A study on development of low cost Digital Train Communication Network for Indian Railways

Akhilesh Misra,
Chief Design Engineer
Rail Coach Factory, Kapurthala
Government of India - Ministry of Railways

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Abstract

In this paper, the author has attempted to study the requirements of train control networks and safety systems for application to high-speed rail travel for Indian Railways and present a concept design of a Train Digital Communication Network based upon common off the shelf (COTS) technologies for lower costs.

This study for the concept design of the COTS based TCN includes identification of sub-systems requiring the communication infrastructure, estimating the data loads and the characteristics and briefly explains how the concept design shall be able to meet the identified requirements. A literature survey of similar developmental efforts is also included.

While the study was initiated, the IEC standard too has undergone revision. Therefore the study further compares the concept model with the guidelines of the revised IEC 61375.

For furthering the implementation of the proposed system on the Indian Railways, the author has also identified the need of setting up a validation test facility for compliance testing to ensure interoperability. The scope, role and requirements of this facility are included as a part of recommendations in the paper.

This paper was originally written in 2013. However, the need for a DTCN standard is every more now. This paper has been reviewed and updated with the developments since its last writing.

Introduction

Microprocessor based control equipment have been introduced on the Indian Railways rolling stock starting 1990's. These systems were built around a central processing core with wired analog and digital inputs. These early systems were standalone and there was little need for communication between intelligent systems.

Lately a number of microprocessor based control systems have been introduced on the railway vehicles that need to interface, communicate and share information with the other systems on the vehicle. However the legacy designs of existing equipment make this communication attempts difficult, resource intensive and expensive.

The availability of multiple manufacturers of equipment compounds the problem further as this creates innumerable combinations of equipment that need to be integrated.

Significant resources are required to be spent towards non-recurring expenditure for integration whenever new equipment is introduced or a configuration change is required.

Since Indian Railways manufactures a majority of the required rolling stock and functions as a system integrator it was imperative that action to standardize the communication systems be initiated.

The need was to adopt / customize or develop a common shared digital communication network for inter-connection between different onboard systems.

The fact that Indian Railways has not yet adopted any particular standard for communication and equipment interoperability, provides a unique opportunity to study and develop and test a communication network system suiting the current and the expected future needs.

Initially all focus was on adoption of the TCN to IEC61375:2007 as it was developed and mature standard made just for this purpose. However during the initial discussions with the stakeholders it was seen that such an adoption had significant issues primarily due to:

1. Cost of equipment
2. Non-availability of local compliance testing facilities, thereby increasing cost of conformance testing significantly.
3. Does not provide adequate data bandwidth to support newer applications.
4. Proprietary extensions by equipment manufacturers preventing interoperability.
5. Poor supporting ecosystem for equipment and expertise.

It was felt that these factors would have a significant bearing on the overall equipment manufacturing costs and maintenance issues in the field and also the design severely limits deployment of high bandwidth applications.

This project was thus initiated with an aim to develop such a network system using COTS equipment to circumvent the issues listed earlier.

This paper summarizes the initial study done for the development / adoption of a standard for train communication networks for Indian Railways. This work is still in progress and many of the details reported here are subject to change along the course of the project.

Literature Survey

The field of communication technologies has been developing at a rapid pace. This presents challenges for selection of technology that can be used for the purpose described as the technology when selected shall continue to be in service for the life-cycle of the vehicles, which may vary from 20-35 years.

The demands on the technology for data communications are highly conflicting. Maturity and stability of the technology platform is required simultaneously with support for higher data bandwidth which is available only on the latest technology, most of which is still developmental.

A literature survey was done to gather information and opinion of the persons who have worked on such issues.

The standard document ***IEC-61375:2007*** was selected as the starting point. The standard is stable mature and implemented. The standard offers features implemented especially for control and monitoring a train consist. The definition encompasses almost all aspects in a layer by layer approach based on the OSI model.

