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A Structured Standardization-Oriented Approach to Modular Railway Monitorization

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Abstract

Better railway infrastructures, faster trains, and safer transportation of people and goods are a must. Nevertheless, despite considerable advancement in standardization, communications, sensing equipment, programmability, and data representation, monitoring of railway systems is still a daunting task, relying on closed solutions, tailored for each specific case. This paper provides a brief overview of the state-of-the-art of railway communication standards, instrumentation, and monitoring, highlighting the benefits and limitations. Additionally, it proposes a way forward that can open new perspectives for open, modular, and effective railway monitorization, with a high potential impact on the railway industry.

Keywords: railway communication standards, smart railway maintenance, railway instrumentation, railway monitoring, software-defined railway monitorization, railway management protocol.

1 Introduction

In an era characterized by increasing urbanization, escalating environmental concerns, and international global connectivity, the importance of rail transportation as a sustainable mobility solution has never been greater [1]. As cities continue to grow, and as European and other directives for the reduction of air travel/carbon emissions are enforced, it is necessary to consider and accommodate the increasing use of railway systems, which become central to worldwide transportation. Investments in high-speed railway systems are being made in every part of the globe, such as in most of Asia, the United States, and Europe, to ensure quick, efficient, low-cost, and environmentally friendly connections between cities. At the same time, these new lines open space for another type of railway traffic, with freight trains also experiencing a growing tendency. This change of paradigm, putting the railway first in terms of transportation options, is having considerable impact along the value chain, from suppliers to final users.

Until now, developing and rolling out open, standardized, and modular solutions for the railway industry was never a priority, and, even with high-speed trains, 2G communications were (and are still) used for many railway operations, even though 4G and 5G are largely deployed and with high coverage around the world. Emerging technologies and approaches are starting to become more popular among the industry, with the rise of Internet of Things for Railways and Big Data paradigms, but this is an area that is still incipient.

The use of legacy Global System for Mobile Communications - Railway (GSM-R) in the detriment of newer communication systems is mostly due to the closed, inflexible way in which most railway systems were built. Nowadays there is an effort to migrate to the use of newer technologies, thus allowing for more efficient operations, with the introduction of the European Railway Traffic Management Systems (ERTMS) [2], and the Future Railway Mobile Communications Systems (FRMCS) [3]. Both of these systems were developed in the scope of the European Union, to provide an "open railway environment" common to all concerned countries. However, there is still a long way to go before railway systems achieve the openness and standardization levels typical of modern computer systems and networks (i.e., solutions that are not specifically tailored for each railway system). Tailored solutions are always closed, inflexible, and costly. They lack robustness and are prone to errors, not having been subject to extensive scrutiny and testing.

In view of the above, in this paper we identify the main problems currently being tackled by the railway industry, as well as the main trends towards tackling those problems. In addition, we propose a framework to overcome the main factors that are preventing the railway industry from adopting a modular, structured, and standardization-oriented approach to an effective and efficient monitorization of modern and future railway systems.

This paper is organized as follows. Section 2 provides a brief overview of relevant problems and needs that affect current railway systems. Section 3 identifies recent standardization trends, which are expected to play an important role in the modernization of existing systems. In Section 4 we put forward a proposal for structuring the operation of railway maintenance systems, explaining its potential for modularization and standardization of railway systems. The conclusions are presented in Section 5.

2 Problemas and Needs

The railway industry is facing consistent growth, both in terms of passenger and freight, attracting the attention of key players, namely the general public, railway companies, investors, and governing bodies. However, the constant pressure placed on the railway sector increases the need to find effective solutions for monitoring all aspects of railway systems. As depicted in Figure 1, this growth puts additional stress on the system, which needs to be constantly monitored, using sensing equipment that generates considerable amounts of data [4] that must be reliably sent over communication channels. So, modern railway monitorization requires adequate solutions for data collection, local and remote data processing, and local and remote data storage, among others [5].

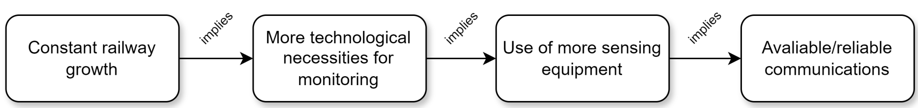

Figure 1: Simplified flow diagram representing the implications of railway growth on monitoring, sensing, and communications.

