International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 6; Issue 11; November 2017; Page No. 7174-7179
DOI: http://dx.doi.org/10.24327/ijcar.2017.7179.1094

Research Article

COMMUNICATION BETWEEN WAGONS: PROPAGATION CHANNEL AND ARCHITECTURE

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A R T I C L E I N F O

Article History:
Received 10th August, 2017
Received in revised form 11th September, 2017
Accepted 30th October, 2017
Published online 28th November, 2017

Key words:
Wireless communication; ZigBee; Railway environment; Connected wagon.

A B S T R A C T

With the growth of wireless technologies at low cost, railway industries are leveraging wireless platform to create efficiencies. Indeed, the aim of the work presented in this paper is a part of a general study concerning the connected wagon. The objective is to ensure communication of data associated to wagon (contents, location…). The paper presents, firstly, a state of existing technologies and the most promising technology for our project: ZigBee. Then, the second part evaluates their performance in propagation environment taking into account channel propagation and coexistence between technologies in 2.4 GHz.

INTRODUCTION

Wireless technologies offer to objects the ability to communicate without human intervention, to analyze and make decisions, and to send information and orders. These features make these objects "smart" since they operate autonomously.

In recent years, some projects were focused on the implementation of a wireless communication in railway sector. Indeed, news solutions are installed on wagons or in infrastructure and the technologies are different according to the context and the application. Then, the challenge is to find the optimal solution for the final application.

Wireless solutions offer many advantages in railways like mobility, flexibility and more facilities to manage trains. Indeed, it is possible to change and move a wagon from a train to another one, and to adapt the implementation to needs and constraints.

In the domain of freight trains, it is necessary to identify the sensitive wagons (transport of hazardous materials, perishable goods…) and also to have information about wagons (weights, location, content…). Collecting information from each wagon allows having information on the constraints for the train movement and on the traceability for logistic management.

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Wireless communication in railway applications are often devoted to communication between train and ground, while just few of them are used to wireless transmission aboard the train. Our project is focused on the study of wireless communication between wagons.

The paper is organized as follows: in section II, a survey of existing systems in railway applications is presented at first, then, promising technology for our project and its characteristics are investigated. In section III, the results of channel propagation analysis are reported. Then, in section IV, the coexistence between technologies already present in railway is analyzed. Section V concludes the paper.

Choice of technology

Most of projects of wireless communication implemented in railway environment are focused on communication between train and infrastructure.

A study of implementation of low power technologies in high-speed trains (300 km/h) between Madrid and Barcelona was carried out in [1]. The experimental results have shown that WSN (Wireless Sensor Network) technology is very competitive. It consumes low energy and simple communication protocol is used.

In [2] authors propose overspeed control system for train. Indeed, RFID (Radio Frequency Identification) tags are placed in the railway signalling system and the on-board systems collecting the information are embedded in the guard's van of the train.

The train runs at a speed as specified for a particular block section, defined by the traffic control center. Railway guard compares the determined speed and the running speed, collecting from the different RFID sensors.

During the last years, the progress of wireless communication technique using low cost technologies, allows to ensure communication along the train to monitor wagons health for example.

In [3], the authors propose a monitoring system of ball bearings, to avoid possible failures. This system uses WSN to monitor temperature and RFID technology to transmit the information to the infrastructure.

In [4], the authors have deployed on train, hybrid technology networking (HTN), which employs WiFi together with ZigBee. The authors explain that it is evident that a smaller cluster size improves performance, since it decreases the number of ZigBee hops required to deliver the data. We should note also that WiFi uses more power to transmit a message, and then smaller cluster sizes will use more transmitting power.

In [5], WiFi is employed to establish the connection between ground station and the train Tsukuba Express in Japan. The access points are deployed along the railway track, and then a continuous WiFi area is formed.

In recent years, wireless communication techniques have rapidly progressed, especially, with wireless communication technology at low cost such as WiFi (IEEE 802.11), Bluetooth (IEEE 802.15.1), ZigBee (deployed enhancement of the IEEE 802.15.4) and RFID.

Table 1 presents the characteristics of various wireless technologies that could be used for the studied application: a wireless communication between wagons, low power and compatible with railways environment.

