IEC 61375-1 and UIC 556 - International Standards for Train Communication

CHRISTOPH SCHÄFERS, GERNOT HANS

DaimlerChrysler Rail Systems GmbH
TTC/ESDE; Neustadter Str. 62; D-68309 Mannheim
Christoph.Schaefers@man.Adtranz.de; Gernot.Hans@man.Adtranz.de

Abstract - The communication system within a train is a central issue for train system integration. Historically, there have been numerous, proprietary and non-interoperable solutions. IEC 61375 and UIC 556 have now been issued as a set of international standards to overcome this situation:

IEC 61375, the Train Communication Network (TCN), defines a communication architecture and the necessary protocols for non-vital communication on train and on vehicle level. It consists of a two-layered, hierarchical architecture to suit the needs of inter- and intra-vehicle communication. UIC 556 and the accompanying UIC codes define the operator's view on the train, the framework for the coordination of the different applications and the operational handling to ensure interoperability between vehicles from different manufactures.

This protocol suite has been successfully explored in operational test trains as well as in large number of actual running projects for DMUs, EMUs, high-speed trains, locomotives, passenger trains, suburban trains, as well as trams. It is used for new vehicles and for vehicle refurbishment.

The article focuses on the TCN and UIC standards, their development and application in actual projects.

I. TCN Development

In 1988, IEC Technical Committee 9 founded Working Group 22 to standardize a common train communication network for railway applications. In parallel (1990 - 1996), a Joint Development Project (JDP) was founded by several rail system suppliers (ABB, AEG, Firema, Siemens) to jointly develop a common prototype for such a communication system and prove the feasibility of the concept. The output of this project was a reference implementation of hardware and software for a TCN network and a laboratory test bed to verify and to tune the behavior.

In 1994/95, the devices developed were used in an ERRI test train running in regular operation between Interlaken, Switzerland and Amsterdam, Netherlands. The tests were executed by the "Industriegruppe Zugbus" (IGZ: ABB, AEG, Firema, Holec, Siemens) and were used to further improve TCN in regular operation. In October 1999, TCN became International Standard (IS).

The work on standardizing the application level was done in parallel to the development of the TCN system, and UIC code 556 was passed in June 1999.

II. Train Communication Network (TCN)

The TCN has been standardized by IEC (IEC 61375-1) and by the IEEE (Std 1473-1999 IEEE Standard for Communications Protocol Aboard Train)[1].

General Architecture

The architecture of the TCN addresses all relevant topologies used in rail vehicles. It comprises two levels, the *Wire Train Bus* WTB connecting the vehicles and the *Multifunction Vehicle Bus* MVB (or optionally another vehicle bus) connecting the equipment aboard a vehicle or group of vehicles (figure 1).

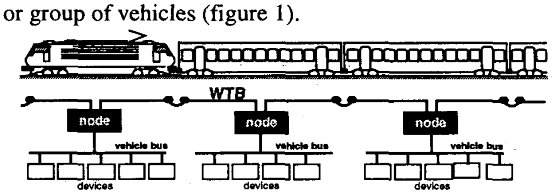

figure 1: physical architecture of the TCN

A vehicle may be equipped with one or several vehicle busses. A vehicle bus may span one or several vehicles as in the case of mass-transit train-sets (MUs) which are not separated during operation.

To cope with a variety of coaches and equipment, TCN uses logical addressing: every node of the train bus is expected to support a number of application *functions* which are each accessible by a unique function number. The vehicle's internal hardware infrastructure must therefore not be known.

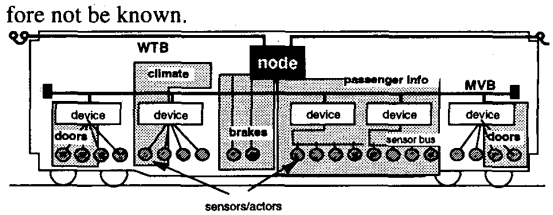

figure 2: logical architecture of the TCN

Each function may be executed by one or by several devices or by the train bus node itself; and each device may execute multiple functions. From the outside, it looks as if the (WTB) node would be executing all functions itself; the internal structure is invisible from the outside.

