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Hi-dependable Wireless Monitoring Solution for Freight Management in Underground Work Sites

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Abstract

Many of the measures taken in underground work sites are collected manually and with the constant intervention of operators and maintenance staff. This may lead, in some cases, to errors and/or planning delays and as a result, to an increase of the final work costs. In the case of railway equipment inside tunnels, mechanisms for monitoring and management are scarce and usually insufficient for proper operation and they become critical during indoors construction work.
Therefore, it is necessary the development of a system able to immediately detect any problem in the train or in the tunnel infrastructure, react quickly and mitigate effectively the possible consequences.
In this context, the European project DEWI (Dependable Embedded Wireless Infrastructure) provides key solutions for wireless seamless connectivity and interoperability in rail domain, among others: automotive, aeronautics and buildings. A "sensor & communication bubble" using wireless technology enables less expensive and more flexible maintenance and re-configuration. ACCIONA Infraestructuras is implementing a prototype capable of managing freight trains at construction work sites, able to prevent disasters and accidents at building (or refurbishment) stage in large underground areas by considering everyday physical parameters of the trains and their loads. This will significantly contribute to decrease project costs, operation and maintenance of the equipment and facilities, as well as to the optimization of the operation of the rail machinery in terms of time. In this paper a first approach to solve the mentioned issues is presented.
Furthermore, the proposed solution shall be able to reduce the effort and time required for integrating WSN solutions and, railway safety-related and multipurpose systems, and to reduce maintenance costs of on-board WSN services.
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Keywords: Efficient resource and cost control; Rail; Safety and Security; Underground work sites; Wireless sensor networks.

1. Introduction

The building or remodelling of large underground areas, such as tunnels, implies very complex projects where some very specific needs appear.

Historically, tunnels have been considered dangerous places where fatal accidents during construction works were inevitable. Not any more: nowadays, tunnel safety is an essential aspect all over the European countries, and particularly in Spain.

Site management during the construction phase is also of essence: effective management of both resources within the tunnel (workers, raw materials, tools, etc.) and the machinery involved is required to accomplish the ultimate goal of improving the effectiveness and efficiency of the construction site.

Most of the resources are moved by trains due to their ability to transport huge amounts of materials consuming less time and effort. Many measurements taken in underground work sites are collected manually by operators and maintenance staff. This may lead, in some cases, to errors and planning delays, increasing final work costs.

In the case of railway equipment inside tunnels, mechanisms for monitoring and management are scarce and usually insufficient for proper operation and they become critical during indoors construction work.

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In this context, the European project DEWI (Dependable Embedded Wireless Infrastructure) provides key solutions for wireless seamless connectivity and interoperability in the rail domain.
Therefore, the development of a quick-response system is necessary. Said system should be able to immediately detect any problems, being them in the train or in the tunnel infrastructure, and effectively mitigate possible consequences.

ACCIONA Infraestructuras has designed a prototype capable of managing freight trains at construction work sites, able to prevent disasters and accidents at building (or refurbishment) stage in large underground areas by considering everyday physical parameters of the trains and their loads.

Figure 1 ACCIONA platform wagons (source ACCIONA)

2. DEWI, an overview

DEWI (Dependable Embedded Wireless Infrastructure) [1] is one of the largest funded European Research & Development (R&D) [2] initiatives with 57 renowned industrial and research partners from 11 European countries. DEWI focusses on wireless sensor networks and wireless communication to provide new applications for citizens and professional users. It envisions to significantly foster Europe's leading position in embedded wireless systems and smart (mobile) environments such as on- and off-road vehicles, railway cars, airplanes and buildings.

For this, DEWI has introduced the concept of a "Sensor & Communication Bubble" – the so-called DEWI Bubble – featuring [1]:

- Locally confined wireless internal and external access
- Secure and dependable wireless communication and safe operation
- Fast, easy and stress-free access to smart environments
- Flexible self-organization, re-configuration, resiliency and adaptability
- Open solutions and standards for cross-domain reusability and interoperability

2.1. *DEWI Rail Industrial Domain*

The DEWI Rail Domain proposes novel solutions to optimize freight management. A Wireless Sensor Network (WSN) [3] will be deployed along the different wagons and locomotives of a train which will send the data about freight status, train composition and/or train integrity to a gateway. This gateway is responsible to store and manage the collected data, sending it to the system or person requiring information, such as the driver or external services. Wireless technologies in the rail domain may ease maintenance, reduce installation costs, and increase the safety level for some applications or systems.

In actual freight management, the link between wagons, the identification of their physical characteristics and parameters and the control of the status of the freight travelling inside the train composition are mainly mechanical processes. A wireless solution provides easier, quicker and dynamic identification and monitoring of the freight travelling inside the train composition, avoiding complex and expensive installations. This is especially interesting for trains transporting hazardous materials where early status detection is very important in order to run safely.

