Chapter 81
Survey of Development and Application of Train Communication Network

Jianghua Feng, Xiangyang Lu, Weifeng Yang and Jun Tang

Abstract This article introduces the history of the key technologies of the train communication network (TCN), describes the existing WTB/MVB technical characteristics, and compares the products and their applications on locomotives and urban rail trains in China. This article further analyzes the technical characteristics of a new generation of TCN and its capability of supporting train control, video surveillance, and passenger information service. At the end of the paper, the future development trends of the train communication network systems are prospected.

Keywords Train communication networks · Wire train bus · Multifunction vehicle bus · Ethernet train bus · Ethernet consist network · Train control and information service

81.1 History of Train Communication Network

In the late 1970s, microprocessors were gradually applied to control the single equipment of locomotives, such as 8086 microprocessors used in the traction control for the locomotives and multiple-unit trains by Siemens and BBC. Hierarchical architecture was also gradually introduced, while the number of the controlled devices increased. Serial communication buses used between control devices were adopted, such as the bus connecting the train control and the traction control for the locomotives by BBC. Furthermore, this bus called MVB is further used for connecting all intelligent devices in vehicles. In the middle of the 1990s, to meet the communication requirements between the devices in the coupled locomotives and multiple-unit trains, train bus DIN 43322 was proposed by Siemens.

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From then on, train communication network (TCN) covering traction control, brake control, auxiliary power supply, passenger information services, and displayer is launched continuously.

In China, Zhuzhou Locomotive Research Institute (Zhuzhou Institute) controlled the static split-phase motors with Z80 microprocessors in the early 1980s [1–4]. In the early 1990s, Zhuzhou Institute developed microcomputer controlled devices for electric locomotives in cooperation with universities and applied these devices on SS_4 electric locomotives. The TCN and traction systems were bonded together and the traction control of the train was completed through TCN. In the late 1990s, the development of TCN became a hot point in the universities and companies. Railway Ministry of China carried out several research projects of TCN, such as the research of CAN network by Shanghai Railway Institute to connect the driver's desk with train control units, the research on control bus of tilting trains by Southwest Jiaotong University based on RS485+protocol, and the research on LonWorks by Sifang Rolling Stock Research Institute and China Academy of Railway Sciences. The products based on these researches were all applied on trains. In 1999, the IEC standards IEC61375 were published. Several companies develop TCN system based on the WTB/MVB technology. Bombardier, Siemens, and Zhuzhou Institute are the most successful companies during the development.

Since 2008, IEC began to investigate the new generation of international standards for TCNs based on real-time Ethernet. The new generation of the TCN system continuously adopted hierarchical architecture. The Ethernet Train Backbone (ETB) and Ethernet consist network (ECN) technologies were adopted for train level and consist level communication, respectively. To meet the requirements on real time, certainty, and reliability for train control, the bandwidths of the ETB and ECN are promoted to 100 Mbps. Siemens, Bombardier, Alstom, Mitsubishi, and Zhuzhou Institute were responsible for formulating different partial of the standards. These companies also developed the new generation of the TCN system based on real-time Ethernet technology. In July 2014, Bombardier, Unicontrols, and Zhuzhou Institute carried out ETB inauguration conformance test in Mannheim of Germany, and the products from different companies reached interconnection and interworking. In April 2015, Zhuzhou Institute built an experiment site and demonstrated ETB-based inauguration experiment of multiple locomotives to the companies within railway area in China; the number of supported locomotives reached 23, and the completion time of inauguration was less than 600 ms. Sifang Rolling Stock Research Institute and Tsinghua University also developed Ethernet-based TCN product, and these companies only developed ECN product by the end of 2014.

In the following sections of this article, technical characteristics and typical application topologies of WTB/MVB and ETB/ECN are first introduced. Then, taking the multiple-unit train as an example, the of ETB and ECN capabilities of supporting train control, video surveillance, and passenger services are analyzed. Finally, the next generation of promising technologies used on the train communication systems is prospected.

