ETALON

D 3.5 Communication Systems and RF Components for Trackside and Power Requirements

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David Vincent	PER	An appropriate strategy to implement a high reliability TEH powered system (section 5.1)

EXECUTIVE SUMMARY

The present deliverable contains the results of Task 3.5, part of the WP3 ETALON project.

The overall objectives of WP3 are to investigate and develop methods for checking the integrity of a train and to design, simulate and prototype wireless communication platforms for sending information on and off board the train. The present deliverable forms part of the off board (trackside) solution.

The specific objectives of WP3 related to trackside are to:

- Define a reliable and secure network infrastructure for track-side communication capable of being powered by energy harvesting;
- Keep a strong link to the findings from WP4 (Energy Harvesting Solutions) during all activities to guarantee seamless operation of all systems without relying on grid power;
- Establish interfaces to existing on and off train systems to allow a seamless integration into the existing infrastructure

The main objective of the Task 3.5 is to identify the most suitable communication solution for trackside object controller in order to distinguish the requirements for energy harvesting solutions. It should be noted that, within the ETALON project, the trackside prototype is related to the energy harvester part, while the communication part is simulated to acquire power requirements and to prove main QoS (Quality of Service) parameters.

The identified solution will be suitable for a fully de-centralized remote control of the trackside objects. This technical measure will assure the safety and security of transmitted data, as well as close to real time transmission speed.

The outputs from Tasks 2.4, 3.1, 6.1 and 6.2 will be used to define the most promising engineering solution for energy harvesting of future cable free object controllers, focusing on low power consumption, high availability and higher bandwidth. This will allow to provide the required amount of data, including transmission of status reports, maintenance information, etc. The communication system architecture will include the interfaces with the field elements (points, level crossings, etc.) and be as versatile as possible to deal with the different types of communications bearers.

All efforts will focus on regional and freight lines and will aid in determining an adequate solution for the energy harvesting systems.

The requirements for energy consumption, robustness, availability, reliability and maintainability of the energy harvesters will be derived from the identified solution and will be used to provide the necessary input for WP4.

In this report the definition of the most promising technical solutions for object controller wireless communications, along with a definition of the requirements for energy consumption, robustness, availability, reliability and maintainability of the energy harvester will be presented.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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COMMUNICATION SYSTEMS AND RF COMPONENTS FOR TRACKSIDE AND POWER REQUIREMENTS

1. INTRODUCTION

This Report describes and presents the results of simulations for Object Controller Wireless Communications (OCWC) based on WSN and LTE technology for trackside in order to compare and select the suitable energy harvester in order to comply with the energy requirements and specifications of the systems deployed in a railway environment.

Simulation is the imitation of the operation of a real-world process or system. The act of simulating something first requires the development of a model; this model represents the key characteristics, behaviours and functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

1.1 SCOPE

In this deliverable four scenarios are simulated, based on two chosen technologies (WSN and LTE) and considering two different Railway use cases:

1) *LTE based OCWC in remote area;*
2) *LTE based OCWC in stabling area;*
3) *WSN based OCWC in remote area;*
4) *LTE based OCWC in stabling area.*

All the scenarios are simulated applying an opensource software Omnet++.

The scenarios are simulated with the input parameters defined according to the system requirements given in ETALON D2.2 and the meaningful outputs correspond to the power consumption patron of the OCWCs and main QoS parameters such as end-to-end delay and packet error (including corruption and packet lost).

1.2 ACRONYMS

ACK	Acknowledgement message
AODV	Ad hoc On-Demand Distance Vector Routing
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
eNode/eNB	Evolved Node (access point of LTE network)
LTE	Long-Term Evolution (a 4G mobile communications standard)
M2M	Machine to Machine
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NED	Network Description
OCWC	Object Controller Wireless Communications
QoS	Quality of Service
RF	Radio Frequency
SCC	Signalling Control Centre (e.g. Interlocking)
SWOC	Smart Wayside Object Controllers
TEH	Trackside Energy Harvesting
UE	User Equipment
WSN	Wireless Sensor Network

Table 1 - Acronyms

2. FUNCTIONAL ARCHITECTURES FOR TRACKSIDE COMMUNICATION SYSTEM

The main objective of this deliverable is to identify the most suitable solution for trackside object controller wireless communications (OCWC) in order to distinguish the requirements for energy harvesting solutions. The final goal is to replace all the wired connectivity for both power and communications by a technically feasible and economic solution based on green energies.

For this purpose, possible architectures for OCWC are proposed and simulated to verify their viability and analyse the interaction with the most suitable types of energy harvesters.

The requirement for energy consumption, robustness, availability, reliability and maintainability of the energy harvesters will be derived from the identified solution and will be used to provide the necessary input for WP4.

2.1 POTENTIALLY SUITABLE TECHNOLOGIES

Nowadays the railway sector is facing the necessity to upgrade its infrastructure to be more competitive with other transportation sectors and be able to provide a trusted service with no fails and better services for its users based on modern technologies. Substitution of wired systems to wireless systems for different types of railway power supply and communications facilities seems to be promising for several reasons, as for example, economic advantages, enabling of use of innovative approaches, flexibility for the deployment, etc.