3. Monitoring solution for freight management in underground work sites

ACCIONA solution describes [4] how to deploy a structural wireless monitoring system capable of measuring the most relevant parameters and physical variables involved in the train mechanical structures and their freight.

Freight trains in charge of transporting the material for construction works should be continuously monitored by identifying their load, the nature of these loads, their weight and physical conditions, in order to achieve the work optimization of the rail machinery in terms of time, project, operation and maintenance costs of the equipment and facilities.

The freight train travels on the railway route inside the tunnel, along with other trains and other construction machinery during the construction works. The train composition is changed outside the tunnel depending on the needs of running works inside. In fact, the cargo is also selected and loaded on their particular wagons, depending on their characteristics, nature, form and weight.

As a result of all of this, each type of wagon should be monitored in a different way with specific sensors adapted to the specific cargo of the wagon.

Table 1 Underground worksites specialized wagons

Wagon	Description
Locomotive Cab	Locomotive Cab is the part of the train where a driver or engineer is located and where you can find the controls necessary for the locomotive's rail operation. Inside this wagon it is necessary the installation of comfort and air quality sensors, in order to improve the wellness and security of the driver. In the same way, air quality sensors have been deployed to exactly know the CO2. Good air quality in tunnels is vital, it affects staff health and therefore, badly managed air quality can have economic and legal implications.
Staff Wagon	Staff Wagon is a wagon in charge of transporting staff along the tunnel and of interchanging workers at the end of each work shift. The same sensors with the same objective as in locomotive cab should be deployed: THL and CO2 sensor.
Bulk Container	These wagons transport material such as granular and powdered diverse merchandise, cement or big blocks of rocks. They are made of steel. Material temperature sensor node is needed for monitoring the bulk cargo status during the transporting process. As the information will be sent and stored, the operators can take care of the real temperature of the material. Then they will able to detect any dangerous reading of temperature that could lead to an accident or in a fault or deformation of the transported material.
Platform Wagon	They are used to load large goods), such as machinery, cables, steel coils and metal vehicles action, among others. Load Detection Sensors could be used to monitor and control the right position of the cargo on the wagon and alert us about falling objects or materials which could damage other transported material or harm the workers. Distance Sensor has the same objective than the load detection sensor. The worker will choose between one or the other depending on the shape and size of the transported material.
Gas or Liquid Wagon	A tank car is a type of railroad car or rolling stock designed to transport liquid and gaseous commodities (such as fuels, oils, hydrogen, natural gas, etc.) that can be necessary for the proper operation of works inside the tunnel. During the construction works, the machinery involved in the daily operations needs to be filled up with fuel or gas; substances of this nature are very flammable and harmful. A thermocouple could be used to monitor the temperature of the gas or liquid wagon during the journey, detecting any threshold that could be dangerous for the proper operation of the constructions works
Platform Wagon	Load Detection or Distance Sensors could be used to monitor and control the right position of the cargo on the wagon and alert the operators of falling objects which could damage other transported material or harm the workers. Depending on the shape and size of the transported material, the adequate sensor will be selected.
Gas or Liquid Wagon	A thermocouple is used to monitor the temperature of the gas or liquid wagon during the journey, detecting the crossing of any thresholds that could be dangerous for the proper operation of the constructions works.

All the mentioned activities are undertaken in the rail yard: a specific place where all the building (or mechanical/maintenance) materials are stored. Emergency services and working site management and control staff are also located at this point.

As it was explained before, the core of the DEWI solution is the concept of the DEWI Bubble. A DEWI Bubble is a logical entity operating in a physical space delimited by the range of the wireless transmission technologies employed for intra-Bubble communications.

Only one DEWI Bubble Gateway will act as the main point of interface with the outside world (extra-Bubble) and it will be able to host one or more wireless sensor networks, where each WSN can operate with a different technology, including legacy standards.