Table 1 Comparison of wireless technologies

Technologies	Characteristics	
	Advantages	*Disadvantages*
WiFi	Wide range	High transmitting power
Bluetooth	Low cost	Short range
ZigBee	Low cost, low power consumption	Low throughput
RFID	Low cost, flexibility	Electromagnetic disturbances.

Taking into account the range and the low energy consumption constraints of the considered application, the study is now focused on ZigBee technology.

ZigBee is an LP-WPAN (Low Power Wireless Personal Area Network). It is a wireless network with short-range and low power consumption.

The ZigBee standard describes the upper layers which are based on the IEEE 802.15.4 standard. ZigBee maintains the PHY and MAC layers of the IEEE 802.15.4 but in addition, defines upper layers for networking security and application control. The ZigBee specification introduces more control overhead and complexity compared to IEEE 802.15.4 but also provides enhanced reliability and interoperability and supports more complicated network topologies.

The IEEE 802.15.4 standard includes two topologies: star or point to point. Above IEEE 802.15.4, the ZigBee network layer allows the creation of mesh networks (mesh) with automatic routing.

The advantages of ZigBee system are multiple, since it is designed for the Internet of Things (IoT). The ZigBee devices require less bandwidth and need only a signal battery to operate for many years. This technology provides a network easy to install, self-configuring and self-healing.

ZigBee supports large number of nodes (65k nodes), and can coexist with other technologies in the ISM (Industrial, Scientific and Medical) band. Indeed ZigBee can change communication channel to the quietest one.

Thanks to all these properties, ZigBee is a competitive technology for wireless communication between wagons.

Propagation channel

Different reflective objects (ground, wagons, pole, etc) which are located inside the wireless propagation area can affect communication in railway environment. These objects can cause reflections, diffractions and/or scattering of electromagnetic waves, and then, fluctuations of received signal. The next paragraphs present the propagation channel analysis to ensure communication between two wagons for the studied application.

Radio propagation characteristics:

To ensure wireless communication between wagons, the ZigBee sensors will be placed outdoor between wagons, as presented in figure 1.

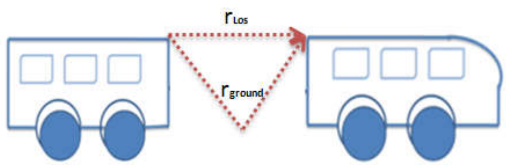

Figure 1 Wireless communication between wagons.

In this case, we have a two-ray ground reflection model; the received wave is composed of two waves, the direct wave and the reflected one on the ground.

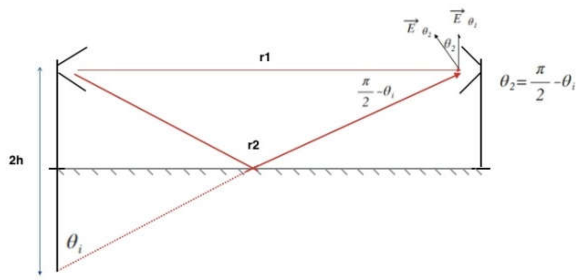

Figure 2 Two-ray ground reflected model

The resulting electric field is determined by the resultant of field generated by two paths (eq1)

$$\overline{E} = \overline{E_1} + \overline{E_2} \qquad \text{(eq1)}$$

The expression of the field received by a antenna in far field according to the distance is as follows:

$$\overline{E} = K f(\theta) \frac{e^{-jkr}}{r} e_\theta \qquad \text{(eq2)}$$

$f(\theta)$ is the antenna radiation diagram. In far field, $f(\theta)$ is defined by (eq3) for half wave dipole.

$$f(\theta) = \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \qquad \text{(eq3)}$$

In order to study the propagation performance, the signal strength is measured at 2.4 GHz with a spectrum analyzer, using double ridge antennas (700MHz-18GHz), as shown in figure 3. The transmitted signal strength is measured, in free space, between one fixed point and another moving point. Electromagnetic wave will be attenuated according to the distance.

Figure 3 View of scenario measurement.

In order to study the two polarizations, vertical and horizontal of electric field, two scenarios changing the orientation of the antennas are analyzed.

