Topology Discovery Protocol for Train Inauguration in Wireless Train Networks

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Abstract: With the recent rapid improvement of wireless communication technology, wireless network gains increasing interest as a train backbone in order to provide the passenger service as well as the original real-time control duties. To use the wireless network as a train backbone, however, the existing standard protocol, IEC Std. 61375 Train Communication Network (TCN), needs to be modified to reflect the wireless-specific characteristics because it was originally designed for the wired network such as switched Ethernet. The train topology discovery protocol (TTDP) that provides automatic network reconfiguration is one of the key TCN protocols to be modified to support a wireless train bus. This paper proposes a modified topology discovery protocol that can be used for a train-wide wireless LAN. Proposed protocol finds the bus topology based on the radio signal strength with maintaining the existing standards and controls the transmit signal power to avoid overhearing problem in wireless network. The time bound to build network topology using the proposed protocol is also estimated by computer simulation.

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Keywords: Train communication network, Ethernet train backbone, Wireless LAN, Topology discovery protocol, IEC 61375 standard

1. INTRODUCTION

In modern railway trains, control systems are based on the computer-based controllers. Real-time data exchange between control devices and sensors plays an important role. For the inter-operability between the on-board control systems from different vendors, IEC 61375 standards series, Train Communication Network (TCN), was proposed as a standard computer network between on-board devices in early 2000’s. Since the main purpose of the early TCN was to replace the existing hardwired control systems with computer-based control systems, its network bandwidth and functions were optimally designed for the nature control and monitoring purpose only. Recently, however, as the demand of the passenger service grows, the demand of the train-wide data highway also increases in modern train system. To provide various novel features as well as the original control functions, IEC revised TCN standards to adopt high speed Ethernet as a train backbone network (IEC 61375-1 (2012)) and since then, researches have been processing on the related areas (Kim et al. (2013), Hwang et al. (2015)).

Meanwhile, with the recent dramatic improvement of wireless communication in speed and reliability, wireless communication replaces the legacy wired network in various application areas including inter-vehicle communication systems and train backbone communications. (Ning et al. (2006), Sarr et al. (2012)). However, since TCN protocols were originally designed assuming a reconfigurable linear network topology using normal wired network, to adopt wireless communication into TCN, careful consideration is required on the existing protocols and modifications, if necessary, has to be implemented.

The train Topology Discovery Protocol (TTDP) of TCN that finds train’s configuration and figures out network topology, cannot be directly used in the wireless communication environment because it was designed assuming each neighboring train vehicle (or car) are connected via a direct wired cable. In such a wired train backbone system, finding a neighbor node is very simple. By exchanging nodes’ network address, usually represented by MAC address, with directly connected neighbor nodes via the HELLO frame, any backbone node (BN) can find its neighbor nodes’ address and, in turn, their relative position in the entire network topology. However, in the wireless communication, the HELLO frame is broadcast and multiple BNs that are not geographical neighbors can receive it, which makes finding the geographical neighbors challenging. Moreover, the wireless network may be inherently less reliable due to the channel noise and interference. Hence, this paper addresses how to modify the standard TTDP protocol when wireless network is used as a train backbone, where reliable point to point communication is almost impossible because of the broadcast nature of the wireless medium.

Salem and Haimovich (2015) showed the performance degradation when TTDP is used in the unreliable wireless communication environment. Liu et al. (2016) proposed the wireless topology discovery protocol (WTDP) which is suitable for implementation on a wireless backbone and investigated its performance analytically. Besides these researches, range of researches have been performed for
This paper consists of 5 sections. Following this section, section 2 describes a short description on the TCN backbone and TTDP and section 3 proposes a modified TTDP algorithm for the wireless network, followed by performance evaluation and conclusion sections.

2. ETHERNET TRAIN BACKBONE

This section describes the Ethernet Train Backbone(ETB) and the Train Topology Discovery Protocol(TTDP) defined in IEC standard, IEC 61375-1 (2012) and IEC 61375-2-5 (2014), briefly.

2.1 Train Backbone Network

Train Communication Network(TCN) has a hierarchical structure with two levels of networks, a train backbone and a consist network as shown in Figure 1. The train backbone connects each car whereas the consist network connects the end nodes(control or sensor devices) within single car. Current TCN standard defines two types of backbone networks; Wired Train Bus(WTB) and Ethernet Train Backbone(ETB). Even though WTB shows better real-time performance, ETB, nowadays, is gaining more interest because it can provide enough network bandwidth to catch up increasing demand for the passenger information and services. By adopting ETB, the on-demand passenger service packet as well as real-time control packets can be transmitted timely through the high bandwidth IEEE 802.2Q switched Ethernet. As the train backbone interconnects the train backbone nodes(BN) within a train and each BN has to manage its own subnetwork for the consist network, the network configuration should be well managed by all the BN’s.

The TTDP algorithm proposed in this paper uses the radio signal strength in finding the neighbor nodes, with which BN’s relative position can be estimated. Since most topology discovery algorithms using radio signal strength were designed for two or three dimensional space, they are very complex and require a lot of premeasured radio signal map, called fingerprint(Russell et al. (2015)). On the contrary, the algorithm proposed in this paper is relatively simple because only the linear topology is considered as a train-wide network and the accurate premeasured fingerprint is not necessary.

This network reconfiguration caused by train composition changes is called train inauguration. Normal train inauguration is defined as train inauguration. When any change is detected or inauguration is enforced, BN also checks for the changes in the train operation, BN also checks for the changes in the train operation. Hence the network configuration should be reconfigured automatically, otherwise, proper user data exchange over the train backbone is not possible.

In real circumstances of train operation, it is possible to change the train composition and orientation of vehicles during the operation. Hence the network configuration should be reconfigured automatically, otherwise, proper train control commands cannot reached the end nodes. This network reconfiguration caused by train composition changes is called train inauguration which is one of the most important and unique features of the train backbone network.

Fig. 1. Hierarchical consist topology

The topology discovery using wireless LAN used in the two dimensional indoor environment(Vasudevan et al. (2013)). The TTDP algorithm proposed in this paper uses the radio signal strength in finding the neighbor nodes, with which BN’s relative position can be estimated. Since most topology discovery algorithms using radio signal strength were designed for two or three dimensional space, they are very complex and require a lot of premeasured radio signal map, called fingerprint(Russell et al. (2015)). On the contrary, the algorithm proposed in this paper is relatively simple because only the linear topology is considered as a train-wide network and the accurate premeasured fingerprint is not necessary.

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