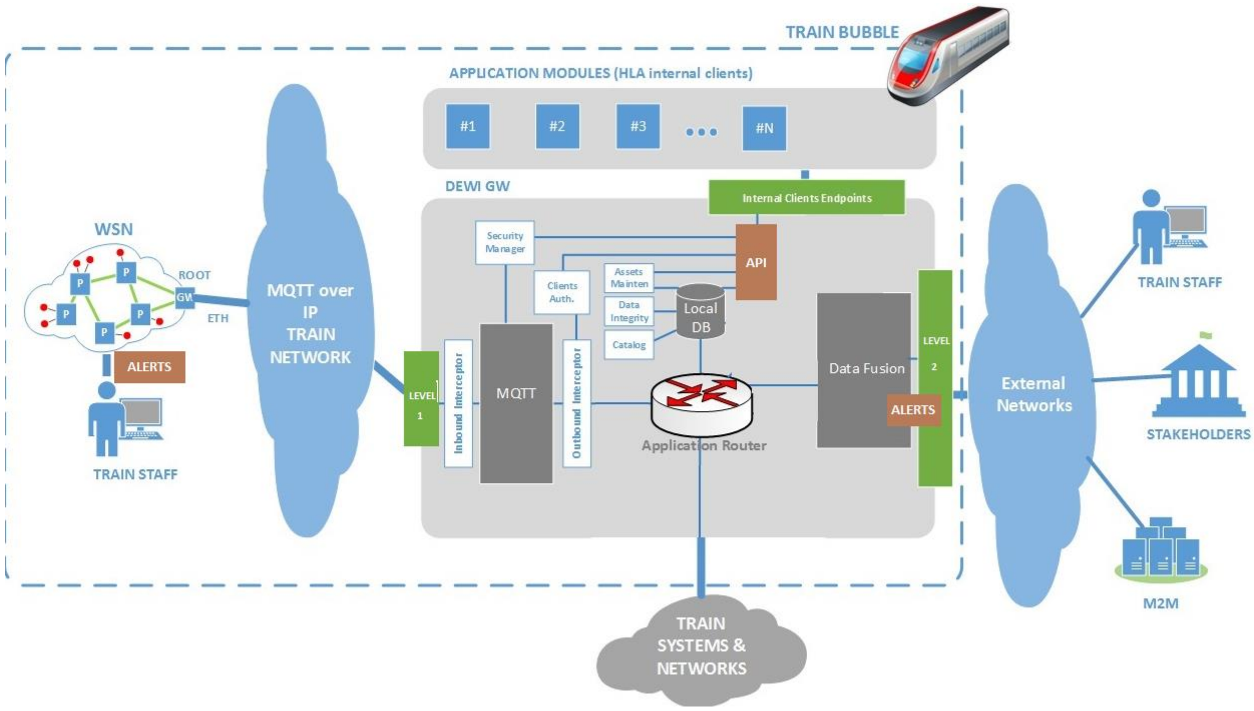

Figure 2 Logic diagram of DEWI Bubble in the Rail domain

The basic structure for ACCIONA WSN Monitoring System is composed by several WSN Nodes with one or more sensors in each one. At least one node for each network, called root node is in charge of collect all data obtained from the sensors nodes and transmit the information to the ACCIONA Coordinator, device in charge of controlling and configuring the sensor network, receiving and storing data (if it is needed) and sending information to DEWI Gateway.

The selected technologies for each level for this solution are:

Level 0: Based on 802.15.4 standard [5] in the 2.4 GHz band [6]. This wireless communication protocol is designed to use in low power devices with low-rates data transmission. There are different network topologies that these devices can use: point to point, start, etc. Data transmission between nodes is wireless through a wireless network with Mesh topology. In our solution, nodes are configured to use mesh networks, where each device capture and transmit its own data and collaborate to propagate data from other nodes to the central communication point.

In this communication infrastructure, each node has a list of other "neighbour" nodes. This list is sorted: the first node is the best option to send data and the last is the worst; the criteria used in this sort are out of scope of this document. When some data packet is ready to send or arrives from other sensor, each node sends data packets to "best neighbour" option, until the packet arrive to a central point where data is collected (also called "root node") and sent to a storage area.

ACCIONA Sensor nodes provides their own communication infrastructure, and these are the main advantages:

- No additional communication infrastructure is needed.
- When any node is broken down, the remaining nodes which were communicating with it can recalculate routes and send data to another working node; therefore, the communications network is more robust compared to others (e.g. star, tree topologies) in the case that any node stops working properly.
- The network can be easily scaled up in large areas just with the addition of new sensing nodes.

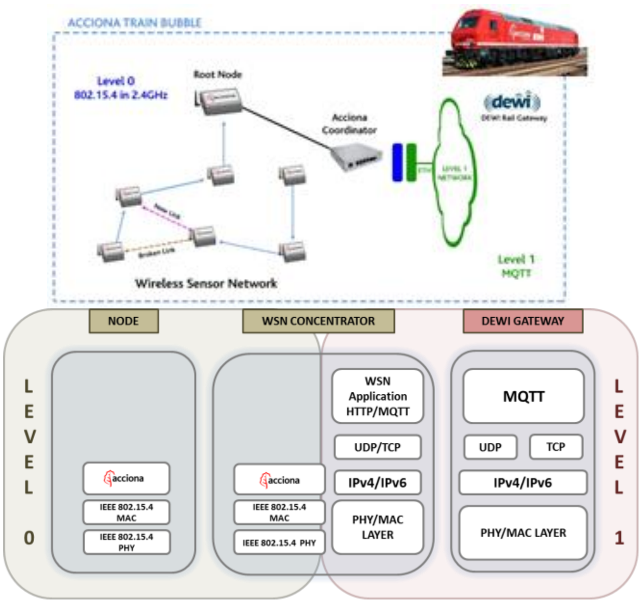

Figure 3 Data flow within WSN. Figure 4 ACCIONA WSN node communicating with server with communication stacks involving level 0 and 1