81.2 Train Communication Network Based on WTB/MVB

81.2.1 WTB/MVB Characteristics

WTB is used for the communication between devices in the different consists during the couple operation. MVB is used for connecting the equipments in the same consist. The layered specification of the standard is shown as Fig. 81.1.

The application leaflets UIC557 and UIC647 specify the application data and behaviors of various onboard equipments, such as traction control unit, door control unit, and brake control. The communication leaflet UIC556 specifies the communication protocols during train coupling, but this protocol is seldom used in China. The TCN protocol includes process data, message data, dynamic coupling, and addressing protocols [5]. The IEC 61375-2-1 and IEC61375-3-1 specify the WTB and MVB, including the physical layer, link layer, network layer, transmission layer, and application layer, respectively. The technical characteristics specified by the WTB/MVB standard system are shown in Table 81.1.

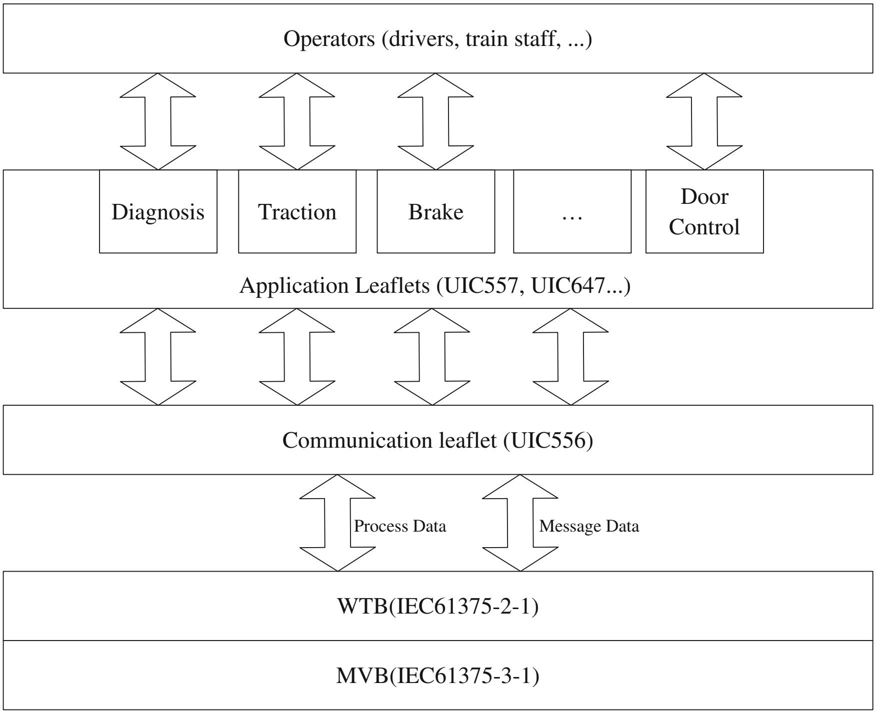

Fig. 81.1 Layered specification of the WTB/MVB-based communication network

Table 81.1 Characteristics of WTB/MVB

	WTB	MVB
Networking mode	Automatic and dynamic	Determined in advance
Physical medium	Shielded twisted pair cable	Shielded twisted pair cable
Communication distance	860 m	20 m (ESD) 200 m (EMD) 2000 m (OGF)
Signal	Manchester codes with 16…32 preamble code	Manchester codes with delimiters
Bandwidth	1 Mbps	1.5 Mbps
Address space	8 bit address	12 bit address
Length of frame	A range of 4–132 byte	2, 4, 8, 16, 32 bytes
Addressing mode	Dynamic addressing	Static addressing
Typical cycle	25 ms	16 ms
Redundancy mode	A/B line	A/B line
Media access	Master and slave	Master and slave
Real-time protocol	TCN real-time protocol	

81.2.2 Widely Applied TCN Products

Zhuzhou Institute, Bombardier, and Siemens are the main suppliers of TCN products. The products of these companies follow the same IEC standard, but the structure and characteristics are different.

