Brief on Communication-Based Train Control (CBTC) Systems

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Abstract: ***A communication-based train control (CBTC) system Communications-based train control (CBTC) is a railway signalling system that makes use of the telecommunications between the train and track equipment for the traffic management and infrastructure control. By means of the CBTC systems, the exact position of a train is known more accurately than with the traditional signalling systems. This results in a more efficient and safe way to manage the railway traffic. Metros (and other railway systems) are able to improve headways while maintaining or even improving safety. In this paper a brief overview of various components of CBTC and their interfaces have been proposed in detail.***

Keywords: Communication-based train control (CBTC), Automatic Train Control (ATC), Automatic Train Supervision (ATS)

1. Introduction

iCBTC system architecture framework consists of several essential components that work together seamlessly to ensure the safety and efficiency of train control. These components include trackside equipment like transponders & balises, onboard equipment such as train control units and communication devices, operation control center for monitoring and command dissemination, a robust communication network, and user interfaces for operator control. The architecture enables precise train localization, automated train protection, route optimization, and real-time communication between trains and the control center. It also supports emergency handling, capacity optimization, and energy efficiency, contributing to the overall reliability and performance of rail transit systems.

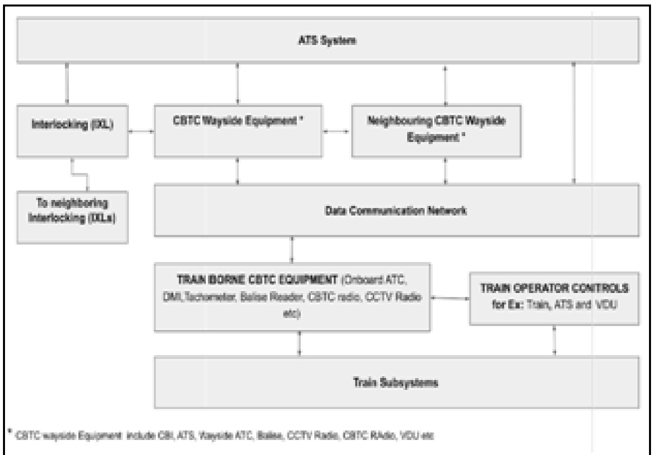

Figure 1: Architecture of CBTC system

The CBTC system's architecture shall be guided by several key goals and objectives to ensure its efficiency, safety, and effectiveness:

- Safety: The architecture prioritizes safety, aiming to prevent accidents and mitigate risks by implementing robust safety features and redundancy mechanisms.
- Scalability: It should be scalable to accommodate varying levels of railway traffic, from small metro systems to larger regional networks.
- Reliability: The system architecture strives for high reliability, minimizing downtime, and ensuring continuous operation even in the face of component failures.
- Performance: Architecture goals include optimizing system performance to maintain precise train control, minimize delays, and enhance overall railway efficiency.

2. Subsystem Overview

This section shall explain details of subsystems of i-CBTC system with their subsystems, functionalities & interfaces.

Computer Based Interlocking

CBI monitors the area of line under its supervision continuously and sends information regarding the state of traffic and the trackside devices back to the ATS and to the wayside ATC (RATC) as well as to adjacent CBIs.CBI is supplied on a geographical (regional) basis and consists of a cabinet with processors and network equipment. The object controller cabinets or input output cards and corresponding wayside device interface modules are also considered part of the CBI subsystem equipment.

CBI Components

The CBI system shall consist of the following components:

- Processing Unit is composed of a 2oo2
- Microprocessor based interlocking equipment to read input from the yard and from ATS/VDU control terminal including wayside CBTC system and process them in a fail-safe manner as per the control table and generate required outputs. Cycle Time and Response Time of the Microprocessor, to read and process the Input shall be fast enough to ensure Safety and avoid any apparent Delay.
- I/O interface Unit is composed of interface unit which shall interface with CBI to drive points and signals using relay interface and vital control of the trackside objects. It is used to provide functional safety as part of

railway signalling interlocking. It consists of I/O units and relays. CBI shall pass command through I/O units to drive points and signals using relay interface.

- Maintenance terminal (MT) - The maintenance terminal provides a user interface for maintenance personnel to monitor and configure the system, perform maintenance tasks, troubleshoot problems, diagnostic, alarms and events. The MT shall log all Events, Commands, Functions etc which should be Date and Time stamped, for enabling complete analysis of Safe and proper functioning of the System.
- Data Logger (DL) :The data logger(optional) shall chronologically monitor and record the status of various field functions like track circuits, points, signals, operator's push buttons/switches (digital Inputs) and level of various analog signals like DC and AC supply voltages, Axle counter signals etc.
- Video Display Unit (VDU) – Video Display Unit is a PC based application Software. VDU is connected to CBI through Ethernet/ OFC interface. Operators can issue commands using the simulated buttons on the VDU screen. It sends the command and receives the yard status and displays the same on the VDU screen. The Control Terminal with VDU Display shall allow Trains to be controlled on the Section, in case of failure of the LATS/CATS System.
- Relay Rack – Relay rack shall be available along with required number of approved types of Relays. Relays shall be such that they can operate/receive Status information from outdoor Signalling equipment (Signals, Points & Axle counter sections etc.) Without any modification / change in the design of outdoor Signalling equipment. The relays shall be centralized in the Station Equipment Rooms.