Since the work was focused on the diesel electric locomotives, corresponding standards used on the AAR were also studied. ***AAR-S-590(2008)*** was found to be very generic leaving a lot to the implementers. This did not appear to offer the level of definition that was planned for the project.

The article titled ***Ethernet as a Train Bus*** *by Manfred Schmitz, CTO, MEN Mikro Elektronik GmbH* details the need for communication networks onboard trains. The article discuses the development of the TCN standard and also points out the shortcomings. Different types of Ethernet deployments have been compared. The non-deterministic characteristics of Ethernet have been stated as one of the major drawbacks for use as a control network for time critical applications. The article points out a significant issue that Ethernet Consist Network relies on use of proprietary and expensive TCN stack. The general import is that a number of significant changes are likely in the design and standards of field buses for TCN.

The team of researchers from East Japan Railway Company, Hitachi and Mitsubishi Corporations, in the article titled ***Development of 100Mbps-Ethernet-based Train Communication Network***, discuss the 100Mbps Ethernet based TCN deployed under the development project named INTEROS. The paper also gives an overview how the train to ground systems can interact for sharing vital and non-vital data. Results of tests of noise immunity and cross talk on the Ethernet network are detailed. The developments for mitigating such issues are discussed. The team has reported successful test of the MUE train equipped with Ethernet as Train Bus.

In their article titled ***T-Ethernet***, *Keiichi Kamata, Hideyuki Takahashi, Toshiba Corporation, Tokyo, Japan,* discuss T-Ethernet as a candidate for TCN. The improvements made in T-Ethernet for railway use have been discussed as: 1) Enabling high speed, 2) Real-time control function 3) Redundant Control Function 4) Improving Noise Immunity. The proposed architecture is 3-tier as compared to 2-tier of IEC61375 TCN. A shared common Ethernet bus architecture is proposed at the data-link layer to share control information in real-time. Token passing methodology is used for bus-arbitration in lieu of CSMA/CD. The paper also proposes use of minimalistic protocols in the TCP/IP suite i.e IP, ARP, ICMP and IP Mulicast. Most of the control data is proposed to be communicated using UDP. Network topology proposed for redundancy includes: ladder configuration and the ring configuration.

Prof. Dr.-Ing. Konrad Etschberger, in the paper titled ***Comparing CAN and Ethernet-based Communication,*** compares 10Mbps, 100Mbps Ethernets and 1Mbps CAN networks. The paper states that CAN has significant advantages over Ethernet due to 1) Higher protocol efficiency, 2) Better bus arbitration, 3) Support for multicasting/broadcasting at lower layers, 4) Low resource requirement for communication processing 5) Higher data integrity.

The paper, ***The Future of CAN / CANopen and the Industrial Ethernet Challenge***, *Wilfried Voss, President ESD Electronics, Inc USA,* discusses the possibility of Ethernet replacing CAN. It states that the different flavors of industrial Ethernet driven by proprietary interests make adoption difficult. The paper predicts that CAN should remain the most cost sensitive field bus solutions for embedded systems.

Study of application requirements

In order to arrive at a concept design of a TCN for Indian Railways, a review of equipment and applications that require such a communication infrastructure was conducted.

The following applications categories were studied to determine the nature of communication requirements. This was done with the view to establish the criteria for evaluation of communication technologies and also lent to identification of issues that need to be addressed at the application level.

A broad division was made between control requirements and infotainment systems requirements.

Control systems requirements

Requirements of control communication are stringent in terms of delay and packet drops, but do not normally need transfer of large volumes of data. The specific characteristics are discussed under the following headings.

Communication between intelligent controllers in a vehicle

This category of communication is normally seen to consist of a single byte or a set of bytes. The data needs to be relayed timely. The refresh intervals required normally vary from 100ms to 500ms.

Error detection and recovery is essential as most of the systems shall declare critical faults and stop operation in case of single or multiple packet loss. The tolerance to packet drops and delays is determined by the control loop cycle-times.