The TCN product based on WTB/MVB of Zhuzhou Institute is called Distribute Train Electric Control System (DTECS), and its module appearance is shown as Fig. 81.2a. The DTECS is designed with a modularized structure based on distributed calculation theory. The modules of DTECS include WTB/MVB gateway module, vehicle control module, digital quantity input and output modules, analog input and output module, bus switching module, serial communication modules, intelligent displayers, and portable test unit. The core TCN protocols, including MVB link layer protocol, WTB link layer protocol, and RTP real-time protocol are

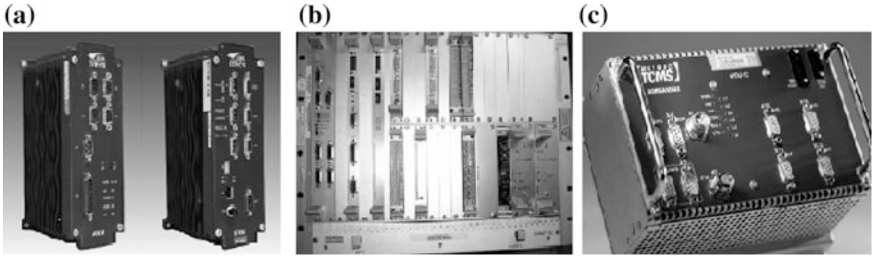

Fig. 81.2 Widely applied TCN products appearance

implemented in these devices. The network management of this system is developed based on the MVB message data.

The TCN product of Siemens is called SIBAS32, which adopts the case-type structure. It is used for controlling, monitoring, and protecting the convertor devices of the traction system in the vehicle. The system is also used to process data for the train control. In addition, the system integrates functions of diagnosis, debugging, and maintaining. The SIBAS32 chassis is flexibly installed with a series of cards, i.e., central processing card and communication interface card. An example of a CCU equipment is shown in Fig. 81.2b.

Bombardier launched its new MITRAC CC TCMS system in 2006. This system is a transition from MVB/WTB to Ethernet. The process data are transmitted with WTB/MVB. The vehicle control and gateway modules are provided with Ethernet interfaces. Although MITRAC CC TCMS is still designed with distributed calculation theory, the functions of VCU and gateway are greatly increased and centralized. The appearance and structure of the product of MITRAC CC TCMS is shown in Fig. 81.2c.

81.2.3 The Application of the TCN Products in China

81.2.3.1 Application on Locomotives

The TCN products based on WTB/MVB are most widely applied on locomotives in China. Table 81.2 shows the statistics of the TCN product applied on different locomotives. The TCN product based on WTB/MVB is the most widely used one.

81.2.3.2 Application on Urban Rail Trains

Urban rail trains have rapidly developed in China [6]. By the end of 2014, the total length of operating lines of rail transit in 22 cities is 3173 km. The number of cities whose urban rail is under-constructing is up to 40, and the length of the

Table 81.2 Basic characteristics of WTB/MVB technologies

Vehicle Model	Number	Train bus	Vehicle bus	Network supplier	Year
HXD1/HXD1B	870	WTB	MVB	Siemens	2009–2012
HXD1/HXD1C/HXD1D/HXD1F	2213	WTB	MVB	Zhuzhou Institute	2009–2014
HXD3B	500	WTB	MVB	Bombardier	–
HXD2/HXD2B	991	FIPT	FIPV	Alstom	–
HXD3/HXD3C/HXD3D	2654	–	RS485	Toshiba	–