Throughout the years, considerable work has been done targeting the development of solutions for optimizing data collection and processing. Work developed around various sensors and techniques provided new insights into the status of the railway systems, such as the works developed by Chia et al. [6], Peinado et al. [7] and Barbosa et al. [8], which provided ways to gather data from specific railway sub-systems (both trains and infrastructure). Although the mentioned work is important, it provided partial views of the system, thus adding to the complexity of the overall problem, without actually solving it. In fact, by adding specific solutions for the monitoring of specific sub-systems, we increase the problem area, thus creating more need for a global and integrated way of data collection, communication, and processing.

As a consequence of the increasing amount of data generated by railway monitoring systems, communications are also affected. The use of GSM-R is being questioned by the community, but it is still the protocol commonly used. Works developed by Allen et al. [9], Hsiao et al. [10], and a more general overview from the 5G network performed by He et al. [11], showed that 4G and 5G networks (namely LTE-R) can bring interesting and much-needed features to the railway sector. With GSM-R still being used in many operations due to its proven reliability, change to 4G/5G is still progressively being made, especially in areas where bandwidth and latency are crucial.

3 Trends in Railway Communication

Nowadays, railways are facing several changes in various segments. In the communication segment, specifically, the major changes are in the *backoffice*, with newer standards being put forward and adopted. As already mentioned, in the railway industry, most of the communications still rely on the GSM-R, due to its proven robustness and reliability. Nonetheless, it is now clear that efficient monitoring requires gathering and exchanging large amounts of data, which is incompatible with the very low bandwidth of GSM-R when compared to 4G and 5G.

One of the major changes is related to the introduction of the Future Railway Mobile Communication Systems (FRCMS) [3], whose objective is to provide a unified, standardized communication solution for railway systems. FRCMS draws on the adoption of recent communication technologies, aiming at the replacement of GSM-R by what is called the Long-Term Evolution-Railway (LTE-R). Additionally, FRCMS will provide a platform for multiple systems to communicate, regardless of the underlying technologies. In the future, this standard will enable data to quickly flow between systems, reaching the correct players, independently of the country or system that receives it. Nonetheless, this paradigm currently focuses on existing legacy systems and not on add-ons that can be provided later in the lifecycle of the systems.

Along the same line, railML [12] is an open, XML-based data exchange standard, developed by railway experts to provide a way to represent and exchange information related to various railway systems, as illustrated in Figure 2. It is a scheme-based paradigm that, in this specific case, is used to describe information related to the systems, and not information provided by sensors. Thus, it can, for example, represent a segment of a railway track, with an identification, start, and end, but it requires some external way to transport another type of information. Nowadays, although this information that describes the railway system is important, it is insufficient when it comes to the evolution in terms of using sensing equipment to monitor the railway systems. Thus, using this strategy to standardize sensing equipment can be crucial to provide scalable and reliable monitoring for the various railway components.

Another relevant initiative is SFERA (Smart communications For Efficient Rail Activities) [13], a protocol developed by UIC to standardize communications between infrastructure and operator managers, specifically targeting the Driver Advisory System (DAS), IRS 90940 (Figure 3). SFERA aims at providing flexible and interoperable messages, formatted in XML, using Subset 126 (ATO-OB / ATO-TS FFFIS). Here, the idea is to provide a standard way to convey train status to infrastructure managers, using two communication paradigms: request/response, and event-based. Nonetheless, as with the previously mentioned initiatives, there is a lack of generality,

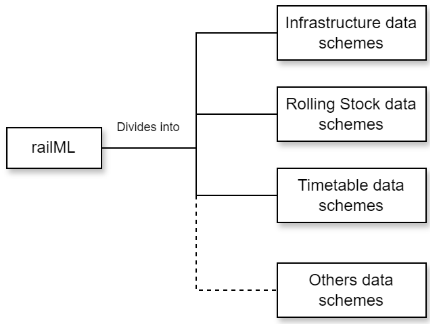

Figure 2: Diagram with the railML schemes. It provides various schemes in order to standardize communications between the systems. Adapted from [12].

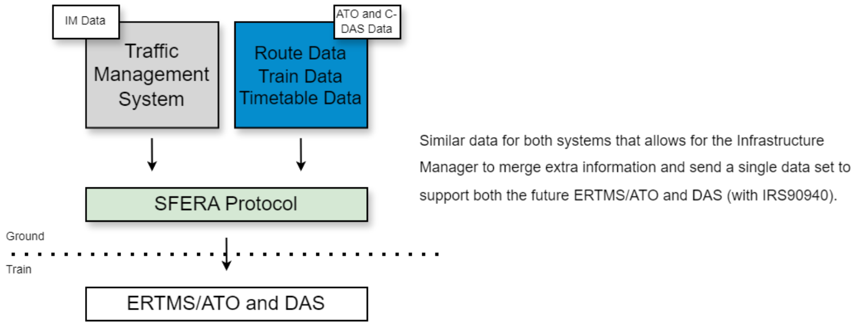

Figure 3: Overview of the SFERA protocol applied to the DAS. Adapted from [13].

as SFERA focuses on a specific part of the railway system, namely DAS.