Multifunction Vehicle Bus (MVB)

The Multifunction Vehicle Bus (MVB) has been specified as the vehicle bus that connects equipment on-board vehicles and between vehicles in a closed train-set.

The MVB operates at 1.5 Mbit/s over three media:

- RS-485 for short distance (Electrical Short Distance Bus, ESD for up to 20m and ESD+[2] for up to 200 m)

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[1] IEEE 1437 defined TCN in a bundle with LON

[2] The ESD+ bus uses the ESD characteristics but with

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- transformer-coupled twisted wire pairs for up to 200 m (Electrical Middle Distance Bus, EMD);
- optical fibers for distances up to 2000 m (Optical Glass Fiber, OGF), especially to be used in EMC harsh environments.

The different media can be interconnected directly with repeaters. The introduction of the vehicle bus allows to reduce considerably the amount of cabling and to increase reliability.

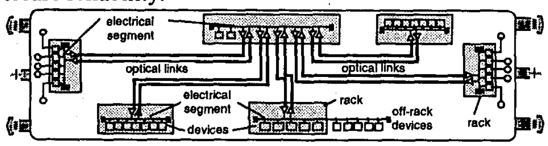

figure 3: MVB layout in a locomotive using fiber optics and electrical medium

The MVB is controlled by a dedicated bus master which may be backed up by redundant masters to increase availability. The MVB is supported by an integrated bus controller (MVBC) which allows to build simple devices without a processor. This chip provides line redundancy at the physical layer: a device transmits on both redundant lines but listens to only one while monitoring the other. The MVB provides high integrity against data falsification. Because of its robust Manchester encoding and its checksum, it fulfils the IEC 870-5 FT2 class (HD = 8).

class 0	repeaters, bus couplers and optical star couplers
class 1	simple actors and sensors which offer the capability to read the device status and to send/receive process data. Typically they possess no application processor (only the bus controller).
class 2	intelligent input/output devices with application processor, but fixed application program (can only be configured). Support process data and message data.
class 3	intelligent programmable devices. Support process data and message data.
class 4	like class 3, but with bus administrator in addition and not necessarily programmable
class 5	like class 3, but with WTB gateway capability addition and not necessarily programmable

table 1: MVB device classes

Wire Train Bus (WTB)

For trains which frequently change composition (such as international UIC trains or suburban trains), the Wire Train Bus (WTB) was designed to interconnect vehicles via hand-plug jumper cables or automatic couplers. For cabling, a shielded twisted wire pair carrying data at 1 Mbit/s is defined which may be redundant[3].

The WTB allows to cover 860 m (which corresponds to 22 UIC vehicles without repeater) and to connect up to 32 nodes. Considering the harsh environment and the presence of connectors and discontinuities on the bus, a digital signal processor is used for decoding the Manchester signal (e.g. the MITRAC AMED chip). To clean connector contacts which may be oxidized, a fritting voltage may be superimposed.

The most salient feature of the WTB (and unique in industry) is its capability of auto-numbering the nodes in sequential order and to let all nodes recognize which is the right or left side of the train. Each time the train composition changes, e.g. when adding or removing vehicles, the train bus nodes execute the *inauguration* procedure which connects the nodes electrically and assigns each node its address.

Train bus nodes are numbered sequentially. In general, there is one node per vehicle. But there may be more than one node per vehicle or none at all (figure 4).

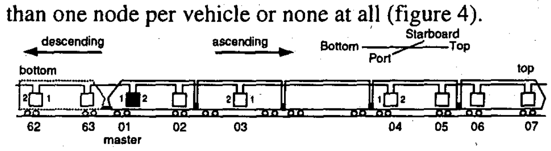

figure 4: train bus nodes and vehicles[4]

At the end of the inauguration, all vehicles are informed of the WTB topography, including:

- their own TCN address, orientation (right/left), and position (after/before) with respect to the master.
- the number and position of the other nodes in the train.