The communication technologies with promising specifications in terms of bandwidth, delay, energy consumption, allocation and ability to converge with the actual internet and compatible with energy harvesters, capable of capturing energy from the railway environment have risen in the last years.

From the communication point of view, the technologies that are being developed with a good potential and that could fit with the railway requirements are:

- Mobile networks;
- Wireless Sensor Networks (WSN).

So, the LTE and WSN technologies have been considered as potentially suitable candidates for providing services that a SWOC may require (ref. [3], [8]).

This deliverable will try to provide a view from the energy consumption perspective in order to compare and find which technology is better for the wayside infrastructure.

2.2 Scenarios and architectures for trackside communication system

In previous deliverables different types of communications suitable for trackside as well as their functional and system requirements were studied (ETALON D2.1, D2.2, D3.1), after that the possible OCWC architectures that could presumably comply with established requirements have been defined. These architectures built on above mentioned technologies have been modelled and simulated for two different Railway use cases with the aim to analyse their power consumption patron and main QoS parameters.

In case of LTE based architecture, it is assumed that the communication bearer will be provided by existing network for train-to-wayside communications, therefore the focus shall be placed on the link between OCWC and LTE base station (eNode) since it is assumed that the link between Signalling control centre (SCC) and eNode is already deployed and out of scope of the simulation.

On the contrary, for WSN based architecture it is necessary to simulate the whole network including the intermediate nodes with a defined communication range to arrive to SCC since this would be an OCWC dedicated network.

Remote area uses case is characterised by a low number of OCWC and large distance to SCC while stabling area is characterized by a higher number of OCWCs installed and a short distance to SCC. Train traffic profile also differs in these use cases being regular in remote areas (1 circulation in defined period of time) and irregular in stabling areas (simultaneous circulations during defined periods of time and large breaks in between). These two profiles have been chosen to be able to better analyse power consumption patron and impact of the interferences on communication quality.

Due to the insufficient knowledge of how the OCWC would be, which modules and internal protocols are employed, how much energy the CPU and other modules would consume, and more especially which communication protocols are used for LTE or WSN communication process for railway, these simulations focus on the amount of energy consumed by the RF hardware of communications module.

Below the chosen scenarios are depicted.

2.2.1 WSN based architectures

In this paragraph, two different scenarios are described, both based on the Wireless Sensor Network (from the simple one to the most complex).

Scenario 1: WSN remote area

In this scenario it is modelled a remote area OCWC where the signal is propagated using WSN nodes as relays until reaching the SCC. The OCWC itself has a WSN node included in it.

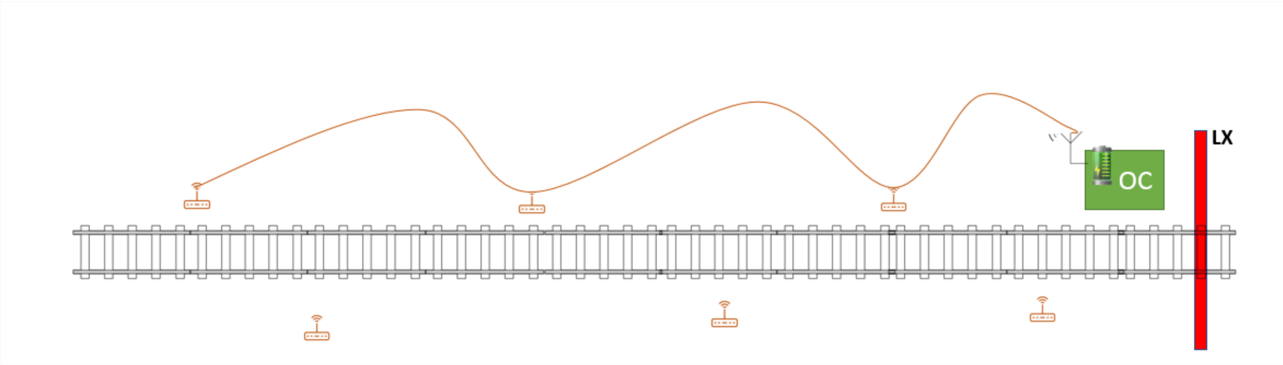

Figure 1 - Remote area topology using WSN network coverage

Scenario 2: WSN stabling area

This scenario is based in a railway stabling area, where all nodes can forward the message until the interlocking is reached, the nodes can be relays or OCWCs, where a OCWC is more complex than a relay, due to the fact that it not only forwards messages but includes actuators and sensors connect to a field element (FE).

