Microservices-Based Approach for Intelligent Railway Control System Architecture

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The symmetry between customer expectations and operator goals, on one hand, and the digital transition of the railways, on the other hand, is one of the main factors affecting green transport sustainability. The concept of an intelligent railway controller (IRC) is introduced as being a piece of cloud software responsible for the control and optimization of railway operations.

railways control systems automation microservices

1. Introduction

One of the most important aspects of transport development, which coincides with the global challenges, is sustainability. Among the different transport modes that make a mobile society sustainable, rails travel represents the most environmentally oriented area due to their small carbon footprint. The sustainable development of railway transport depends on the possibilities of symmetry between the requirements for highly reliable, safe, and secure services, as well as efficient and productive operation, on one hand, and digitalization, which drives new technologies in the rail industry, on the other hand.

The European Railway Traffic Management System (ERTMS) is a key enabler of the digitalization and sustainable transition of railway transport. ERTMS is a European standard designed to achieve interoperability throughout Europe and provide higher performance, increase efficiency, and improve track utilization and customer experience [1][2]. ERTMS has two components, namely the European Train Control Systems (ETCS), which comprise the core signaling and train control systems, and GSM-R, which will be inherited by the Future Railway Mobile Communication System to provide stable, secure, and reliable connections.

ERTMS/ETCS Level 3 is a train control system wherein movement authorities are generated at the track side and transmitted to the train via radio communication. This model enables continuous supervision and control of train speeds through communication with the trackside ERTMS subsystem. This process makes it possible for trains to run in moving blocks closer together while maintaining safety requirements and, thus, increasing the track capacity [3]. ETCS Level 3 has the potential to allow considerable infrastructure saving and address capacity constraints. ETCS Level 3 is still under development, and multiple issues have to be addressed before it can be operationally implemented. Highly reliable radio communications and train virtual coupling are two problems, the solutions to which will enable capacity increases and open the door to further automation.

The application of artificial intelligence (AI) in railways can foster the deployment of ERTMS in several areas, including predictive trackside maintenance, traffic management, energy efficiency, etc. [4]. The integration of AI and machine learning (ML) with Internet of Things (IoT) sensors in engines, brakes, wheelsets, and coaches has the potential to improve safety and reliability, and deploying sensors across trackside systems can empower proactive maintenance [5][6].

2. The European Railway Traffic Management System (ERTMS)

The challenges facing the development of the ERTMS, including its implementation, safety, communication interoperability, human factors, and the diversity of formal methods, languages, and tools for modeling, verifying, and validating ERTMS products, were discussed in [7].

Signaling systems play an essential role in the control, supervision, and protection of safe train movements, and their availability influences the railway system's performance. The railway networks have a reserve for lower maintenance costs, more availability, and capacity if non-centralized signaling systems are considered. Bearing in mind that the decentralized solutions used for railway signaling systems increase their complexity and inherent safety requirements, it becomes evident that safety validation, which is carried out using a system of methods, is necessary. The approach that is widely adopted by the industry is scenario-based testing, though its sufficiency to assure the necessary safety level of the complex signaling systems is in question. An alternative means of verification, which is both rigorous and already used in the railway domain, is formal verification. However, despite the successful applications of formal methods for decentralized railway signaling, the steps taken in this regard have been limited.