Additionally, user defined information may be appended that informs about

- type and version (locomotive, coaches...) of other vehicles and supported functions
- permanent and dynamic properties of the vehicles (e.g. presence of the driver)

For example, UIC defined such user information in [UIC556] (refer to chapter III).

The inauguration procedure is complex since it does not only care for correct numbering and identification of the nodes but also for the transition between low-power sleep mode to active mode. To allow a fast recovery in the event of bus disruption, every node has the ability to become bus master. In such an event, mastership is automatically transferred to a neighboring node.

WTB	MVB
up to 860 m	up to 200 m / 2000 m
auto-configuration	fixed configuration
orientation detection	no orientation
relative addressing	absolute addressing
up to 32 nodes	up to 256 stations
1.0 Mbit/s	1.5 Mbit/s
25 ms cycle time	1 ms cycle time

table 2: summary of WTB and MVB characteristics

Common Real-time Protocols (RTP)

WTB and MVB differ in physical and link layer. But with respect to higher layers and especially to user interfaces, both obey to the same protocols which are called *Real Time Protocols*. This paragraph outlines the RTP's principles:

Data Traffic

The TCN provides two types of data service:

1) **Process Variables** which reflect the train's state like speed, motor current, operator's commands. The transfer

galvanically isolating interfaces (opto-couplers).

[3] UIC requires redundant cabling.

[4] The master node receives address 01. Nodes in top direction are numbered ascendant, nodes in bottom direction descendant starting with 63

time for Process Variables must be short and deterministic. To guarantee this delay, Process Variables are transmitted periodically.

2) **Messages** carry infrequent but possibly lengthy information, e.g. diagnostics or passenger information. Message length varies between a few octets and some kilo-octets. The transmission delay of messages must be short, but variations are permitted. For this reason, Messages are transmitted on demand.

Periodic and Sporadic Medium Access

The periodic (process data) and sporadic (messages) data traffic share the same bus but are treated separately in the devices. All busses pertaining to the TCN are expected to provide these two basic data services. The periodic and sporadic transmission of data is controlled by one device acting as master. This guarantees deterministic medium access. To this effect, the master alternates periodic phases and sporadic phases:

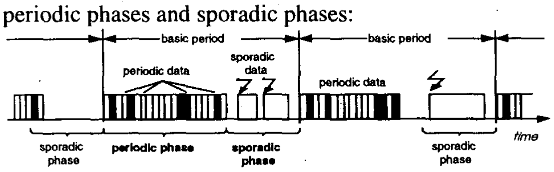

figure 5: periodic and sporadic data transmission

The periodic phase occupies a fixed slot of the bus time. During that time, the master polls variables in sequence. Periodic data is associated with transmission of states and need not to be acknowledged by the destination(s) since they are periodically retransmitted. The basic period is either 1 ms or 2 ms on the MVB and 25 ms on the WTB. Less urgent variables can be transmitted every 2^{nd}, 4^{th}, etc. basic period, with the longest period being 1024 ms.

The sporadic phase between two periodic phases allows devices to transmit data on demand. Sporadic transmission is associated with the transmission of events which are any state changes including communication. Therefore, events are acknowledged to ensure that no state change gets lost.

Process Variable Transmission

Transmission of variables is triggered by the master which broadcasts a request frame for a certain variable or a set of variables. In response, the device which sources the variable answers by broadcasting to all devices a frame containing the requested value. Each device interested in this variable picks up the value (figure 6).

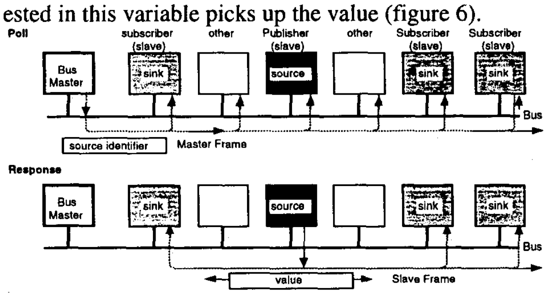

figure 6: Process Variable transmission

The format of the frames is fixed at configuration time for all parties. Process Variables are stored in *ports*. A port is a memory region in a shared memory, the *Traffic Store* (TS), which application and bus access independently. On the MVB, each device can be subscribed (as source or as sink) to up to 4096 ports. On the WTB, a node can source only one port and sink up to 32. Thus, the Traffic Stores implement a distributed database refreshed by the bus.