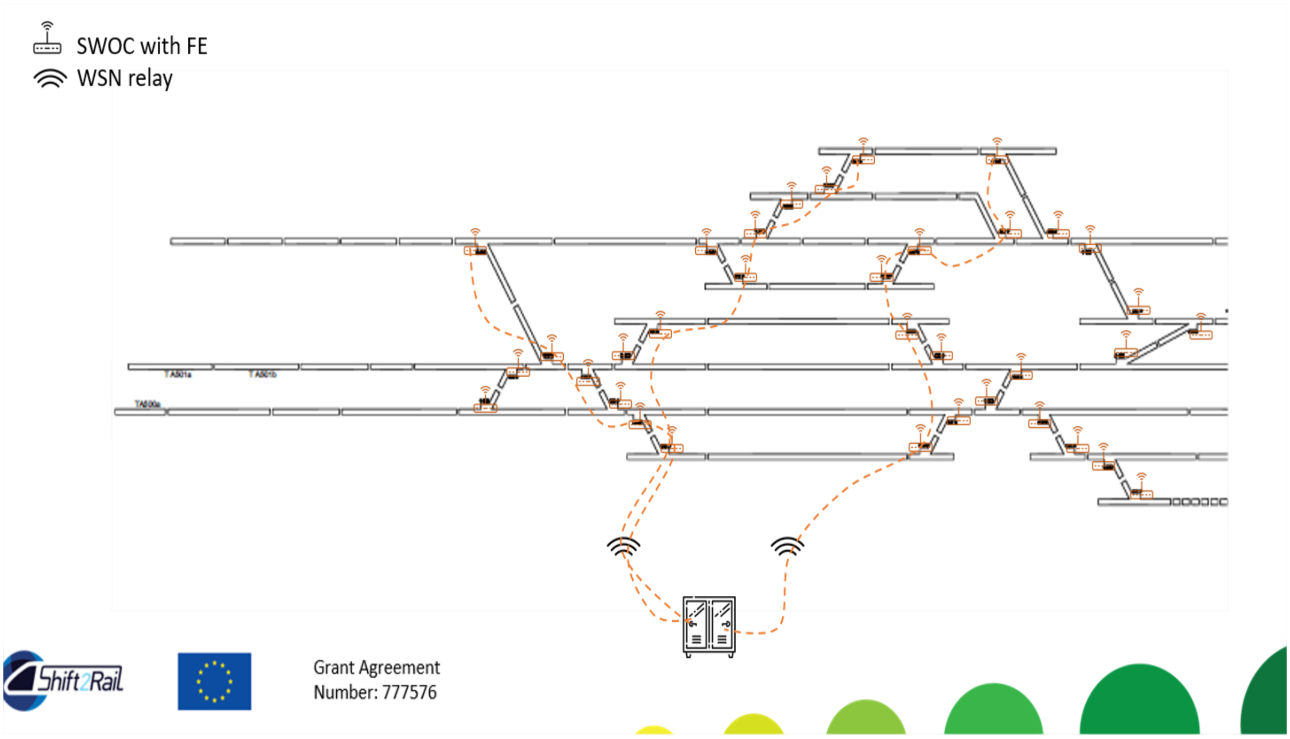

Figure 2 - WSN stabling area

2.2.1 LTE based architecture

A Node B, also known as Evolved Node B (abbreviated as eNodeB or eNB), is the element in E-UTRA of LTE that is the evolution of the element Node B in UTRA of UMTS. It is the hardware that is connected to the mobile phone network that communicates directly wirelessly with mobile handsets (UEs), like a base transceiver station (BTS) in GSM networks.

Scenario 3: LTE remote area

In this scenario it is modelled a remote area OCWC where the signal is propagated using an LTE antenna and the coverage of already deployed infrastructure to reach the interlocking. The communication between eNode (eNB) and SCC is outside of the scope since the simulation focuses on the energy consumption of the end device (OCWC).