Despite the limitations of the mentioned proposals, there is, nevertheless, a positive aspect in all of them: standardization. With the railway industry facing continuous growth, it is necessary to standardize the systems in order to ease the development and deployment of effective railway management solutions. However, these paradigms focus on specific railway sub-systems, with very specific benefits. Namely, in FRMCS, the objective is to introduce newer mobile networks in the railway sector, maintaining the current needs. With railML and SFERA, the aim is to provide specific schemes and standards to ensure interoperability and flexible communications for specific (i.e., niche) railway sub-systems. Policy-based approaches can be part of the solutions, as the one presented by Pencheva et al. [14], but they are insufficient to tackle the problems raised by the continuous growth in railway data. Hence, it is important to develop a global, integrating approach that can simultaneously allow for local views of sub-systems and global system views. Such an approach should be able to deal with all the needs of current and future railway systems, namely in what concerns data collection, data processing, and communication and, at the same time, not being an obstacle to the scalability, performance, openness, and robustness of railway maintenance, monitoring, and management systems. This is the topic of the next section.

4 The Missing Piece

Typically, current railway monitoring systems use tailored approaches and are implemented using a variety of protocols and communication systems. The used approach is anything but modular, scalable, and open, which poses several obstacles to the development of controlled, large-scale, and robust monitorization systems, despite the fact that the target railway systems are increasingly complex and critical. If we draw a parallel with the Internet and complex networked systems, one way of managing and controlling a large network or system is to use an approach inspired on the Software-Defined Networking (SDN) paradigm [15]. SDN is designed to manage large, complex networks, by defining various planes (Data, Control, and Application planes), with well-defined interfaces between planes and well-defined communication protocols, allowing for decoupling and providing more flexible management of the various network components. Applying this to the railway industry sector, Figure 4 shows the overall architecture of a proposed “railway SDN”, which we named Software-Defined Railway Monitorization (SDRm), in which different railway actors and protocols are presented [16].

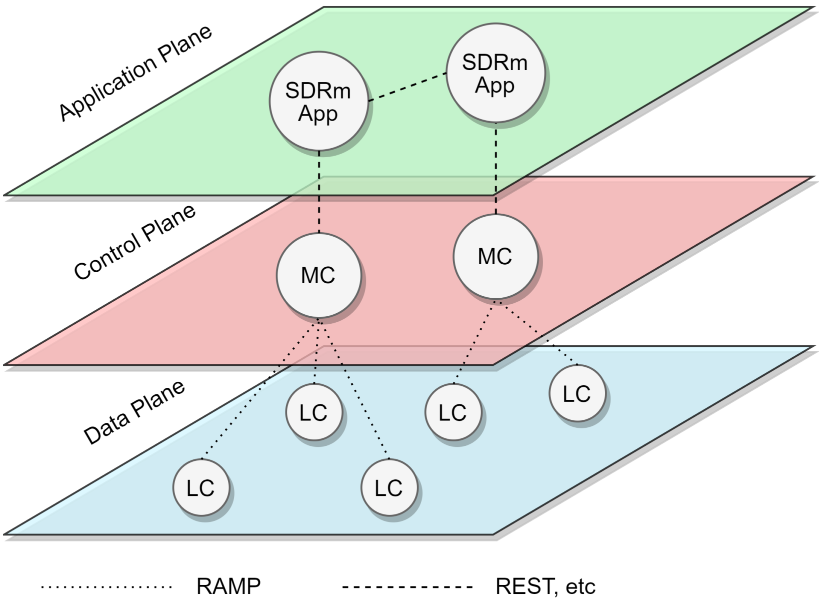

Figure 4: Layered view of the SDRm and respective actors.

In the Data Plane, the railway systems are equipped with a Local Controller (LC) that is responsible for collecting data provided by monitoring and sensing systems. Then, locally-processed and/or raw data is sent to the Control Plane, which then processes it in a Main Controller (MC). Main Controllers are intelligent systems able to detect problems and assess the systems in near real-time. Finally, in the Application Plane, third-party apps use the results to further explore other uses. Between the

Data and Control planes, there is a proposed protocol, which we named RAMP (RAilway Management Protocol), with the objective of providing a standardized, open way of communication between the Local and Main Controllers. Here, the purpose is to make sure that the controllers can communicate without problems, irrespective of the models, brands, and specificity of the involved sub-systems. With this approach, it is possible to develop scalable monitoring systems (involving many Local Controllers and several Main Controllers), with optimal performance. The development of independent modules for the various components, with well-defined interfaces, is also essential for the robustness and openness of any SDRm-based railway monitoring system.