Communication between intelligent controllers on a train

The controllers on a vehicle are tightly integrated. It is seen that the level of integration between controller's onboard different rail vehicles is comparatively lower. Therefore the response times required from the network can be increased. More stringent response time requirements are expected if the train has distributed traction controllers and brake systems that need to be controlled over the network.

The remaining characteristics for communications are similar to those between controllers on the same vehicle.

Communication external to the train

This type of communication is not included in the planned scope of work as these are controlled by the standards for signaling. These are discussed here only for the sake of integration requirements.

These are expected to consist of the following categories.

- Communication between train and other trains
- Communication between train to ground based infrastructure

The Indian Railways has not yet standardized communication requirements like in-cab signaling or communication based train control (CBTC). A number of projects are active for addressing such requirements. For example in a parallel project of Train Collision Avoidance System (TCAS) uses UHF narrow band data radios for communication. The packet size is 40-50 bytes. It is felt that these systems shall be able to interface with the rest of the train networks using dedicated store-process-forward protocol translators.

In case IP based networks are implemented the design shall be further simplified.

Passenger infotainment and security systems

Such systems typically are expected to have high volume of data to be transferred. Some of the important systems expected to be provided on trains are discussed in the following paragraphs.

Information displays / passenger announcement

Information displays are expected to be of two types, one which display character messages and others which may display audio / video information.

Character displays normally have low volume of traffic and can tolerate large delays. Audio/video applications are expected to generate high volume of traffic requiring low delay and low errors. However most of the traffic is one way and broadcasting can be used thus reducing the data bandwidth requirements.

Internet Access

For Internet access low latency, high bandwidth with low error rates is required. This is expected to be one of the more demanding applications.

Media streaming devices (video on demand)

Requirement for such devices is expected to be similar to audio /video information displays. Data requirements can be reduced by broadcasting. Incase more than one entertainment channel is planned; systems need to be designed for selective broadcast.

Surveillance Systems

Although surveillance systems such as video cameras generate a large amount of traffic, the high bandwidth requirement can be made more manageable by storing the information locally and sending on the network only when required.

Selection of networking technology

The important question at the initiation of the project was whether it would be feasible to have only one type of network for both the vehicle and the train bus. As seen in the papers covered under literature survey, both the models are available. The IEC-61375:2007 standard makes a clear distinction for these, where as the Japanese Rail MUE train project favours Ethernet for both.

The initial leaning was to have one common network, Ethernet with TCP/IP for all communications. However, when the plan was discussed with the embedded systems developers, the proposal had a lot of opposition. The primary reasons cited were:

1. Lack of determinism
2. Heavy resource requirement for running TCP/IP stack which may affect the cycle times on the small embedded systems.
3. Very low efficiency for low volume data transfers. Most of the embedded systems send 1 byte or just a few bytes.

Consensus was on a two tiered approach i.e. to have one technology for vehicle bus and Ethernet with TCP/IP for Train Bus.

CAN bus was favoured for adoption as the vehicle bus by most of the system developers. The reasons given were:

1. Simple programming interface most suited for small controllers.
2. Robust bus with simple and effective arbitration scheme.
3. Adequate data bandwidth for required application.
4. Widespread use in military, aviation, marine and industrial applications.
5. Easily available software tools and test equipment.
6. Low cost.
7. Familiarity with the technology resulting in easy availability of expertise.

A set of criteria was also determined for the purpose of evaluation of these technologies for their suitability to the requirements for vehicle and train bus and locate the gaps which need to be addressed during the course of development.

The foremost criterion was to steer clear of proprietary implementations and use only open and widely used standards. This was essential to prevent a vendor lock-in and also to reduce costs.

The underlying principle is that if customization is needed, the design shall be that of the Indian Railways.

The application specific criteria that were evolved are discussed in the following paragraphs. These are based only on the perception of the system developers for determining the suitability of a network technology for the application on hand.