The principle of source-addressed broadcast allows the independent operation of the applications and of the bus. The application processor is interrupted on reception or transmission only for time synchronization. Determinism is ensured from end to end by the periodic nature of the application processes and of the bus. Since Process Variables are transmitted periodically over the bus, there is no need for an explicit retransmission in case of occasional loss. To cope with persistent faults, the bus controller maintains for each variable a counter, which indicates how long ago the variable was refreshed. In addition, a check variable may be transmitted with each variable to certify its timely and correct production.

Message Transfer

Applications exchange messages transparently over the Train Communication Network. (An application does not see if its peer resides on the same bus, on the same station, or anywhere else on the TCN).

Application communicate on a Client/Server basis: a conversation consists of two messages, a Call sent by the Client and a Reply sent in response to it by the remote Server. Messages are divided into small packets for transmission. Each packet carries the full address, which identifies its source and destination. The train bus nodes route the packets, using a Function Directory that indicates which device is executing which function. A retransmission protocol cares for flow control and error recovery. This transport protocol is executed by the end devices only; intermediate nodes only intervene in exceptional cases (inauguration, for instance).

The Real-Time Protocols and the ISO OSI Reference Model

The TCN has been specified in accordance to the ISO OSI 7-Layer reference model. MVB and WTB differ only in the layers 1 and 2 (physical layer and link layer). Because process data are neither routed, nor need a transport protocol or a session protocol, the application interfaces directly with the link layer. Messages, on the contrary, are routed from MVB to WTB and need flow control and application acknowledge involving all layers.

TCN Gateway

The TCN gateway connects one or more MVBs with the WTB. The marshalling of process data from MVB to WTB and vice versa is done by a special gateway application program, the so-called Process Data Marshalling (PDM). The way how process data are marshaled must be configured in dependency of a specific application. Routing of messages is done within the network layer of the Real-Time Protocols (RTP). The routing requires some information about the internal structure of the vehicle. Especially the mapping between logical function and physical MVB device is required which is preconfigured in the function directory table.

Train Network Management (TNM)

The Train Network Management helps in configuring, commissioning, and maintaining the TCN system. To this effect, a Network Manager may be connected to the TCN. The Manager has access to all devices connected to the TCN, in the same and in other vehicles.

The Manager can inspect and modify other devices through an Agent, which is an application task running in each device capable of being managed. The Agent has local access to the managed objects: process variables, protocols information, memory, tasks, clock, etc. Management Services are specified to read and write the managed objects, along with the format of the Manager Messages.

III. UIC Communication

TCN describes the basic communication mechanism for intra-vehicle (MVB) and inter-vehicle (WTB) communication. TCN does however not define an application specific profile like the content of process data frames and messages, their meaning, the time period of process data, special requirements concerning redundancy and so on. UIC (Union Internationale de Chemin de Fer) recognized that prescribing TCN for usage in freely composed passenger trains is not enough to ensure interoperability between vehicles from different manufacturers. This insight led to the definition of a profile for passenger trains.

The definitions for cabling are defined in UIC code 558. The communication related part of the profile (train inauguration, content of process data frames and messages) is defined in UIC code 556 [UIC556]. The application of the defined process and message data has been described in the accompanying UIC codes 557 (diagnosis), 647 (remote traction control), 560/660 (door control) and 54x (brake control). In this chapter, the basic communication concept as it is defined in the UIC code 556 shall be explained.