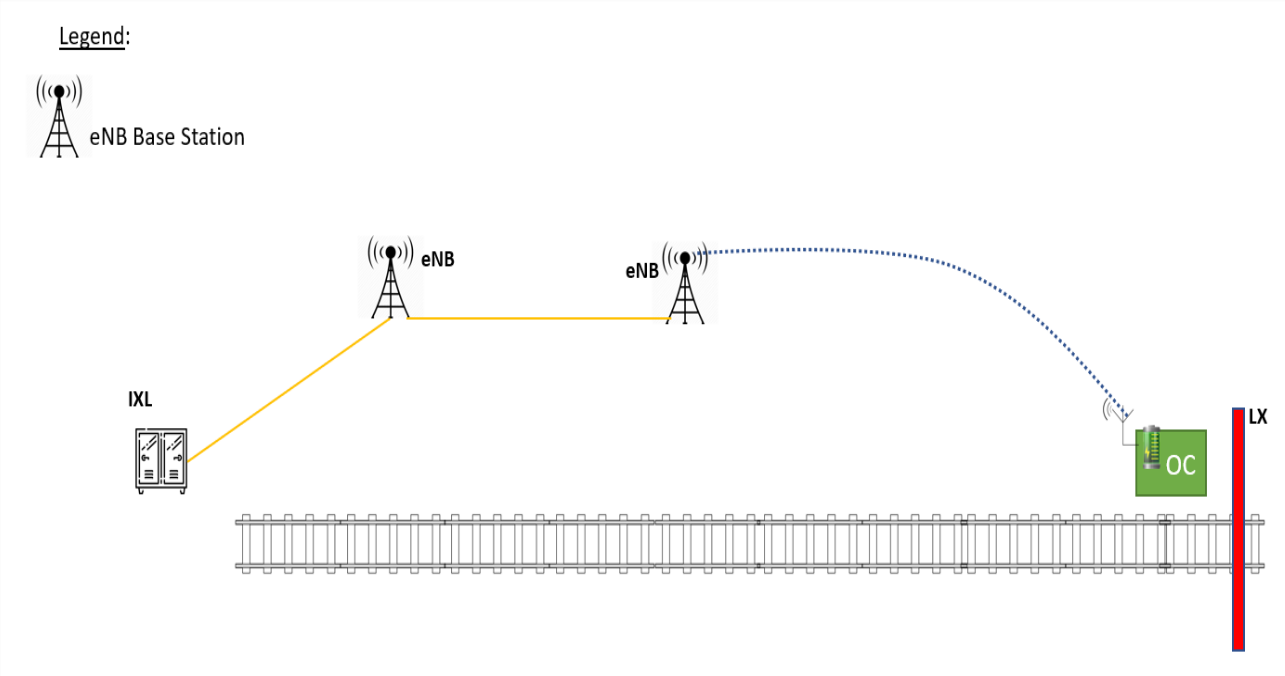

Figure 3 - LTE remote area scenario

Scenario 4: LTE remote area

This scenario is based in a railway stabling area. All LTE devices will communicate directly with the eNode. As in scenario 3, the communication between the eNode and the interlocking is out of the scope of this deliverable. More than one node will generate traffic in order to simulate a stabling area were communication could start from different places.

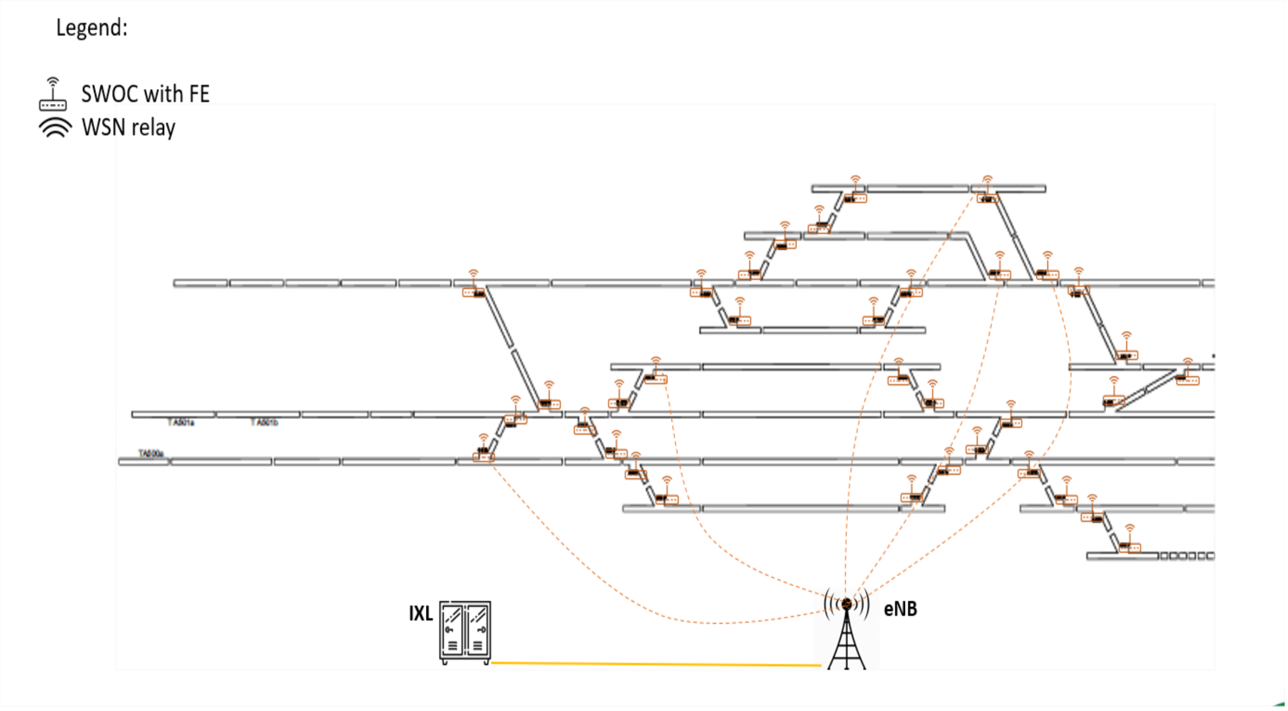

Figure 4 - LTE stabling area scenario

3. METHODOLOGY USED FOR THE SIMULATION OF CHOSEN ARCHITECTURES

In this chapter the chosen simulation tool is presented, as well as the model parameters and the main outputs that will be generated.