Criteria for evaluation of networking technology

In order to evaluate the desired attribute and compare the same with the capability of the networking technology to meet the same a set of evaluation criteria was created.

The study team also created an arbitrary scale denoting capability of a networking technology to meeting a requirement or the perceived requirement in the application. The scale consists of integers from 1 to 10 for grading each criterion. When used for a networking technology evaluation, Unfavourable was assigned 1 and most favourable assigned 10. When the same scale is used for defining requirements the numbers would interpret as: 1 would indicate least required and 10 shall denote a very vital requirement.

This method was selected for conducting a comparative analysis of the networking technologies and also to determine the capability to address the perceived requirements of the TCN.

Criteria Category	Sub-Criteria	Capability / Requirement	
		Low (1)	High (10)
Nature of Data	Volume	Low	High
	Speed	Low	High
	Latency	High	Low
	Determinism	Low	High
	Security	Poor	Reliable
	Error Tolerance	Poor	Reliable
Complexity of implementation	On-board resources	Heavy	Light
	Supporting ecosystem	Limited	Vast
Physical characteristics	Distance	Short	Long
	Noise immunity	Poor	Good
Features at lower layers	Plug & Play	Poor	Rich
	Fault recovery	Poor	Rich
Equipment Cost	Cost	High	Low

Table 1: Criteria for Technology Comparison

The requirements for each of the two tiers of the proposed TCN was also tabulated on the same criteria set and graded using the same scale.

This method of evaluation was developed as the impact of all relevant factors could be seen together. Additionally, it is felt that this method would also indicate the gaps that need to be addressed at the higher layers in the software stack such that the overall system requirements can be met.

The T*able 1* lists the set of criteria and the value set devised for comparison of networking technologies for their capability to meet the requirements for a given application.

Results of the study

Each network technology was evaluated for the criteria with grades being awarded as detailed in the *Table 1*.

The results were compiled into radar diagrams for analysis and comparison. These diagrams are as given in the figures below.

The radar diagrams were selected as these provided an easy way to depict multiple attributes on a single diagram. This also allowed creation of overlapping diagrams allowing the requirement versus capability to be mapped.

The *Figure 1* shows the perceived requirements of the vehicle bus indicated on the radar diagram. Similarly, the *Figure 3* indicates the perceived requirements of the train bus.

The *Figure 2* shows the requirements of vehicle bus overlaid with the features provided by CAN bus as vehicle bus. The gaps that need to be addressed or mitigated are now easily identified.

This exercise has been repeated for Ethernet as a train bus and the results obtained are indicated in *Figure 4*.

This analysis helped in understanding the differences in requirements of vehicle and the train bus as perceived by the system developers. In addition, it provided a clear view of the shortcomings of the technologies that need to be addressed in the development of a network communication stack to provide a robust train communication network.