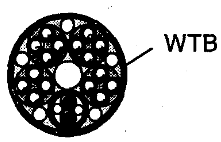

figure 7. 18-wire-UIC cable as defined in UIC558

Architecture

The most obvious difference between TCN and UIC communication is the fact that UIC only defines train bus communication. Vehicle internal communication is beyond the scope; a vehicle is rather treated as a 'black box' that only provides a set of logical functions. In this sense, there is some similarity to the logical architecture of TCN. This is reasonable because vehicles are bought from different manufacturers and normally differ in the internal design and functionality. On train bus level, communication takes place between vehicles and not between nodes. There may be a 1:1 mapping between nodes and vehicles (if a vehicle incorporates exactly one node), but this must not be true if train-sets[5] or vehicles with more than one node are involved. Thus, since UIC decided to take the WTB for train bus, a mapping between UIC addressing scheme (vehicles and functions) and TCN addressing scheme (nodes and functions) is essential.

Data Telegram Types

In correlation to the TCN data model, the UIC distinguishes R(egular)-telegrams which are mapped to TCN process data and E(vent)-telegrams that are mapped to TCN messages.

Process data originating from all functions within one vehicle are collected in one R-telegram that is cyclically broadcasted on the WTB. The time interval between two emissions (individual period) is fixed to 100 ms, the maximum length of a R-telegram is limited to 1024 bits. Data structure and contents of the R-telegram depend on some dynamic and static vehicle properties. UIC 556 defines four telegram types:

- *R1* to be emitted by the leading vehicle[6] only
- *R2* to be emitted by traction vehicles only (if not leading)
- *R3* to be emitted by all other vehicles
- *void* to be emitted if the UIC inauguration failed

Since the R-telegrams are broadcasted, each vehicle receives the R-telegram of all other vehicles. Besides data types and semantics, UIC defined some rules ('process data marshalling') that shall be applied for the correct interpretation of received R-telegrams. (Example: The R-telegram data 1.9 or 1.10 (status indication: all doors left/right closed) have to be ANDed over all received R-telegrams in order to achieve the final value of this data.)

E-telegrams, on the other hand, are sent point-to-point (single vehicle address) or point-to-multipoint (collective address, group address) between functions. All the E-telegrams are defined with respect to syntax and semantics and have a common 10 Byte-header.

Addressing

As mentioned, UIC addresses vehicles and functions within the vehicles. Vehicles are simply numbered from 1 to n. A set of rules unambiguously defines which end vehicle receives the address 1 (for instance, if the end vehicle is a leading vehicle then this vehicle gets address 1). The assignment of the *vehicle address* to the individual vehicles is done during the so-called UIC Inauguration (see below). Vehicles can be grouped, either pre-defined (*collective address*, e.g. 'leading vehicle', 'all vehicles with 1st class passenger seats', 'all sleeping cars') or user defined (*group address*).

UIC 556 further defines the function numbers to be used for traction, doors, light etc.

UIC Inauguration

As a result of TCN inauguration, the WTB nodes know their WTB address, their position and their orientation with respect to the TCN master. This information is not sufficient for UIC addressing because the mapping between WTB node address, the corresponding vehicle ad-

[5] A UIC train-set may consist of up to 6 vehicles which are interconnected by for example one MVB and share one WTB gateway.

[6] The 'Leading Vehicle' is the vehicle within a train composition which has overall control of the train (typically the vehicle with the activated driver's cab).

dress, and the orientation with respect to the train's reference direction is not known. For UIC addressing, additional information is needed like for instance the number of vehicles that are controlled by a node or the position of the leading vehicle. Supplying more detailed information about the vehicle is the task of the UIC Inauguration. The UIC Inauguration makes use of the TCN-WTB feature to broadcast application information describing the vehicle ('vehicle descriptor') during the distribution of the TCN topography. This mechanism ensures a completion of the UIC Inauguration within typically less than 1 second. As a result, each WTB node has a consistent collection of all vehicle descriptors. These descriptors are used to build up the *NADI* (Node Address and attribute DIrectory) which finally contains a description of the whole train. Since the algorithms that are used are normalized, all nodes will possess an identical copy of the NADI. For inclusion of vehicles without a running gateway, or for adding information to the NADI, the NADI result may be corrected.