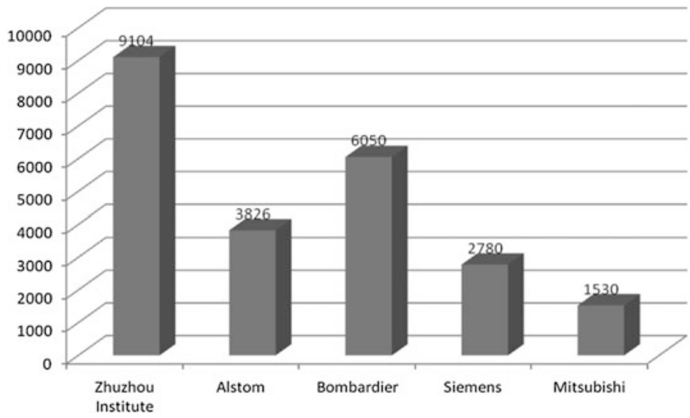

Fig. 81.3 Quantity of TCN system applied on urban rail trains (unit: set)

lines under-constructing is up to 4073 km. The number of operated and under-constructing urban rail trains is about 30,000. Zhuzhou Institute, Bombardier, Alstom, Siemens, and Mitsubishi are main suppliers of the TCN system for the urban rail trains in China. The DTECS of Zhuzhou Institute is applied on the urban rail transit trains in 24 cities, including Fuzhou, Nanjing, Nanchang, Ningbo, Shanghai, Beijing, Guanghzou, and Shenzhen. The number of the applied DTECS system exceeds 9000, and the market share is in the first place. The Fig. 81.3 shows the application of TCN product of the main TCN product suppliers.

81.3 Train Communication Network Based on ETB/ECN

81.3.1 ETB/ECN Characteristics

ETB and ECN are the train and vehicle communication networks based on real-time Ethernet technology, respectively. Figure 81.4 is the layered specification of the ETB/ECN-based communication network. The application profile IEC61375-2-4 specifies the application data and behaviors of TCMS equipments, mainly including traction control unit, door control, air conditioner control, and brake control [7]. Compared with WTB/MVB, ETB/ECN supports onboard multimedia data, including video surveillance/CCTV and PIS etc. The video surveillance/CCTV and PIS are specified by IEC62580-2 and IEC62580-4, respectively [8]. The communication profile IEC61375-2-3 specifies the communication protocols, including Train Real-time Data Protocol (TRDP), process data, message data, addressing protocols based on Uniform Resource Identifiers. The standard IEC61375-2-5 and standard IEC61375-3-4 specify the physical layer, link layer, network layer, transmission layer, and application layer of each layer ETB and ECN, respectively. Meanwhile, the IEC61375-2-5 specifies the inauguration of the backbone during

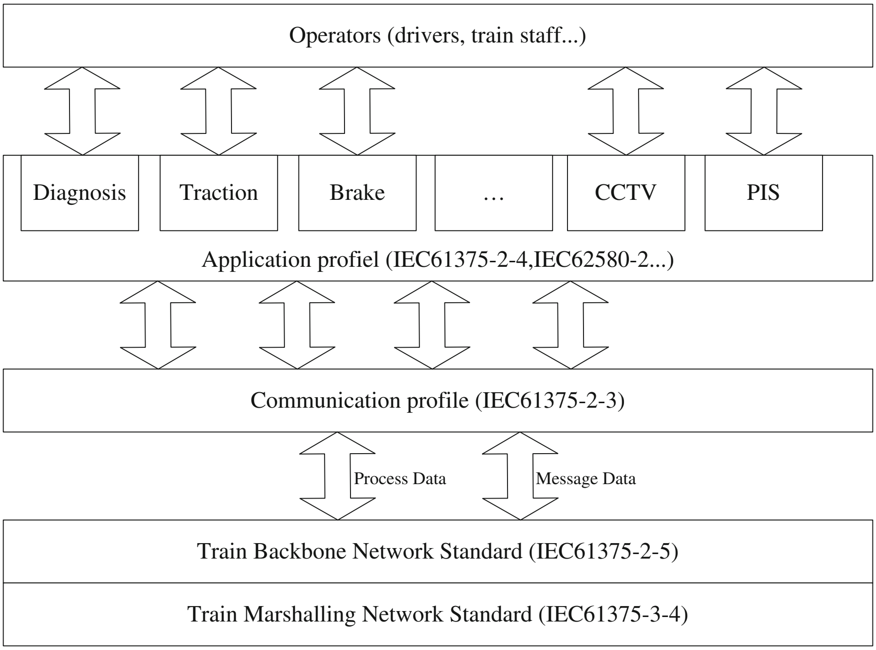

Fig. 81.4 Layered specification of the ETB/ECN-based communication network

the train coupling. To meet the reliability requirement, the link aggregation and ring redundancy topology are used in ETB and ECN, respectively.