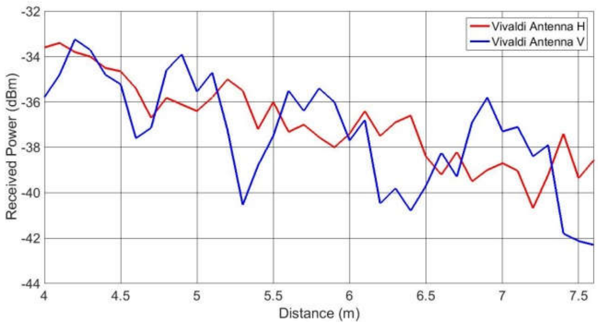

Figure 4 The measured power according to the distance.

In figure 4, the received powers in vertical polarization (Blue one) and in horizontal polarization (red one) are presented. The amplitude of the first is determined by the power of the line of sight ray. The second component is induced in the antenna by the wave reflected from the ground. The results obtained shows that the signal power in vertical polarization is strongest. This depends on the radiation pattern of the antennas that can change with the antennas orientation.

To approach the real conditions, measurements were then, performed using antennas mounted between cars (Figure 5).

Figure 5 Propagation between cars.

The average height of cars is slightly less than 3m, and it is usually the same for wagons. In order to study the propagation performance, the signal strength is measured at 2.4 GHz with a spectrum analyzer, using the same double ridge antennas as previously. The antennas are placed at fixed height 1.5m. The results are presented in figure 6.

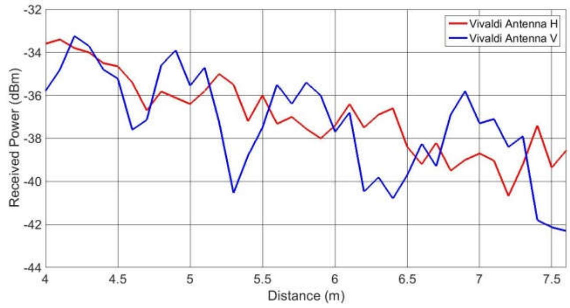

Figure 6 The measured power according to the distance.

In figure 6, the received power in vertical polarization (blue one) and power in horizontal polarization (red one) are presented. The results obtained in vertical polarization indicate indeed that the total field is the sum of the line of sight field and the reflected one on the ground. We can note that in horizontal polarization we have less fluctuations of the received signal.

Configuration and architecture

In order to define the more appropriate position of the sensors, three scenarios are analyzed. In the first one, the antennas are placed between wagons (at a fixed height 1.5m), in the second scenario, the antennas are installed between wagons but at the same height of the wagons. The top of the wagons is 3m. Then, in the third scenario, the antennas are mounted on the top above the roof of the train, placed in the middle part of the roof of each wagon. The scenarios are shown in Figure7.

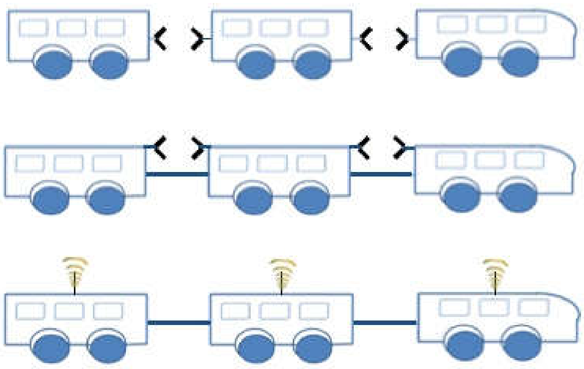

Figure 7 The scanrios of positioning antennas.

To compare these scenarios, the transmitted power is measured. To approach the real conditions, measurements were performed using antennas mounted between cars. The cars are 6.45m long and 3m high. The first scenario is shown in figure 5, the second and the third are both shown in figure 8.

Figure 8 The scanarios of positioning antennas.

The signal strength is measured in free space, between one fixed point and another moving point. The comparison of measured power in these three scenarios is shown in figure 9.

