2017, a total of 3,600 columns of China–Europe HST were launched, which exceeded the total of HSTs of the six years from 2011 to 2016. China–Europe HST have become a landmark achievement in the construction of the "One Belt and One Road".

In China, the use of HSR system is becoming increasingly prominent among travelers because an HST can provide a comfortable experience and an efficient service. Moreover, travelers expect high-quality wireless communication on an HSR private network to satisfy their network requirements, therefore, an HSR private network communications service is essential for a normal train operation.

To detect the range of weak coverage of private network in the HSR environment, the first thing is to locate HST. According to the interview of a driver of a Chinese HST, until September 21, 2017, the rule for HST driving in China is that the maximum speed of each bullet train should be approximately 300 km/h. Generally, the acceleration to reach the maximum speed requires approximately 5–6 min. However, in the acceleration process, owing to the required speed limit, the acceleration is not fixed, and the deceleration process generally lasts for 6–7 min. Thus, the maximum speed when driving to different train station is 80 km/h or 60 km/h or 40 km/h. Because the speed of an HST changes at any time, the complexity of positioning the HST is increased.

There are three approaches for tracking and locating a railway train including using only the vehicle on-board equipment, only the ground equipment, and combining the vehicle on-board equipment and ground equipment. Without the equipment, based on the rule of HST driving in China, this paper just use HSR uses information collected by base stations and base station information provided by the telecom operators of China to locate a HST.

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Ordinary trains also run on the HSR tracks, therefore, when analyzing base station database of BS_HSR and the information on the users accessing the HSR private network, the first step is to obtain the information on the HSR users from the complete user information. In the second step, based on the rules for HSR driving, the position of the abnormal RRUs is determined and the weak-coverage 4G wireless network is identified.

Our three major contributions can be summarized as follows: (1) The HSR user information extracted rule is proposed, and the linear filtering is used to modify HSR user information of one HST. (2) This paper consider that the adjacent sites are staggered on both sides of the railway line, the HSR line is fitted based on base station information. (3) Speed model based on the gradient descent algorithm is used to locate HST. Substituting abnormal base station information into the speed model, the location of the abnormal RRU was obtained.

In the rest of this paper, we discuss the related works in Section 2. We present our proposed speed model for locating HST in Section 3. Base station information is extracted to fit HSR line, and HSR user information is extracted and modified followed by the performance results in Section 4. We conclude in Section 5.

## 2. Related works

At present, the speed of a HST running on the Beijing–Shanghai HSR (BS_HSR) is as high as 350 km/h. Consequently, the Doppler frequency shift and high-frequency deep fading caused by the high speed would result in a high rate of handover (HO) failure and cell re-election errors, thereby affecting the perception of the HSR users of the internet. To reduce the HO times, the HSR private network uses a multi-cell combination technology [3] that adopts a single baseband unit and multiple RRUs covering a cell to form a single logical cell.

Although the time of handoff is reduced by using a multi-cell combination technology, an appropriate handoff algorithm can improve the success rate of the HO and cell reselection. Various scholars proposed HO schemes different from the traditional HO scheme to improve the success rate of the HO and reselection. Because a mobile relay station can determine whether a train moves into an overlapping region based on the current measurement value, LUO et al. [4] introduced a HO scheme that adjusted the time to trigger and entering and leaving conditions of the trigger HO at different positions, which could promote or prevent the HO at appropriate places and ensure a trigger HO at those positions for a better signal quality. In [5], Pan et al. proposed an enhanced HO scheme that involved an improved measurement procedure and a group in-network HO procedure. Other scholars [6,7] also suggested HO schemes by utilizing the location information. By the measurement of the user equipment velocity, in [8], two types of HO algorithms were introduced that adjusted the HO parameters of the long-term evolution evolved NodeB. Reference [9] presents the simulation results of a self-optimizing network in an LTE mobile communication system that used load balancing and HO parameter optimization. In other references such as [10], the HO parameters of an LTE base station were tuned to improve the overall network performance. To reduce the rate of HO failure, [11] provides a comprehensive discussion of the key aspects and research challenges of the mobility management (MM) support in the presence of femtocells. Lee et al. [12] proposed an LTE femtocell-based network mobility scheme. Lu et al. [13] proposed a remote antenna unit selection assisted HO scheme to attain a seamless HO and reduce the HO failure probability for an HSR communication systems.

The above methods included HO algorithms and the multi-cell combination configuration strategy to improve the success rate of HO. However, in addition, the protection of a base station and the normal operation of its RRUs are also very important. The current RRU abnormal diagnosis methods are mainly based on a manual determination in real-world operations. We first study train positioning methods to increase the detection efficiency, reduce the testing costs, and most importantly, to complete the process of detection using computers. Then based on the information of the time and corresponding base station that an HSR user finds abnormal in the private network, we identify the location of the abnormal RRU or weak coverage-4G network.

The Global System for Mobile Communications-Railway (GSM-R), which was introduced in [14], is currently deployed in numerous countries including China to ensure the interoperability of HSTs. To make a train safer, for instance, [15] presented the monitoring system designed for early detection of wireless interference that may introduce the GSM-R vulnerabilities. In [16], several shortcomings of the GSM-R are identified and strategies for deriving the location information in a railway environment are briefly explained. Though some major drawbacks of the GSM-R are described in [17], it is still a successful technology. Another location system in China is the BeiDou Navigation Satellite System [18]. It is the third mature satellite navigation system after the United States Global Positioning System (GPS) and Russian GLONASS satellite navigation system (GLONASS). In the BeiDou Navigation Satellite System, using a high-precision satellite navigation and receiving module, the real three-dimensional coordinates, HSR train speed, and running direction are obtained by a real-time dynamic difference method and precision single-point positioning methods [19]. An agency from Xinhua News reported that the independent research and development unit of the BeiDou Navigation Satellite System in China, for the first time performed a test flight on 103 aircraft of the ARJ21-700 aircraft that completely independently designed and manufactured by China [20]. The BeiDou Navigation Satellite System is also used in other application scenarios such as estimating the sea level changes [21] and retrieving the TEC values on the GEO SAR propagation path [22].

In general, obtaining a high-accuracy location of a train is studied based on using multi-sensor information. In [23], Zhang et al. proposed a reference scheme for positioning a train by utilizing the GPS and railway wireless communication network. Other methods based on the balises and speed sensors only improve the positioning accuracy of an HSR. In [24], based on the positioning data on balises, Chen et al. proposed three position computation models based on the least square method, support vector machine, and least square support vector machine to reduce the positioning error compared with an average speed model. The authors also established other three models by neural computing, developed online learning methods to update the parameters of the neural computing models [25]. In [26], the linear Kalman filtering approach was used to estimate the position state with the data of the onboard equipment. In [27], based on the current balises, odometer, and speed sensors, the authors proposed LSSVM-online, IPEM-online, L0-norm-online, and hybrid-online to reduce the location error and increase the real-time performance.

Even though the GSM-R, BeiDou Navigation Satellite System, or other satellite navigation systems can identify the location of a train accurately, they require extra devices and area for the telecom operators. Because it is realistic to use these operators, we develop a novel strategy that simply employs the information of the users accessing or dropping an HSR 4G network and the distribution information of the base stations to locate an HST.

## 3. Speed model for locating HST

In the user information presented later in Section 4.2, only the cell number representing the base station that a user accesses in the HSR private network can reflect the HST position. A speed model should be established to locate an HST in the range of an RRU belonging to a base station.