The basic technical characteristics specified in the ETB/ECN standard are shown in Table 81.3. Compared with WTB/MVB, the bandwidth of the ETB/ECN network is promoted to 100 Mbps, and the size of the maximum data packet is promoted to 1500 bytes. The rich bandwidth provides a good capacity to transmit the process data, diagnosis data, maintaining data, status monitoring data, video surveillance, and passenger information service data.

81.3.2 Train Control and Information Service

The ETB/ECN-based TCN system has the abilities to provide train control and information services. For example, the product DTECS-2 of Zhuzhou Institute is a new generation of TCN based on ETB and ECN. The DTECS-2 includes the ETB node (ETBN), ECN node (ECNN), Ethernet Vehicle Control Module (EVCM), Ethernet Input and Output Module (EIOM), Ethernet Data Record Module (EDRM), and Ethernet Wireless Module (EWLM). The DTECS-2 is also designed with a modularized structure based on distributed calculation theory. Figure 81.5 shows the appearance and structure of the products of the DTECS-2 system.

Table 81.3 Basic characteristics of ETB/ECN

	ETB	ECN
Networking mode	Automatic and dynamic	Determined in advance
Physical medium	Cat5e twisted pair cable	Cat5e twisted pair cable
Communication distance	100 m	100 m
Bandwidth	100 Mbps	100 Mbps
Packet length	1500 Bytes	1500 Bytes
Addressing mode	Dynamic	Static
Typical cycle	10 ms	10 ms
Minimum cycle	4 ms	1 ms
Redundancy mode	Link aggregation	Ring
Media access	CSMA/CD	CSMA/CD
Network layer	IPV4	IPV4
Transmission layer	UDP multicast/unicast, TCP	UDP multicast/unicast, TCP
Real-time protocol	TRDP	–
Application layer service	DHCP, DNS, SNTP, SNMP	DHCP, DNS, SNTP, SNMP

Fig. 81.5 Appearance and structure of the products of DTECS-2

Figure 81.6 shows an example of the ETB/ECN-based train communication system for multiple-unit trains. The ETB formed by ETBN provides 200 Mbps bandwidth with link aggregation. The ECN formed by ECNN provides 100Mbps bandwidth. The end devices including EWLM, EVCM, and CCTV device are connected to the Ethernet ports of ECNN. The fault diagnosis and maintaining data are also transmitted through the same network.

In order to guarantee the real time, reliability, and safety of the TCN, a series of technologies are adopted in the ETB/ECN system.