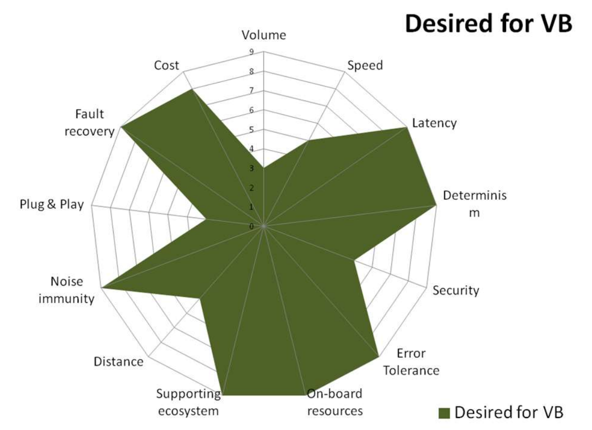

Figure 1: Required Characteristics for Vehicle Bus

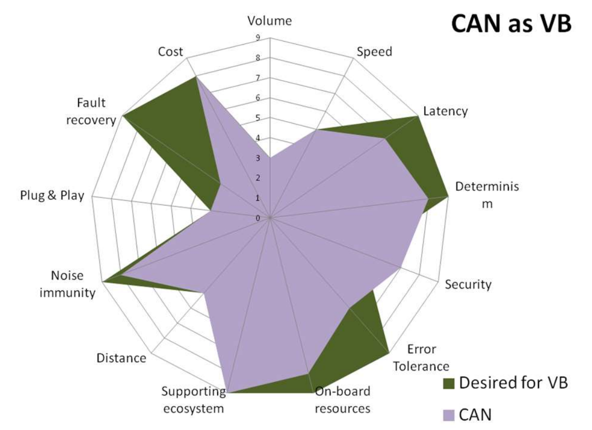

Figure 2: CAN as Vehicle Bus

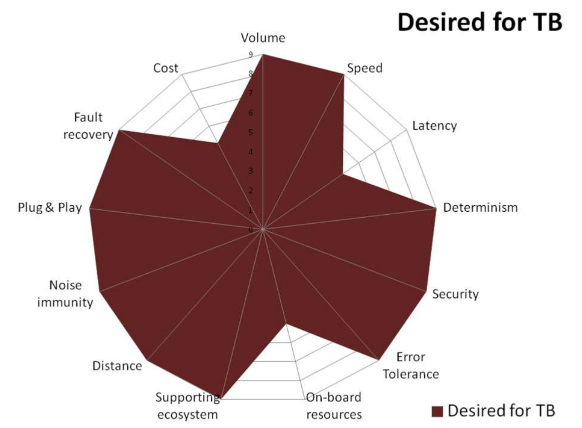

Figure 3: Required Characteristics for Train Bus

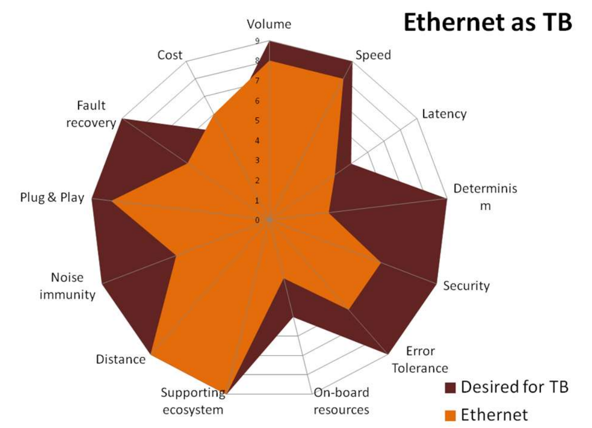

Figure 4: Ethernet as Train Bus

Network Topology

A model of the network topology was the next important decision.

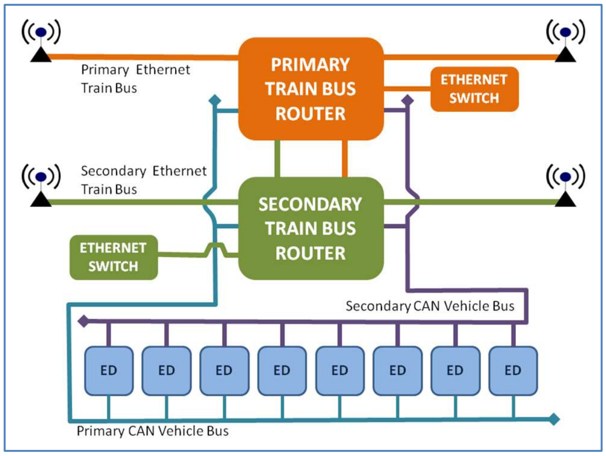

Figure 5: Proposed network topology in a vehicle

The prime consideration in the making of the topology layout was to ensure that there is no single point of failure. This was drawn from the need that all vehicles shall provide a '*limp home*' feature in case of equipment failure to enable the crew to clear critical sections of track.

This requirement needed redundant networks.

The concept design of the network was developed as detailed in the *Figure 5*. It uses two Ethernet networks as train bus and two CAN buses as the vehicle bus.