3.1 SOFTWARE

OMNeT++ (Objective Modular Network Testbed in C++) is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators.

Within this tool, "network" is meant in a broader sense which includes wired and wireless communication networks, on-chip networks, queueing networks, and so on. Domain-specific functionality such as support for sensor networks, wireless ad-hoc networks, Internet protocols, performance modeling, photonic networks, etc., is provided by model frameworks, developed as independent projects. OMNeT++ offers an Eclipse-based IDE, a graphical runtime environment, and a host of other tools. There are extensions for real-time simulation, network emulation, database integration, SystemC for HW description integration, and several other functions.

Although OMNeT++ is not a network simulator itself, it has gained widespread popularity as a network simulation platform in the scientific community as well as in industrial settings and is building up a large user community.

OMNeT++ provides a component architecture for models. Components (modules) are programmed in C++, then assembled into larger components and models using a high-level language (NED). Reusability of models comes for free. OMNeT++ has an extensive GUI support and due to its modular architecture, the simulation kernel (and models) can be embedded easily into applications.

The base for the simulation was run using INET [7], Simulte [5] and Castalia [6] framework of Omnet with some modifications in order to meet the requirements of the trackside scenarios (ETALON Deliverables 2.1 and 2.2).

3.2 MODEL PARAMETERS

The model consumption is a state based, where the consumption depends on the antenna's states of transmission, receiving, busy, idle or in a transition and the duration of these states.

For WSN AODV (Ad hoc On-Demand Distance Vector Routing) protocol is used in order to dynamically find the route to the sink. The use of AODV will increase the energy consumption due the need of keeping alive the route. For LTE, static routing has been configured and all nodes are able to reach the eNode directly. In WSN Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) has been configured in order to avoid collision between nodes. This protocol, for accessing the radio medium, will increase drastically the end to end delay. LTE ACK for checking proper reception has been also configured.

In both WSN and LTE scenarios, the Line of Sight has been considered.

Typically, in LTE networks when the User Equipment (UE) is far from the eNode, the UE activates the amplifier to increase the range, but this also increase energy consumption considerably. In this simulation we consider that all nodes are in range and the amplifier is in off state.

To simulate data traffic in railway environment, it has been configured in relation to the intervals between train circulations including acknowledgement messages until battery depletion. In the remote area scenarios, it is considered that the headways between trains can randomly vary from 60s to 180s, causing the necessity to establish communication link between SCC and OCWC when train approaches the trackside object. In stabling area scenarios, the operational conditions are different, since the interval between circulations can vary from 2 to 3 hours but it is considered that several trains can arrive in the same time (e.g. in case of end of service in the line)[1].

In the case of LTE an MTU (Maximum Transmission Unit) of 1500 bytes has been chosen, while for the WSN scenario a packet size is of 128 Bytes.

In remote area scenario either in LTE and WSN the traffic flows from hostB (represents eNode in LTE or interlocking in WSN) in a random interval between 60s and 180s.

In stabling areas scenarios either in LTE and WSN the traffic flows from hostB (eNode in LTE or Interlocking in WSN) to Host A, A1, A2, A3 and A4 in 8000s to 10000s, 9700s to 10000s, 9500s to 10000s, 7000s to 7500s and 6000s to 9000s respectively.

The battery introduced in the simulation has capacity of 15000 Joules.

The type of medium used for transmitting radio waves is a scalar type which represent a random distribution of events. In this medium Noise is added with a power of -90dBm and the receivers sensitivity and its energy detection were adjusted to - 85 dBm. The communication range is 250 m for WSN and 500 m for LTE.

The tables below contain the parameters considered for energy consumption and RF equipment (ref. [1], [2]).

[1] Detailed information about system normal and degraded operational conditions and message sequences can be consulted in the ETALON Deliverable 2.2 (Chapter 4).

State	Power Consumption
offPowerConsumption	0 mW
switchingPowerConsumption	1 mW
receiverIdlePowerConsumption	111 mW
receiverBusyPowerConsumption	240 mW
receiverReceivingPowerConsumption	240 mW
transmitterIdlePowerConsumption	111 mW
transmitterBusyPowerConsumption	300 mW
transmitterTransmittingPowerConsumption	300 mW

Table 2 - Energy consumption parameters for LTE

State	Power Consumption
offPowerConsumption	0 mW
switchingPowerConsumption	1 mW
receiverIdlePowerConsumption	55 mW
receiverBusyPowerConsumption	55 mW
receiverReceivingPowerConsumption	55 mW
transmitterIdlePowerConsumption	55 mW
transmitterBusyPowerConsumption	250 mW
transmitterTransmittingPowerConsumption	250 mW

Table 3 - Energy consumption parameters for WSN

Parameter	LTE	WSN
Distance	250 m to 500 m	250 m
Sensivity	-85dbm	-85dbm
Noise power	-90dbm	-90dbm
Energy detection	-85dbm	-85dbm
Transmitter power	1.4 mW	1.4 mW
SNR threshold	4 db	4db

Table 4 - RF Parameters

4. SIMULATION RESULTS

In the present Chapter, the results of the simulations for the chosen scenarios are inserted in the form of graphs, exported from the simulation tool.