<u>Level 1:</u> ACCIONA DEWI nodes inside the WSN use an architecture and/or communication protocol different from the one used to communicate to the DEWI Gateway. Hence the WSN concentrator needs to manage the access to the bubble, manage the underlying nodes as expected in its architecture, and manipulate packets to a format DEWI Gateway is able to construe (and vice versa). This case breaks the architecture into two tiers, separating completely the ACCIONA WSN from the DEWI Gateway, with the need of a complex concentrator. The Level 1 protocol chosen has been Oasis MQTT [7] because is a loose coupling of publishers and subscribers, as both can work abstracting from the other and ignorant of system topology (on client/server paradigm the client cannot send data unless server is running, and server cannot receive unless client is running) and has a better scalability of the network, through parallel operation, message caching, tree-based or network-based routing, etc.

As a result of all the findings and decisions explained in the previous sections, the characteristics of the WSN to be deployed in the train are condensed in the following table.

Table 2 Features of the WSN for Underground Trains

Wagon	Sensors	Units	Location	Energy Supply	Sampling Frequency [8]	Latency [9]
Locomotive Cab	WSN Coordinator DEWI Gateway	1	Near the control panel	24V sockets	-	-
Locomotive Cab	Root Node	1	Near the control panel	24V sockets	-	-
Locomotive Cab	THL	1	Roof Cab	Rechargeable Batteries	1s	⩽ 1 second
Locomotive Cab	CO2	1	Near the control panel	24V sockets	30s	⩽ 1 second
Staff Wagon	THL	1	Roof Wagon	Rechargeable Batteries	1s	⩽ 1 second
Staff Wagon	CO2	1	Near the door	24V sockets	30s	⩽ 1 second
Bulk Container	CT	1	On top of the wagon	Rechargeable Batteries	5s	⩽ 2 second
Platform Wagon	Load Detection	1	Near train wheels	Piezoelectric/Solar	30s	⩽ 1 second
Platform Wagon	Distance	1	Near train wheels	Piezoelectric/Solar	30s	⩽ 1 second
Gas/Liquid Wagon	CT	1	On top of the wagon	Rechargeable Batteries	5s	⩽ 2 second

THL Temperature, Light and Humidity
CT Contact Temperature

3. Conclusion

So far, wireless technology is not widely used in underground construction sites. However, ACCIONA is sure that it can provide the base for developing new functionalities, like freight monitoring or increasing pre-existing functionalities like safety.

Proposed solution designed inside the scope of DEWI project, is focused on providing key solutions for wireless seamless connectivity and interoperability in rail tunnel infrastructures.

ACCIONA expects to implement this solution in the near future and, in this way, ease maintenance, reduce installation costs and increase safety levels not only in underground construction sites, but also in other kinds of sites that will be managed all over the world.

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References

[1] Rom, W. (2013). DEWI Dependable Embedded Wireless Infrastructure. DEWI Use Case Booklet. Page 53.
[2] Galster, P. (2014). The “DEWI” EU-project – 40 million Euros for a wireless future.
[3] Yick, J. Mukherjee, B et al. (2007). Wireless sensor network survey. Department of Computer Science, University of California, Davis, CA 95616, United States.
[4] Prototyping WSN Use Case 4.5 – WSN for Freight Advanced Monitoring and Management System D405.003 (D4.5.3). Pages 16–24.
[5] Sastry , N. Wagner, D. (2004). Security Considerations for IEEE 802.15.4 Networks.
[6] Mourya Bharadwaj Mantri . (Oct. 2013). Performance analysis of 2.4GHz IEEE 802.15.4 PHY under various fading channels
[7] MQTT For Sensor Networks (MQTT-SN) Protocol Specification .Version 1.2 Andy Stanford-Clark and Hong Linh Truong. http://mqtt.org/
[8] Liu, X. Wang, Q. (2006). Optimal Real-Time Sampling Rate Assignment for Wireless Sensor Networks. ACM Transactions on Sensor Networks, Vol. V, No. N, January 2006, Pages 1–34.
[9] Dousse, O. Mannersalo, P et al. (2004). Latency of Wireless Sensor Networks with Uncoordinated Power Saving Mechanisms.