The Ethernet Train Bus

The two Ethernet buses are termed as the Primary Ethernet Train Bus (PETB) and the Secondary Ethernet Train Bus (SETB).

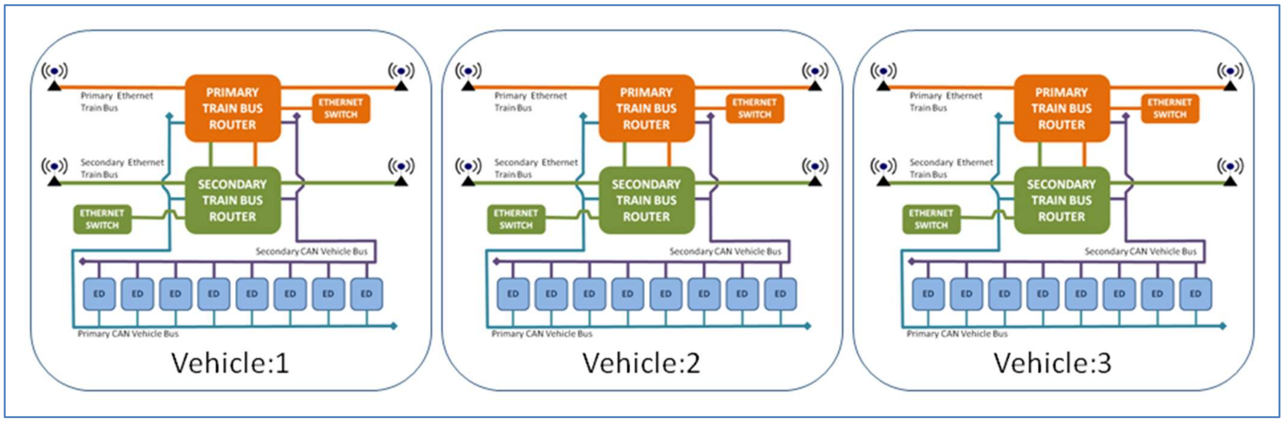

Figure 6: Proposed network topology in train formation

Both the Ethernet buses are planned to be deployed using guidelines of structured cabling in two tiers i.e. back connection between routers and switches connected to the backbone to provide the field connections.

It is proposed to use the PETB for Train Control and Monitoring Systems (TCMS) applications and the SETB for the passenger infotainment systems. The SETB is also proposed to function as a failover redundant bus for PETB. This shall be done by suspending the passenger infotainment systems in the case of failure of PETB.

A significant challenge is the selection of the connection assembly for inter-vehicle connections. This problem has been reported in the project undertaken by the East Japan Railway Company (*Reference 4*).

The problem is expected to be more severe on the Indian Railways as the operating conditions require frequent changes in train configurations. This shall necessitate frequent connections / disconnections thus reducing connection reliability.

It is planned to explore wireless options as replacement to wired inter-vehicle connections.

The CAN Vehicle Bus

The proposed concept design used two CAN buses designated as the Primary CAN Vehicle Bus (PCVB) and the Secondary CAN Vehicle Bus (SCVB). Both the buses are proposed to be used simultaneously thus providing the required redundancy.

Failure of any one bus shall only result in the crew being informed. In the event of failure of any one CAN bus full control communication shall be available hence meeting the requirements for limp-home feature.

The challenge in using CAN as the vehicle bus is caused by the very nature of the arbitration scheme. As the network traffic levels increase the nodes lower in the addressing scheme are less likely to be able to transmit. Therefore allocation of addresses in the most optimal manner is essential. The other option is to use a time based communication methodology that ensures that all nodes communicate atleast once in a cycle or after a fixed number of cycles, akin to a heartbeat.

The challenge is to find the optimal scheme suitable for every condition. These are the issues that have been identified for the software development phase.

Equipment and Software development

This project development is still a works in progress.