4.1 WSN BASED ARCHITECTURES

In WSN, use of CSMA/CA protocol, AODV protocol and the insertion of interferences between nodes could vary the expected results depending on the chosen number of nodes.

The first step of this simulation is to create a dynamic route with AODV protocol, this includes the messages of topology creation, responses and keep alive messages, which will add a considerable amount of energy consumption. Delay will be increased too, due to the use of CSMA/CA, because the channel can only be occupied by one node at the same time, this means that AODV keep alive messages will also contribute in the same amount as data packets for increasing delay. The CSMA/CA in this simulation is applied to avoid a massive collision and the retransmission caused for it, this could be the cause of a faster depletion of the battery than expected.

In order to simulate a more realistic scenario the sending interval is a random number between 60 seconds and 180 seconds which will simulate railway traffic of 1 to 3 trains per minute in a uniform manner until depletion of the battery. As in the LTE example in order to be able to compare results, the interval of traffic generation is exactly the same. The selected bitrate is extracted from the datasheet [1] which is 250kbps, the Maximum Data packet is 128B according to Zigbee specification with 28 Bytes for headers.

```
*.host*.**.bitrate = 250kbps
```

The energy consumption of the nodes is based on the antenna state which is different in transmission, reception, idle or transition state.

```
**.hasStatus = true
*.host*.wlan[0].radio.energyConsumerType = "StateBasedEpEnergyConsumer"
*.host*.wlan[0].radio.energyConsumer.offPowerConsumption = 0mW
*.host*.wlan[0].radio.energyConsumer.switchingPowerConsumption = 1mW
*.host*.wlan[0].radio.energyConsumer.receiverIdlePowerConsumption = 55mW
*.host*.wlan[0].radio.energyConsumer.receiverBusyPowerConsumption = 55mW
*.host*.wlan[0].radio.energyConsumer.receiverReceivingPowerConsumption = 55mW
*.host*.wlan[0].radio.energyConsumer.transmitterIdlePowerConsumption = 55mW
*.host*.wlan[0].radio.energyConsumer.transmitterBusyPowerConsumption = 180mW
*.host*.wlan[0].radio.energyConsumer.transmitterTransmittingPowerConsumption = 250mW
```

In the stabling area architecture, the initial conditions are the same as in the remote area with the particularity that there are more nodes, that start the communication and that relay the data to the sink. There is as well a redundancy foreseen to be able to reach the sink trough more paths.

In the stabling area simulation, the configuration differs a little bit related to the previous case due to the intervals gap of sending packet are increased. In the remote area case, the intervals were a time between 60 and 180 picked randomly to try to adjust to the traffic of trains in a real railway line, in this case due to it is a stabling area the times picked are around 8 to 10 trains per day per OCWC, as already mentioned in Model parameters section.

4.1.1 WSN- based remote area OCWC architecture

In the present section the simulation results are presented in the form of graphs exported from the application for the Scenario 1: WSN-based remote area OCWC.

In Figure 5, a WSN remote area setup is simulated where AODV protocol dynamically changes the route if an unexpected event happens to a node. Dark blue line shows the complete flow of the communication, while teal lines show the device to device communication.