A formal model that validates the principles of ETCS Level 3 was presented in [8]. The impact of the capacity of different signaling systems was investigated in [9], where the comparative analysis showed that the implementation of hybrid ETCS Level 3 solutions can improve the capacity of high-density commuter lines. In [10], the authors proposed a methodology that could be used for formal modeling, verification, and performance evaluation of moving block systems. In [11], a modular and extensible architecture for testing a moving block signaling system was presented, wherein trains received instructions to move to a specific position on the track, in contrast to the fixed block signaling method. In [12], the authors presented an analysis of the railway's capacity using high-performance ERTMS signaling systems, considering the effects of route congestion conflicts at the railway stations and delay propagation. The effects of an ERTMS speed profile filtering on the train driver's braking behavior, running time, and workload were studied in [13]. In [14][15][16], the authors presented approaches that enable the formal modeling and verification of a moving block system in ERTMS Level 3, which preserves the safety properties. The experience gained from the above-mentioned studies enables the identification of future research goals to improve the formal specification and verification of real-time systems, as well as the recognition of some limitations concerning the usage of formal methods and tools in the railway industry. A formal method for stepwise development and model checking of state transition systems that represent the behavior of interlocking system models was presented in [17]. A control scheme for distributed multiple high-speed train control, which was based on an event–trigger mechanism, was presented in [18]. In [19], a restructuring scheme of railway signaling systems that may be used to improve the process of engineering, construction, commissioning, and operational safety was described. In [20], the authors analyzed the principles of railway signaling system design and applied a comprehensive approach that considers railway stock parameters and infrastructure facilities. In [21], the author proposed a multi-agent technique to optimize the scheduling of the virtual coupling of trains. In [22], an IoT device was proposed as part of a signaling system, which may be used to monitor and log data related to train movements. The problem with virtual coupling trains concerning capacity performances and potential gains over traditional signaling systems was addressed in [23]. The results of a comparative analysis showed that the biggest capacity improvements of virtual coupling relate to scenarios in which the trains use different routes. A model for the safety evaluation of railway traffic under particular conditions of uncertainty was proposed in [24]. In [25], a stochastic analysis of the safety of train movement during an earthquake was performed. An edge-computing-based platform for testing signaling systems on site was described in [26]. A virtual reality environment that assists in installing, updating, and maintaining railway signaling systems was presented in [27].

AI has the potential to play an important role in all areas of railway transport, including safety, security, autonomous control and driving, sustainability, transport planning, and passenger mobility. AI/ML applications may be used for both real-time control and non-real-time control. AI/ML applications may be used for automatic train protection (continuous train control to keep the speed restrictions), automatic train operation (speed regulation, station stopping, and train and platform door control safety), and automatic train supervision (supervision of train status, automatic routing selection, automatic schedule creation, and automatic system status monitoring) [28][29][30]. A method for AI-based automated train operation was described in [31]. The use of AI/ML could revolutionize predictive maintenance in railway transport by detecting equipment issues before they become critical [32][33]. An integrated method for the predictive maintenance of railway infrastructure, which is based on deep reinforcement learning and digital twins, was proposed in [34]. The adoption of AI is also well-suited to crowd control, customer service, delay prediction, freight and infrastructure monitoring, etc. [35][36]. A method for the intrusion detection of railway events in distributed vibration sensing, which was based on deep learning, was presented in [37]. An algorithm for railway traffic planning that may improve the system performance was proposed in [38]. An optimization method that used rescheduling strategies for freight railway operations and considered train delay times and priorities was proposed in [39]. The application of AI in scheduling high-speed train operations was illustrated in [40], where the authors studied passenger flow characteristics, train load rates, and train service quality. In [41], a project that studied the methods and models involved in the safe use of AI/ML in train movements, which is called safetrain, was presented in order to improve the safety and reliability of train operations. AI-based methods for reliable railway engineering that consider robustness and transparency have been investigated. The application of the concept of digital twins in railways was investigated in [42], where the authors proposed a workflow of digital twin design that considered specific requirements that lead to high reliability and safety.

3. The Concept of an Intelligent Railway Controller

The proposed control system architecture defines the railway management automation and orchestration (RMAO) platform that is responsible for the orchestration, operation, management, and automation of managed railway elements, such as trains and trackside equipment. The RMAO hosts the trackside functions of ETCS and automatic train service (ATS), also known as the traffic management system (TMS), as defined in the ERMTS/ETCS architecture. The functions related to the security and safety of all trains and monitoring of trackside equipment are the responsibility of the intelligent railway controller (IRC) and reside in the RMAO layer. The railway edge cloud is a cloud computing platform that provides an environment in which to run virtualized managed functions (IRC, trains, and trackside equipment).