The project plans to develop the Ethernet train bus routers and equipment for CAN based vehicle bus.

The Ethernet routers are planned to be developed using single board computers running embedded

Linux. For the CAN bus only a software stack is planned as most controller architectures have CAN interfaces built-in. A dedicated CAN interface module card for the vehicle bus connectivity shall be planned if required.

It is planned to use open source stacks and customize these to provide network communication services required for TCN as detailed in the IEC 61375 and the UIC 556.

The following have been identified for development of communications software:

1. Software for the Ethernet/CAN Train Bus Routers
2. Software for the CAN Bus Interfaces

Software for Train Bus Routers

TCP/IP software stack is proposed for the Ethernet based train bus. This is easily implementable and is continuously under development.

A large number of embedded Linux based open source TCP/IP router implementations are easily available. This provides a rich resource for selection of a suitable start point.

A particularly interesting candidate is the open source firmware (see http://dd-wrt.co.in) used on the Cisco-Linksys Wireless Router WRT54GL. This provides support for wireless bridging which can be used for wireless inter-vehicle connections.

Some of the additional features to be included in the software for the routers are expected to include the following. (The list is not exhaustive.)

- PETB and SETB failure monitoring with automated switchover to the redundant mode configuration of the train bus.
- Function as bus masters of the PCVB and SCVB with failure monitoring and automated switchover to redundant configuration of the vehicle bus.
- Integration of TRDP of the *TCNOpen Project* (see http://www.tcnopen.com) for enabling real-time communication on Ethernet train bus.

Software for CAN Bus Interfaces

Although a number of CANOpen communication stacks are available both in proprietary domain and as open source, these are not directly adaptable for use due to the chosen network topology. Therefore some customization is expected.

Inclusion of the CANOpen as consist network (CCN) in the June 2012 revision of the IEC standard for TCN (IEC-61375-3-3) has provided a major fillip. It is expected that a number of specialized protocol stacks implementing the CCN requirements shall soon be available. However, these may not be available as open source, and hence may not lend to customization. Such proprietary stacks can be expensive to deploy.

It is planned to proceed on development of the protocol stack for implementation of CCN services albeit slowly and closely following the developments in the industry.

Cost comparison of proposed solution

The cost of implementation of TCN on the MVB and WTB technologies described in the IEC61375:2007 was one of the reasons for initiation of this project. The following table provides a comparison of cost of implementation on a hypothetical twenty-four coach Indian Railways train with two locomotives. It is assumed that each locomotive shall have 30 end-devices on the vehicle bus and coaches 20 each. The cost of passenger infotainment systems are excluded as these cannot be deployed on the older TCN technology.

The cost estimates for TCN with WTB-MVB in the table are based upon rates quoted to Indian Railways by manufacturers of such equipment.

The cost of TCN with ETB-CCN are estimated using cost of similar COTS equipment increased about five times for arriving at a cost of equipment suitable for the harsher environment onboard railway vehicles.

Note: The multiplying factor of 5 times has been taken based on the experience in development of similar equipment for application on locomotives. The equipment designed for meeting the environmental conditions is normally seen to be 3 to 5 times in cost as compared to regular commercial grade equipment.

TCN with WTB-MVB interfaces						
Veh. Type		**WTB-MVB Equip.**		**MVB Equip.**		**Total**
Type	**No.**	**Qty./Veh.**	**Cost**	**Qty./Veh**	**Cost**	
Loco	2	1	$ 5,700	30	$ 860	$ 63,000
Coach	24	1	$ 5,700	20	$ 860	$ 5,49,600
					TOTAL	**$ 6,12,600**

TCN with ETB-CAN interfaces						
Veh. Type		**ETB Equip.**		**CAN Equip.**		**Total**
Type	**No.**	**Qty./Veh**	**Cost**	**Qty.**	**Cost**	
Loco	2	2	$ 2,500	60	$ 50	$ 16,000
Coach	24	2	$ 2,500	40	$ 50	$ 1,68,000
					TOTAL	**$ 1,84,000**

Table 2: Comparative Costs (Figures are approximate)

Note: The equipment for TCN on ETB-CCN is estimated to be double of that for TCN with WTB-MVB due to the requirement of the secondary failover topology.