As stated, the SDRm paradigm and RAMP protocol can provide a path to achieve the final objective of standardization. Hence, Figure 5 provides a small example of the use of the RAMP protocol. The idea of RAMP is to make use of a pub/sub-based application protocol (e.g., Message Queuing Telemetry Transport - MQTT [17], or Advanced Message Queuing Protocol - AMQP [18]) to define precise topics for communication between the Local and Main Controller. In this case, the use of the topics $/mc\_id/data/$ and $/lc\_id/alert/request$ would be the same for this example as for other usages. Moreover, also the data exchanged between the controllers is defined, with specific keywords being used for the communication. Among some of the keywords, it must inform where the systems are installed (rolling stock - RS, or trackside - TS), the location, identification, and type of RS or TS where it is installed (e.g., train service number, type of train, kilometer point, line, type of signaling, among others). There is also a mandatory payload subset when sending information that must contain several keywords, but it is also built to have custom content to fit the necessities of each usage. Besides that, RAMP is built to have a defined result table. It is based on the HTML response status and it is used to reduce the size of the information that is exchanged. For example, if a specific data returns an invalid status, the response message would have a code that indicates which problems were detected. This result table aims to consider various problems and it is built so it can be quickly and easily updated.

RAMP provides a specification and framework for each situation, from the first handshake to a disconnect. Moreover, it also defines the message formats and message exchanges. For the overall railway industry, providing systems with standardized monitoring can help with efficient data collection and processing, fixed communication settings, a clear definition of data exchange, quicker monitoring implementations, and scalable and interoperable solutions, among other characteristics.

5 Conclusions

In addition to being increasingly used, railway systems are getting larger and more complex, which points to the unavoidable need for better monitoring and management of such systems. Nowadays, efficient and effective monitoring involves large amounts

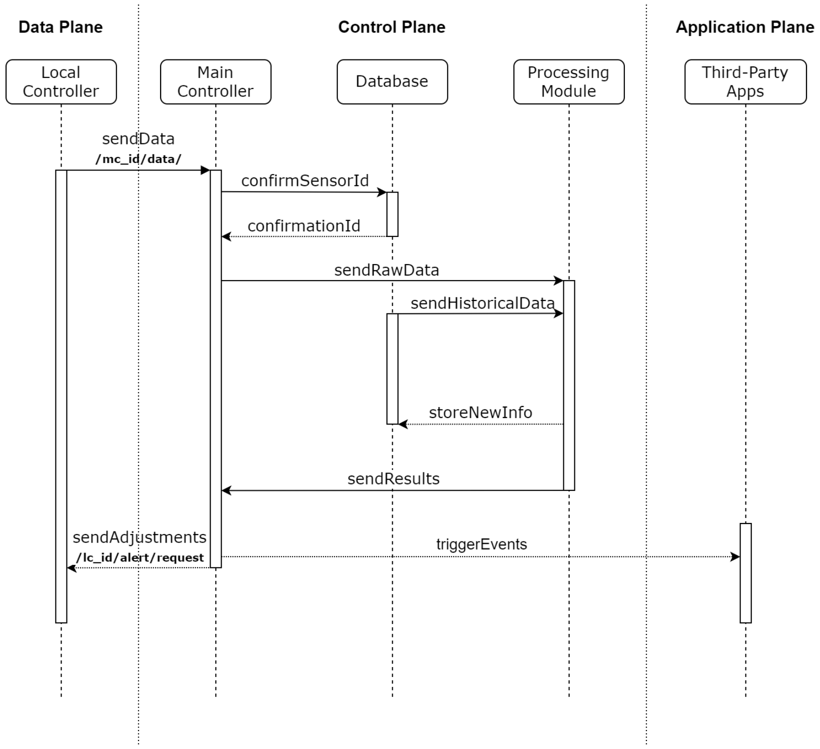

Figure 5: Sample sequence diagram showing interactions between planes.

of sensed data, high bandwidth and low latency for data transfer, and local and central processing for knowledge inference and extraction. These are not possible with closed, tailored solutions, as the ones used until now. Standardization and openness are, thus, a must.

In this paper, we have identified the main problems and some emerging solutions for railway systems monitoring, mostly centered on some specific sub-systems and on communications. The limitations of such systems were identified, and this served as motivation for the presentation and proposal of an approach to scalable, performant, open, and robust railway maintenance, monitoring, and management. Naturally, this is just a first step that must be explored and assessed in real railway systems. This is the main objective of our near-future research.

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