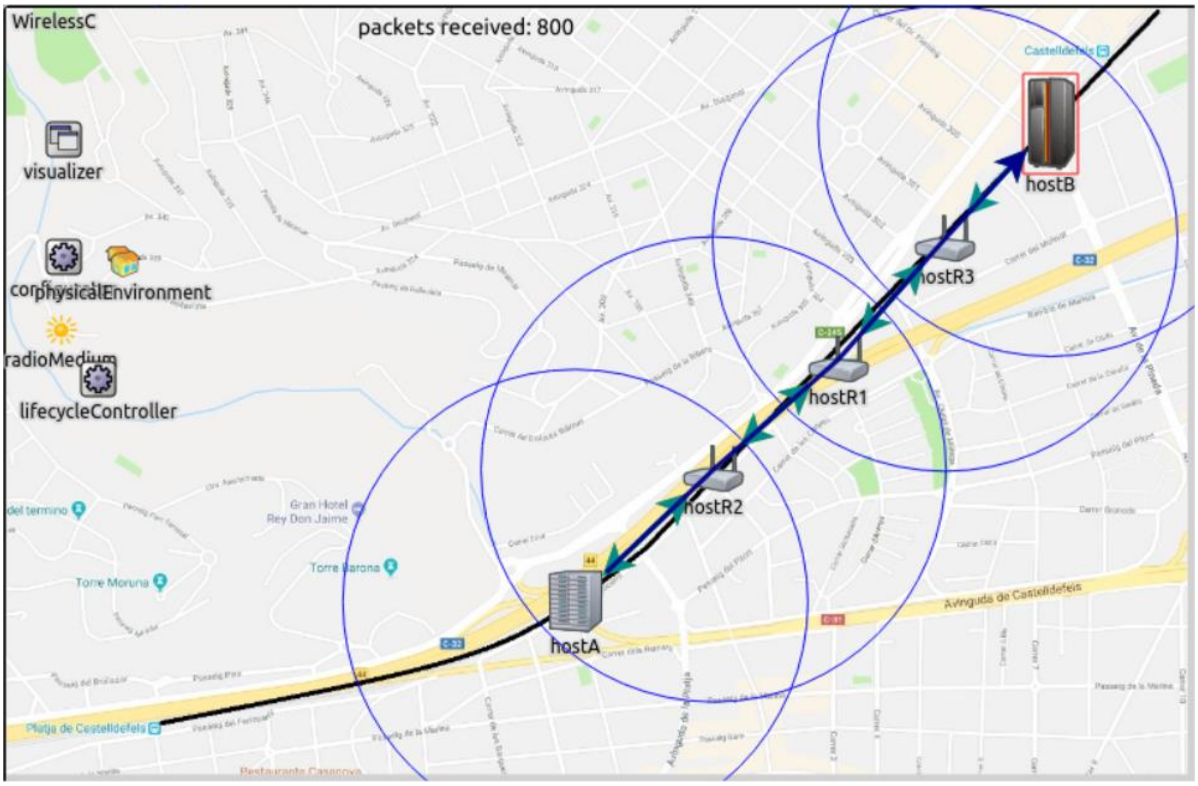

Figure 5 - WSN remote OCWC Simulation

The Hosts R1 to R3 model simple nodes that have the function relaying the data to the interlocking.

In a real case scenario R2, R3 and R1 would have redundancy to avoid unexpected events, but it has been removed in order to clarify the meaning of the results. The routing table is generated in a dynamic way using AODV and IPv4 protocol. CSMA/CA is used for collision avoidance and acknowledgement for reception confirmation. Light Blue arrow shows the device to device communication and the Dark blue arrow shows the complete flow of a data packet going from the OCWC to the SCC.

```
*.host*.wlan[0].radioType = "IdealRadio"
*.host*.wlan[0].macType = "CsmaCaMac"
```

The generated traffic flows as explained before, from HostA to HostB (OCWC to SCC).

```
*.hostA.numUdpApps = 1
*.hostA.udpApp[0].typename = "TCPBasicApp"
*.hostA.udpApp[0].destAddresses = "hostB"
*.hostA.udpApp[0].destPort = 5000
*.hostA.udpApp[0].messageLength = 128B
*.hostA.udpApp[0].packetName = "TCPData"
*.hostB.numUdpApps = 1
*.hostB.udpApp[0].typename = "TCPSink"
*.hostB.udpApp[0].localPort = 5000
```