Setting up of conformance testing facility

Lack of widespread conformance testing facilities also contributed significantly to the cost of deployment of MVB and WTB technology.

In order to avoid the proposed TCN system having the similar problems, setting up of a conformance test facility has been included in the scope of the project.

The conformance test facility is planned to model a full train of 26 vehicles normally consisting of 24 coaches and 2 locomotives. The train composition is planned to be configurable permitting a variety of configurations to be modeled.

The facility shall be setup using COTS hardware, using desktop computers, laptops and low cost microprocessor boards. The core functional requirement of the planned setup is to provide facilities for testing the communication systems in all layers of the OSI model.

One of ambitious aims of the project is also to achieve application layer level interoperability, which at this stage of the project, appears to be on the distant horizon. Nevertheless, the conformance testing facility planned as a part of the development exercise includes this requirement.

This is required to enable development of modular equipment which could be replaced one to one without significant modifications in the overall control systems.

Concept compared to IEC61375:2012

The project was initiated prior to the issue of the revised edition of the IEC standard. Therefore the relevance of the project after the release of the new TCN standard has been debated. The significant issues are as follows.

1. The new standard provides for Ethernet as a Train Bus in addition to the WTB. This concept model is in conformance.
2. CANOpen is used as a Vehicle Bus in the form of CCN. The concept model conforms.
3. The concept model differs from the specified network topology by proposing dual vehicle bus.

The above paragraphs indicate that the concept model almost tallies with the requirements of the revised standard.

The need for this project is now felt evermore as the IEC standard only states the requirements. The implementation details are still open and as seen earlier, proprietary solutions conforming to the standard are likely to be developed. These are not expected to be inter-operable.

This project plans for providing the network building blocks for TCN and also aims to develop conformance testing facility that shall include interoperability testing.

Relevance for high speed rail systems

Development of a robust TCN for Indian Railways is an infrastructural requirement for rolling stock for high speed rail systems. The modern Train Control and Monitoring Systems need a train wide network to ensure all required parameters are continually captured and processed in real-time for ensuring safe train operation.

The *UIC Code 660 (Measures to ensure the technical compatibility of high-speed trains)* details the requirements of high-speed trains. Some of the important requirements necessitating the need of TCN are discussed in the following paragraphs.

The code limits the axle loads of high speed trains. In order to generate the required tractive effort necessary acceleration, the powered axles have to be distributed throughout the train consist. This configuration needs control of distributed traction systems, requiring a communication network.

The code calls for each bogie to be monitored for stability and also for monitoring the axle box temperatures. These requirements specify automated reduction of power and speed or application of brakes. Thus a communication and control system is required to sense remote parameters and dispatch the same to a processing unit to warn the crew and also initiate appropriate response.

Similarly, door controls need to be interlocked with the traction controls. This requires control and feedback from each door on the trainset, essentially requiring a network.

The above are just a few examples where regulations create requirements for a reliable train control network. The requirements increase many fold when passenger safety and comfort are considered.

Limitation of the concept

This project described in this paper is in the initial stages of progress. Many of the concepts detailed here are subject to changes due to improvements or impracticality likely to be encountered during development.

The development of the Train-18 Trainset has also resulted in the development of the indigenous TCMS based on the IEC 61375-2012 ETB-ECN topology. This is an incredibly significant (but hidden) development which huge of scope of deployment.

This development serves well for trainsets with distributed traction systems. But it seems to be an overkill for the traditional trains with Hot-on-Traction. Such trains need a vehicle-wide and train-wide digital network infrastructure which will enable the current smart devices to communicate and form the foundation for deployment of smarter control systems.

The system concept described in this paper is a suitable for such applications.

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