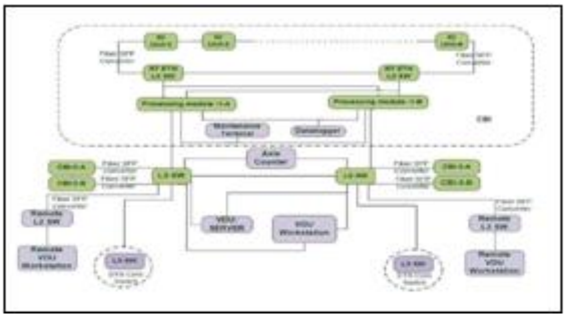

Figure 2: Block Diagram of CBI System

Vehicle Automatic Train Control (VATC)

The on-board ATC (VATC) provides the basic train protections of positive train separation, safe speed determination, and position determination. This determination is based upon the train's actual situation and the allowed path established by the wayside ATC (RATC). The VATC constrains the train operator's possibility to select operating modes as per the operation of train & preconditions. It also performs the vehicle functions of train initialisation, train-line control, and correct side door enable. The VATC receives conflict points and speed limit restrictions from the RATC and processes this data to direct the devices which enable train movement. It responds to the RATC with its train location and other train status information. Key ATO functions performed by VATC provide train speed regulation; precision stopping, dwell times, door control, and diagnostics, within the ATP supervised pre- established safety principles. The ATO train control can be provided either with a driver in attendance (ATO Mode) or without a driver (UTO Mode).

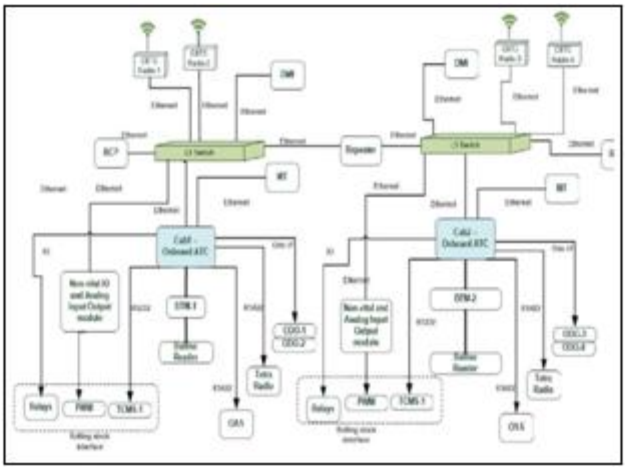

Figure 3: Block Diagram of Onboard ATC System

VATC Components

Two VATC system equipment are installed on each train onboard & each VATC is composed of 3 main parts and peripheral equipment:

- Processing Unit is composed of a 2oo2 processing platform performing safety critical functions for automatic train protection (ATP) & an high availability redundant processing platform performing automatic train operation (ATO) and non-vital carborne functionality (DMI) and interfaces to the Propulsion/Braking/Doors (RS) device;
- I/O interface Unit is composed of interface unit for interfacing with VATC which are responsible for managing vital and non-vital I/O. Safety relay boards for the rolling stock interfaces &non-vital relay boards for the rolling stock interfaces
- Peripheral Equipment: Following peripherals equipments shall be connected with VATC:-
- DMI (Driver Machine Interface) for displaying VATC commands & status. o Tachometer / Speed Sensor for speed & wheel rotation measurement of Tag/Balise reader modules for train position determination;
- Communication Unit is composed of a PMC board which is responsible for communication with the Mobile Radio system, on-board Ethernet communication, speed sensor input, and ATP/ATO maintenance;
- Maintenance terminal (MT) - The maintenance terminal provides a user interface for maintenance personnel to monitor and configure the system, perform maintenance tasks, and troubleshoot problems.
- Radio Communication Processor (RCP)- This module is used for transmission & reception of messages from on-board ATC to wayside ATC through radios and vice versa.

This interfacing is recapped in the functional block diagram in figure below:

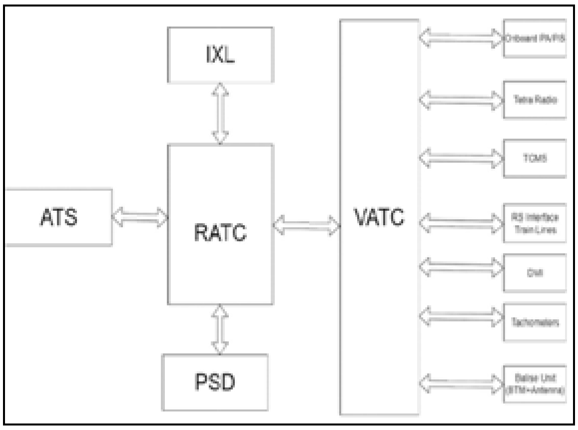

Figure 4: Interface Diagram of ATC System

The VATC system shall interface with following equipment, systems & subsystems: RATC system