Implementation

UIC communication has to be supported by the gateway which includes a software module called *UIC Mapping Server* (UMS). This UIC Mapping Server mainly performs the UIC Inauguration and the NADI build-up. The module follows the design that is defined in the UIC code 556 annex 3. Besides the basic services mentioned above, the UMS also provides some services that allow control of WTB operation, definition of groups and reading respectively modifying the NADI. To make these services remotely available, an interface software module (UMSI) may be implemented as an application which can be installed on any programmable unit that is connected to the MVB. The UMSI provides a functional interface of the UMS services towards the application software.

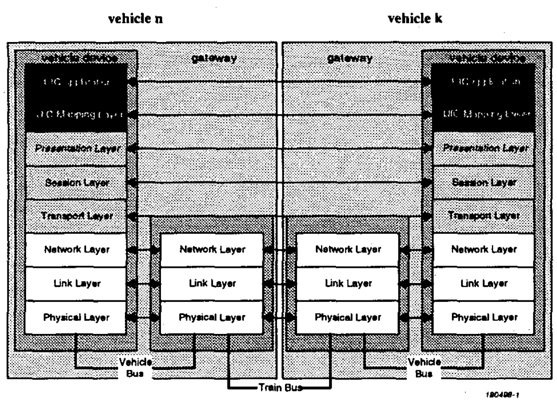

figure 8: TCN/UIC stack for inter-vehicle communication (after inaugurations)

IV. TCN Projects

From 1996 until 1999, the E.U.-project ROSIN (= Railway Open System Interconnection Network) successfully demonstrated the interoperability concerning inter- and intra-vehicle communication between several different manufacturers' equipment[7]:

- demonstrating intra-vehicle interoperability for mass transit
- demonstrating inter-vehicle interoperability for passenger trains
- showing openness towards external systems (GSM-gateway for online diagnostic monitoring).

Further, it demonstrated solutions for exploiting TCN for freight trains and retrofitting coaches with existing, simple cabling.

The test suites for UIC conformance testing describe how interoperability for WTB nodes may be verified and are included in UIC code 556 as annex 8.

MVB interoperability is verified on TCN as well as on application level by the projects' system integrators.

TCN Suppliers

The list of TCN equipment has considerably increased during the last years and is supplied for example by Adtranz, Alstom, Ansaldo, Deuta, Duagon, GE Harris, FAR Systems, Faiveley, Hagenuk, IFE, Knorr Bremse, Mannesmann Rexroth, Schneider Electric, Selectron Lyss, Secheron, Siemens, and Wabco.

Vehicle Projects

In the last few years, TCN has been successfully applied to an ever increasing number of vehicle projects. It is being used and proven for well over thousand locomotives for DB AG, FS, SBB, ÖBB, OSE, PKP, Russia, and Britain; the ICE3 high-speed trains for DB AG and NS; a few hundred EMUs and DMUs for Britain, Germany, Italy, Switzerland, Norway, Sweden, Denmark, Australia, Brazil, and Portugal; a few hundred trams for Switzerland, Germany, and Austria; the metros in Stockholm, Manila, Pusan, Iran, and Prague; and a few hundred coaches for SBB, ÖBB, and FS.

As TCN usage is becoming wide-spread, the retrofit business is starting to become more important beyond the initial small projects. E.g. DB AG currently has a tender for retrofitting about 2000 coaches with WTB.

The initial TCN "killer" applications which drive the usage of this technology are diagnosis to improve the availability of the rolling stock and remote traction control. In the second wave, innovative Passenger Information Systems and other passenger comfort applications gain more and more importance.

REFERENCES

[TCN] TC 9/WG22; *IEC 61375-1*; TCN Standard; International Electrical Committee

[UIC] UIC 556 Steering Group; *UIC Code 556*; 2nd edition; May 1, 1999; Union International de Chemin de Fer, Paris

[7] The project consortium consisted of ABB, Adtranz, Alstom, Ansaldo, CAF, Firema, LAB, Siemens in cooperation with UIC and UITP.