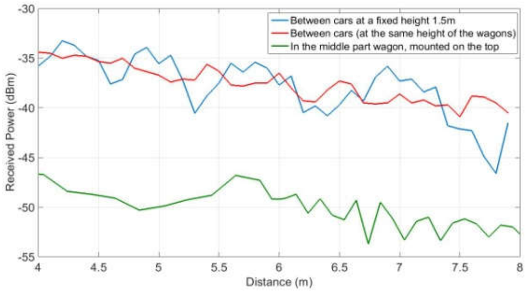

Figure 9 The measured power according to the distance.

For the received power when the antennas are placed between wagons at a fixed height 1.5m (blue curve), the reflected ray is indeed the total field of the line of sight ray and the reflected one on the ground. However, for the second scenario when the antennas are placed at the same height of wagons at 3m (red curve), they are less fluctuations. In fact, these experiments exhibit considerably more variations in terms of received power, presumably since the channel between cars at 1.5m is more affected by reflections on the ground. The obtained results show that the signal quality in the third scenario is the weakest. In this case, the antennas are mounted on the top, above the roof of the cars. The roof of the cars (also of train), is made of metal, therefore, the second ray (reflected on the ground) will be reflected on metal surface and will be lost.

Table 2 summaries the characteristics of various scenarios.

Table 2 Comparison of the proposed scenarios

	Characteristics		
	Propagation ray	**Nodes number n=wagons number**	**Disturbance**
Scenario 1	Two-rays (The reflected ray on the ground and the line of sight ray)	2n-2	Less disturbances
Scenario 2	Two-rays (less flectuations)	2n-2	More disturbances (between catenary and pantograph)
Scenario 3	Two-rays (The reflected ray on the ground and the line of sight ray)	n	More disturbance (between catenary and pantograph)

The positioning of the sensors depends also on the location of other RF antennas such as WiFi. A preliminary study of the coexistence between ZigBee and WiFi will be presented in the following section.

Coexistence Between Zigbee And Wifi

Both fixed and mobile communication networks are proposed in railway. A secured, robust and reliable network is essential to support information exchanges. Different projects and technologies must coexist to help transport operators to fulfill their mission. The spectrum of these technologies is shown in figure 10.

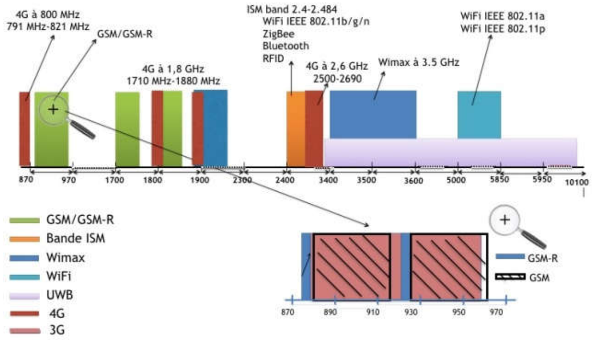

Figure 10 Spectrum of technologies present in railways

The 2.4 GHz ISM band provides an attractive medium to develop free application. Since ISM band is a shared spectrum allowing unlicensed operation of wireless services, coexistence between these services needs to be considered to ensure that requirements are maintained.

Wireless technologies, such as WiFi, Bluetooth, RFID and ZigBee share the 2.4 GHz band. The access to the medium in this band, by different services is typically not coordinated. Therefore, coexistence between services in the 2.4 GHz can suffer significant mutual interferences and performance degradations.

At first, a preliminary study focuses on coexistence between WiFi and ZigBee. The transmitted powers of WiFi nodes and ZigBee nodes are typically 100 mW and 1 mW, respectively, which can affect the ZigBee information exchange. Indeed, ZigBee packets can be lost.

The authors in [6] found that ZigBee packet loss is as high as 87%, with a WiFi (IEEE 802.11b) sender located between two ZigBee nodes.

The WiFi architecture consists in several components which interact to provide a wireless LAN for supporting station mobility, transparently upper layers, mainly in the ISM 2.4 GHz band (IEEE 802.11 b/g/n), but also in the 5 GHz band (IEEE 802.11 a/p).

Each new generation of these standards results is a rising in throughput, speed, range, reliability without energy consumption increasing.