- On-board Passenger Information System (PIS)/ Passenger Announcement System (PAS)
- Tetra Radio
- Train Control and Management System (TCMS)
- Tachometer
- Balise Reader
- Driver Machine Interface (DMI)
- Rolling Stock
- Radio Communication Processor (RCP)

Region Automatic Train Control (RATC)

The Wayside/Region ATC subsystem is responsible for enforcing train speed restrictions and providing real-time track condition information to on-board trains. The Region ATC (RATC) or wayside ATC is allocated for control purposes into geographically separate areas called regions. Each RATC performs all the vital functions to control the safe movement of CBTC trains within, and adjacent to, its boundaries. It monitors train positions, enforces speed limits, and ensures compliance with safety rules. Wayside ATC communicate with on-board ATC systems by passing target point, movement authority and provide critical information for safe train operations.

The wayside ATC's primary function is managing the movement authority for each train in its area of control and it does this by tracking of the train occupancies throughout its region, receiving (over the radio-based subsystem) train borne VATC-generated position data from vehicles in the area and from this information calculates stopping points to send to the VATC beyond which the train shall not pass. Each RATC is also connected, via the COM DCS subsystem, to its adjacent RATCs, as well as to its corresponding region CBI and ATS subsystem.

Wayside ATC system shall be SIL-4 system and it consists of two sets of two out of two hardware architecture with identical/diverse hardware and identical/diverse software. Both wayside ATC (active and hot standby) units perform functions in parallel. In addition, hot standby processor(s)/ systems using similar 2 out of 2 hardware and software architecture shall be compatible with the facility of automatic changeover. Failure of hardware will facilitate automatic changeover in a fail-safe manner without affecting train operation. The train operation shall not be affected and there shall be no unsafe occurrence due to switching over from main system to standby system. It shall also ensure that any fault, which affected the main processor/system, does not affect the hot standby processor/system.

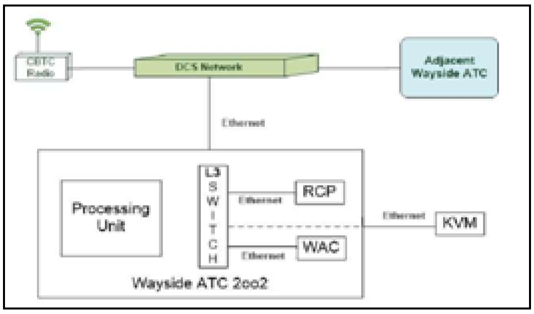

Figure 5: Wayside/ Region ATC System

RATC Components

Wayside ATC Subsystem shall consist of Processing Unit, Maintenance Terminal (KVM type), Wireless Line Controller (WLC) & Radio Communication Processor (RCP) so wayside ATC hardware shall be compatible to communicate with each module. The processing unit shall be directly connected to switch, MT and Event logger. Adjacent Wayside ATC's, CBI,

ATS, CBTC radios shall be connected through DCS network. Following shall be

- Processing Unit is composed of a 2oo2 processing platform performing safety critical functions for automatic train protection (ATP) & a high availability redundant processing platform performing automatic train operation (ATO) and non-vital carborne functionality (DMI) and interfaces to the Propulsion/Braking/Doors (RS) device;
- Maintenance terminal (MT) - The maintenance terminal (KVM) provides a user interface for maintenance personnel to monitor and configure the system, perform maintenance tasks, and troubleshoot problems.
- Radio Communication Processor (RCP)- This module is used for transmission & reception of messages from wayside ATC to on-board ATC through radios and vice versa.
- Wireless Access Controller (WAC)- It provides a seamless roaming experience and authentication for access points which are distributed in wireless networks.

The RATC system shall interface with following equipment, systems & subsystems:

- Adjacent RATC system
- CBI subsystem
- ATS subsystem
- Maintenance Terminal
- VATC subsystem
- Platform Screen Door (PSD) system
- Radio Communication Processor (RCP)

The RATC system shall interface with following equipment, systems & subsystems:

- RATC system
- CBI system
- Passenger Information Display System (PIDS)/ Passenger Announcement System (PAS)
- Tunnel Ventilation System (TVS)
- Master Clock
- Traction Power System

3. Conclusion and Future Work

A CBTC system, which operates within a metro/railway infrastructure and interacts with various internal and external entities. In this paper, we have proposed understanding of its context for comprehending its role and impact. i-CBTC system integrates multiple subsystems to enable seamless train control and monitoring. It ensures safe train movements, regulates train speeds, coordinates interlocking functions, and facilitates communication between wayside and on-board components. For future work, we plan to extend the proposed framework to consider more advanced train control models for safety purpose. Implementation of various train our algorithm in real systems is part of our future work as well.

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