The concept of IRC is introduced to enable the exposure of data and analytics to facilitate automation and improved resilience of railways. The programmability of IRC allows the onboarding of third-party applications to implement different automation and management use cases. The proposed innovative intelligent architecture defines two kinds of IRC: one type that operates in non-real-time in more than 1 s, which is named time-tolerant IRC (TT-IRC), and another type that works in a control loop from 10 ms up to 1 s, which is named time-sensitive IRC (TS-IRC). The TT-IRC is a part of the RMAO and provides functionality that leverages data-driven approaches and analytics to improve railway operations. It controls the railway elements through the TS-IRC via policy guidance and manages the ML model workflow. The R1 interface between TT-IRC and TS-IRC is used for policy management and provisioning of enrichment information. The TT-IRC runs applications (ttApp) that provide value-added services for the inspection of railway lines, damage detection, predictive maintenance, and passenger flow analysis. The TS-IRC hosts applications (tsApp) used in driver assistance systems, such as driving and braking control, collision protection systems, and the enforcement of TS-IRC policies. More details about the R1 interface between TT-IRC and TS-IRC can be found in [43].

The TT-IRC can access external data (enrichment information) that can be used for train control and track monitoring. It uses ttApps to analyze different information and generate policies, such as policies for the control and optimization of train movements, generation of information, performance of data analytics, AI/ML model monitoring, and AI/ML workflow support. The TT-IRC exposes services, such as data sharing and access to data for ttApp applications, via an internal interface, e.g., to perform ttApp management functions (mitigation of ttApps conflicts) and service exposure functions (service registration and discovery, authentication, authorization, etc.).

Figure 1 shows the overall view of the service-based TT-IRC architecture.

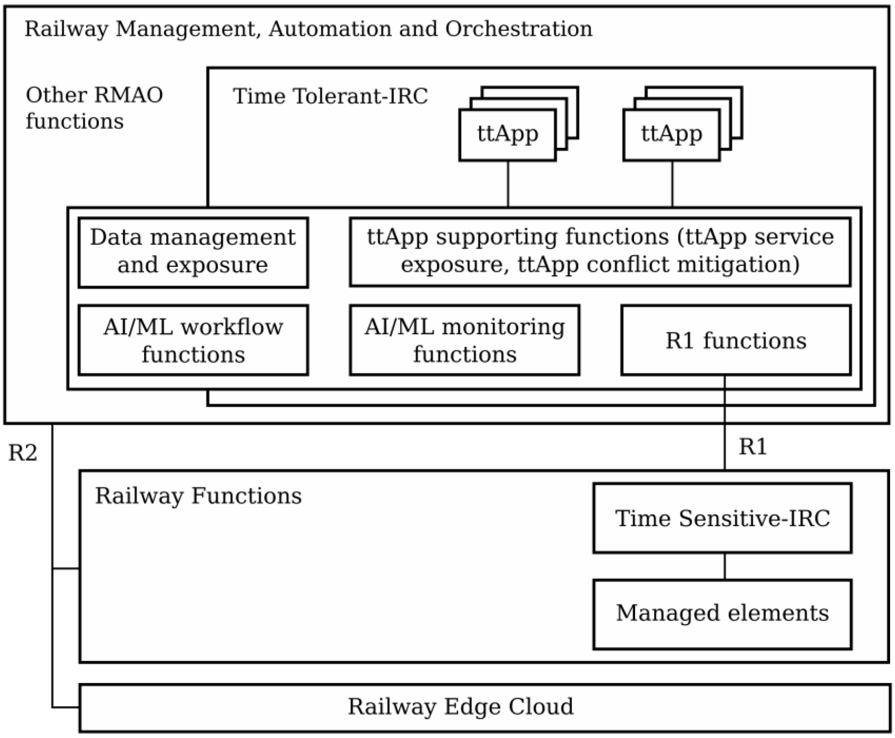

Figure 1. Overall view of the service-based TT-IRC architecture.

The design of the TT-IRC may follow the principles of the microservice architecture, whereby the TT-IRC functions are designed as RESTful services. REST stands for representational state transfer, which is an architectural style used in distributed systems. The main concept in REST is the resource, which represents any physical or logical entity. The resource is uniquely identified based on its uniform resource identifier (URI), and it is manipulated using HTTP methods: GET is used to retrieve information about the resource, POST is used to create a new resource, PUT is used to update the resource information, and DELETE is used for resource removal.

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