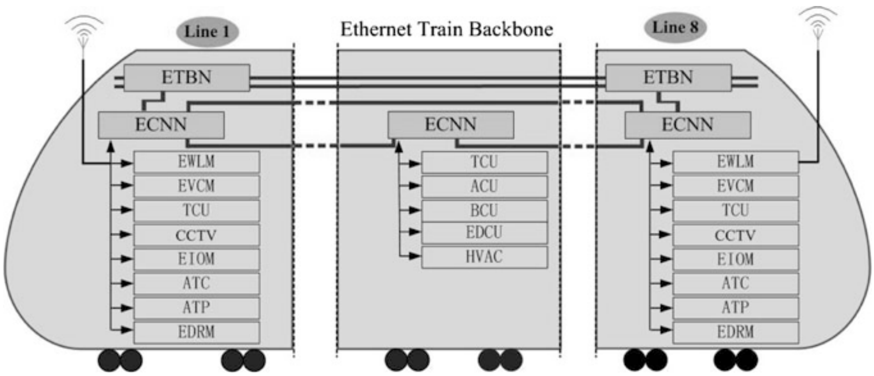

Fig. 81.6 An example of the ETB/ECN-based train communication network

81.3.2.1 VLAN

In order to avoid the impact to the TCMS from the simultaneous transmission of multimedia data, the process data in TCMS, the multimedia data are divided into different virtual LANs. According to the different cases, the bandwidths of divided VLANs are different. For a CCTV composed of 16 cameras with 2-Mbps data rata, the transmission of the multimedia data is 32 Mbps. In this case, the 100 Mbps bandwidth can be divided into 50 Mbps for the TCMS and 50 Mbps for the multimedia system. When the VLAN is applied, the device in the multimedia VLAN cannot access to the TCMS and the safety of the TCMS system is guaranteed.

81.3.2.2 Multicast

In the TCMS system, the data from different devices including the traction control unit, brake control unit, and I/O devices are aggregated to the vehicle control module. On the other hand, all the commands from the vehicle control module are distributed to the related devices. This characteristic makes the multicast technology suitable to be used in the TCMS. During the power up, the vehicle control module publishes several ports to transmission multicast data to a series of devices within a same type. Hence, the data flow is optimized through putting the communication data into different multicast packet.

81.3.2.3 QoS

Quality of Service (QoS) is used to guarantee the transmission delay when the process data of TCMS and multimedia data are switched in the ring that consists of network and link aggregation backbone network. When the end device is to transmission data, the DSCP in the IP head will be filled according to the data type. The network supervisor data will be filled a QoS value with 7 or 6, which means this data class owns the highest priority to be switched. The priority level for the process data is 5 or 4, and the priority level for the multimedia data is 3 or 2. The ECNN switches the TCMS data and multimedia data according to the QoS to guarantee the real time.

81.3.2.4 Redundancy

In order to guarantee the reliability, the whole link from one end device to the other is redundant. End device can adopt two Ethernet cards to provide 2 separate links to the ECNN. For the consist network, the redundancy function is carried out by the ring network protocol. When an ECNN or a line is out of work, original virtual open links are closed to guarantee the normal transmission of the inner data of vehicles. For the gateway from the ECN to the ETB, the fault-tolerance capability can be guaranteed by double-node backup. When one ETBN is invalid, another ETBN can immediately take over the invalid one to rebuild the network topology and transmit data. To the backbone, when a link of an ETBN is in failure, the data transmission is automatically switched to the other link through the link aggregation protocol to guarantee the normal work of the train backbone.

81.4 Prospect

With the development of big data and mobile Internet technology, Internet+ and Made in China 2025 project is proposed. Intelligent remodeling is realized in various traditional fields. Through deep digitization and wide interconnection and interworking, the QoS, total cost during the product life will be greatly changed. Realization of high-density data collection and storage, high bandwidth and highly reliable data transmission becomes crucial. On the other hand, it is important to realize the intelligence of rail traffic and support the intelligent services, such as remote monitoring, fault diagnosis, video surveillance, fault prediction, product healthy management, maintenance management, and passenger information. Therefore, the wireless communication and wire communication with a large bandwidth may be the development trend direction in the future.

81.4.1 Optical Communication

Optical communication is a potential technology for the TCN because of the large network capacity and strong interference resistant capability. Optical communication comprises an onboard optical switching network and train-ground free-space

Fig. 81.7 FSO communication experiment in Japan

optical (FSO) communication. The Fig. 81.7 shows the FSO communication experiment carried out on high-speed trains in Japan [9].

81.4.2 Wireless Communication

Wireless communication is widely applied to various fields. In the rail traffic area, wireless communication technology is applied to the signal systems, wireless distributed power operation, status remote monitoring, and diagnosis. The signal system comprises CBTC for metro and CTCS system of main line railways. The state-of-the-art wireless communication technologies, such as 5G technology, high-speed WLAN technology, and millimeter wave technology, may be technologies for the TCN in the future.

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