In WiFi 802.11b, there are 14 possible channels in 2.4 GHz frequency range. The channel width is 22 MHz and each channel is spaced 5 MHz apart, which creates overlap between WiFi channels. Indeed, to avoid using overlapping channels, IT professional will often use channels 1, 6 and 11 for access point as presented in figure 11.

ZigBee uses 16 channels in the same range; but the channel width is 2 MHz as shown in figure 11. Indeed, each WiFi channel (1, 6 or 11); can interferes with 4 channels ZigBee.

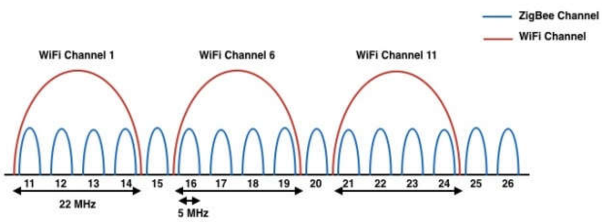

Figure 11 IEEE 802.11 and IEEE 802.15.4 channels in 2.4 GHz ISM band.

Simulation study

The coexistence between ZigBee and WiFi is studied by simulation. Simulations are carried out in two scenarios. In the first scenario we model ZigBee network. The idea is to place the ZigBee sensors in each wagon, to ensure wireless communications between wagons. Then, a WiFi network is added. In order to study the worst case, a profile for video conference application is configured for WiFi nodes, as shown in table III. ZigBee with WiFi model is shown in figure 12.

Table 3 Simulation parameters

Parameters	*Value*
Number of ZigBee nodes	• 1 coordinator • 5 routers • 11 End devices
Destination	Random
Packet size	1024 bytes

The throughput, the delay and the media-access delay are carried out. At first, we model ZigBee network. We use 11 end devices in a straight line, to respect the train configuration. Then, we add WiFi nodes. We compare the throughput, the delay and the media access delay. The results are shown in figure 13, 14 and 15.

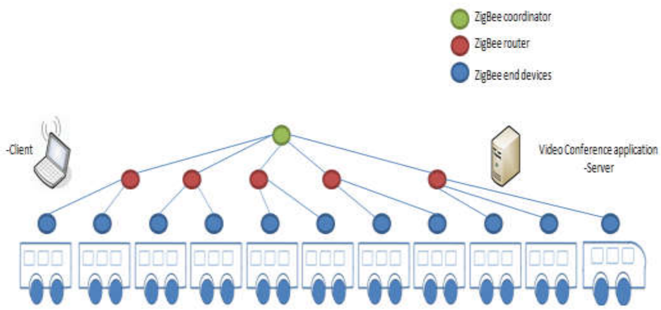

Figure 12 ZigBee and WiFi network.

Throughput

The throughput of data transmission in wireless system depends on a number of variables such as packet size, transmission rate, received signal power, received noise power and channel conditions.

ZigBee's throughput is lower than WiFi is. Its maximum speed is 250 kbps, much lower than WiFi offers. However, our application does not require a high throughput.

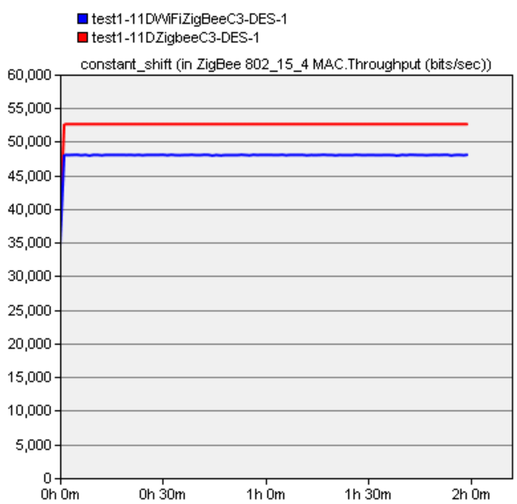

Figure 13 Throughput ZigBee in the two scenarios.

Indeed, the information exchanged is data associated to wagons that can be transmitted with ZigBee's flow To evaluate the impact of WiFi on ZigBee, we compare the throughput of the two scenarios. Results are shown in figure 13. Initially only ZigBee is used in the simulation and the throughput is above 53 kbps (red curve). When the WiFi is introduced, the throughput of ZigBee is drop to 48 kbps (blue curve). It can be noted that throughput decrease when we have ZigBee with WiFi in the same environment.

Propagation delay

The propagation delay is the amount of time taken by a communication signal to travel from the source to the destination over a given transmission medium. It depends on the physical medium of the link, the distance and the throughput. Figure 14 shows the comparison of propagation delay of the two scenarios.

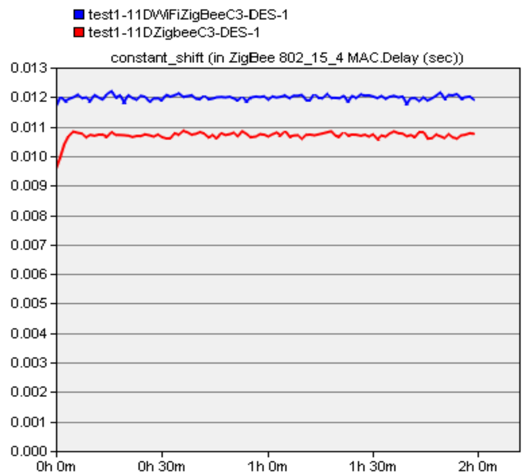

Figure 14 Delay ZigBee in the two scenarios.

The delay is below 0.01s when ZigBee network is used alone, and is drop to 0.012s when WiFi is introduced.

Media Access Delay

To avoid interferences, ZigBee uses Clear Channel Assessment (CCA) mechanisms to detect when the channel is free [7].

The channel sensing duration of ZigBee parameters is 0.1 second.

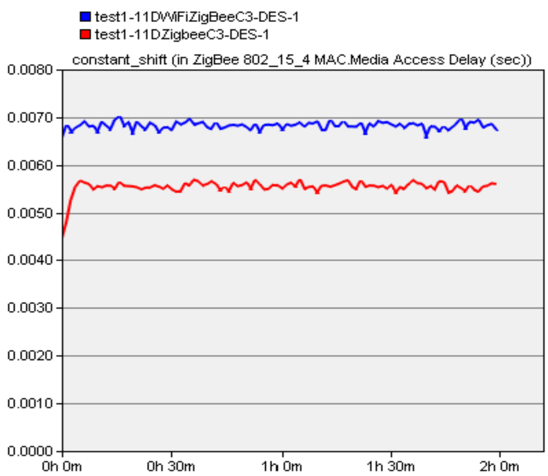

Figure 15 Media Access Delay in the two scenarios

Initially, when only ZigBee is used, the media access delay is below 0.0060s and when WiFi is introduced, the value is increased above 0.0060s. Indeed, the presence of WiFi in the same environment of ZigBee network is dropping the media access delay. In fact, the backoff slot unit of ZigBee is 320 µs and it is 9 µs WiFi (IEEE 802.11b simulated in this study). The shorter timing gives WiFi node priority over ZigBee nodes to access the channel.

CONCLUSION

ZigBee technology offers good performance to ensure wireless communication between wagons, in terms of low cost and low power consumption. Indeed, it guarantees a long battery life and autonomy for 'lonely wagons'. However, railway environment is rich in disturbances, with the channel effect and the presence of other wireless technologies using in communication between train and infrastructure. In order to evaluate the channel effect, we have presented in this paper the measurement of transmitted signal in free space using cars. Then, we studied the coexistence between ZigBee and WiFi using simulations.

Future work will be dedicated to evaluate the effect of power signal flowing along the catenary or the rail, sparks between catenary and pantograph on ZigBee transmission.

Acknowledgment

This work is carried out within a PhD funded by the region Nord-Pas-de-Calais of France and ICAM engineering school.

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How to cite this article:

Sara Iben Jellal *et al* (2017) 'Communication Between Wagons: Propagation Channel And Architecture n', *International Journal of Current Advanced Research,* 06(11), pp. 7174-7179. DOI: http://dx.doi.org/10.24327/ijcar.2017.7179.1094

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