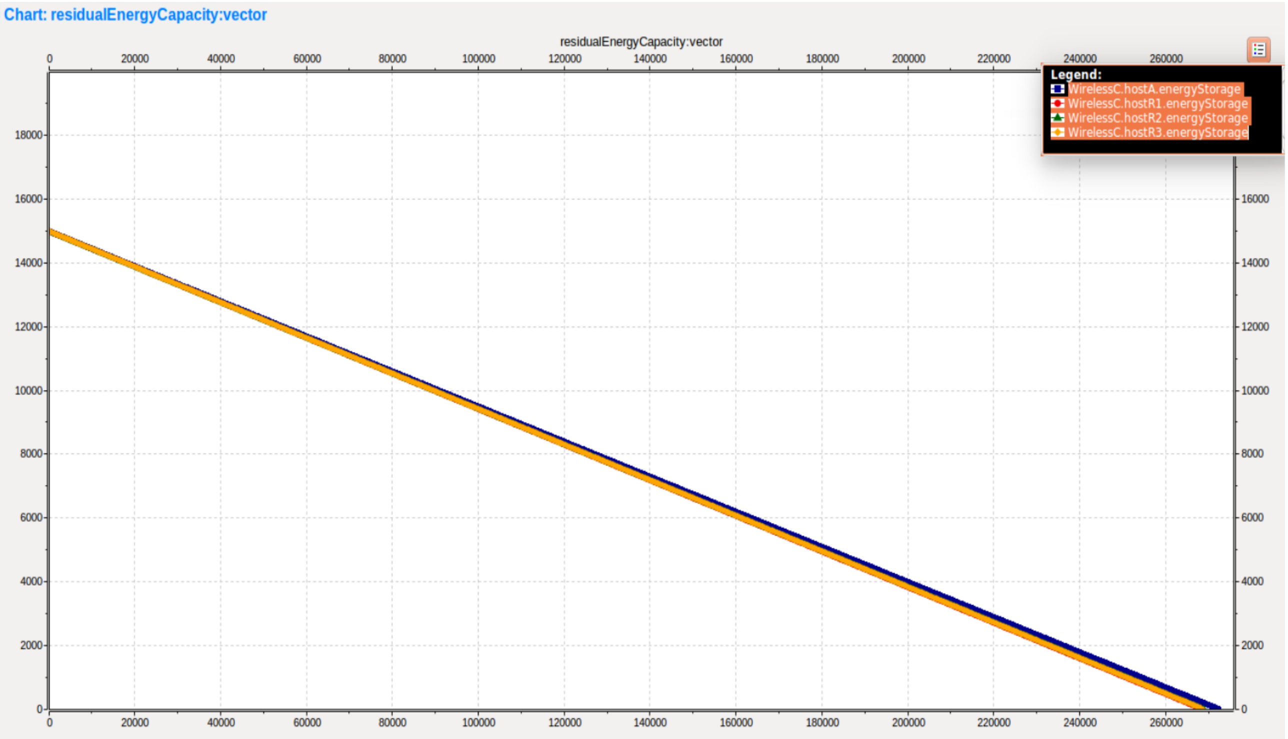

Figure 6 - Complete plot of the energy consumption

In Figure 6, it is shown a full view of the energy consumption of the HostB which models OCWC attach to a trackside object.

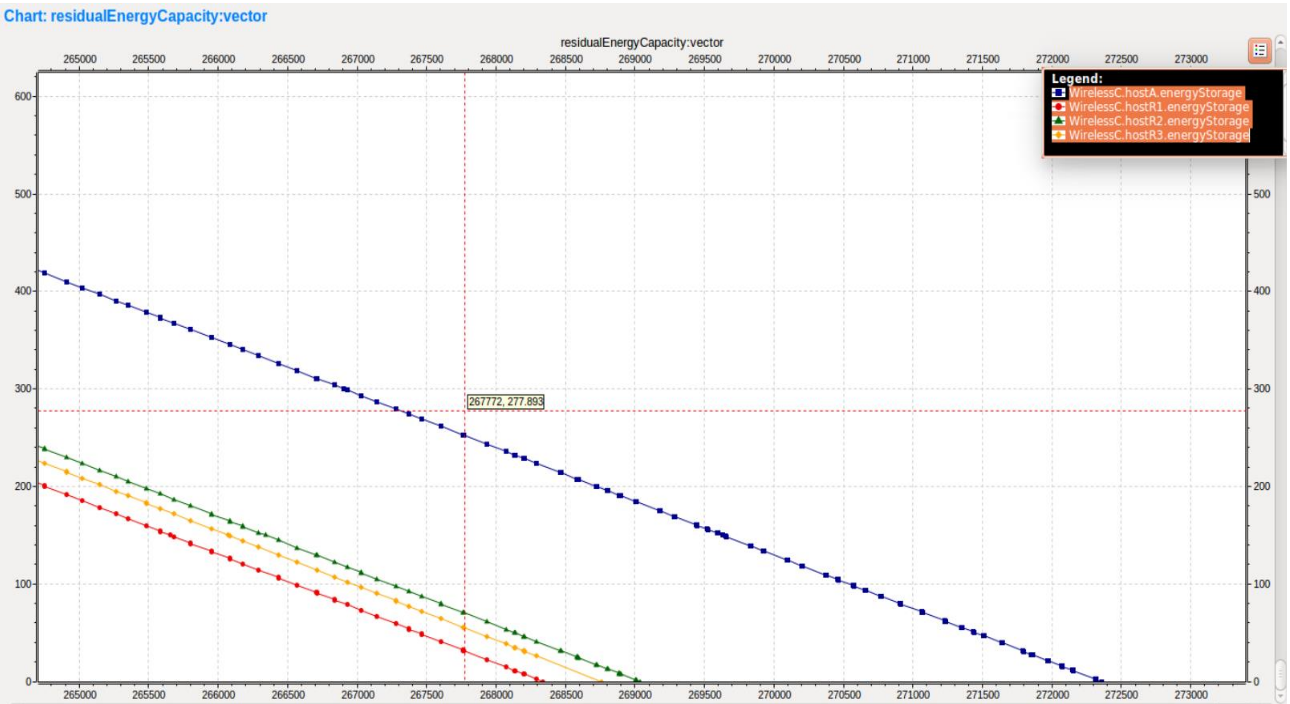

Figure 7 - Depletion of energy storage (zoomed)

In the Figure 7 it is depicted a closed up of Figure 6 representing an instant where the energy goes to depletion. It is shown the instance where each node reaches the value of 0 joules.

According to the simulation, HostA is the one who will last the most, near 272500 seconds which corresponds to 3 days, 3 hours and 41 minutes. The host that will last less is node R1, persisting for roughly 3 days, 2 hours and 31 minutes (268300 seconds). Host R1, which is the one that is in the middle of the topology, is the one with the highest energy consumption.

Figure 8 shows the end to end delay in the WSN of the remote area, X-axis show the time and Y-axis shows the number of packets that took the time defined in X-axis.

The delay varies considerably depending on the technology applied, since in case of WSN there are more nodes involved in the communication and due to CSMA/CA procedure, so when a channel is busy other nodes cannot transmit, which implies that if a node within the communication range is transmitting for example an AODV packet for knowing if neighbours are alive, this packet will occupy data transferring and acknowledgement.

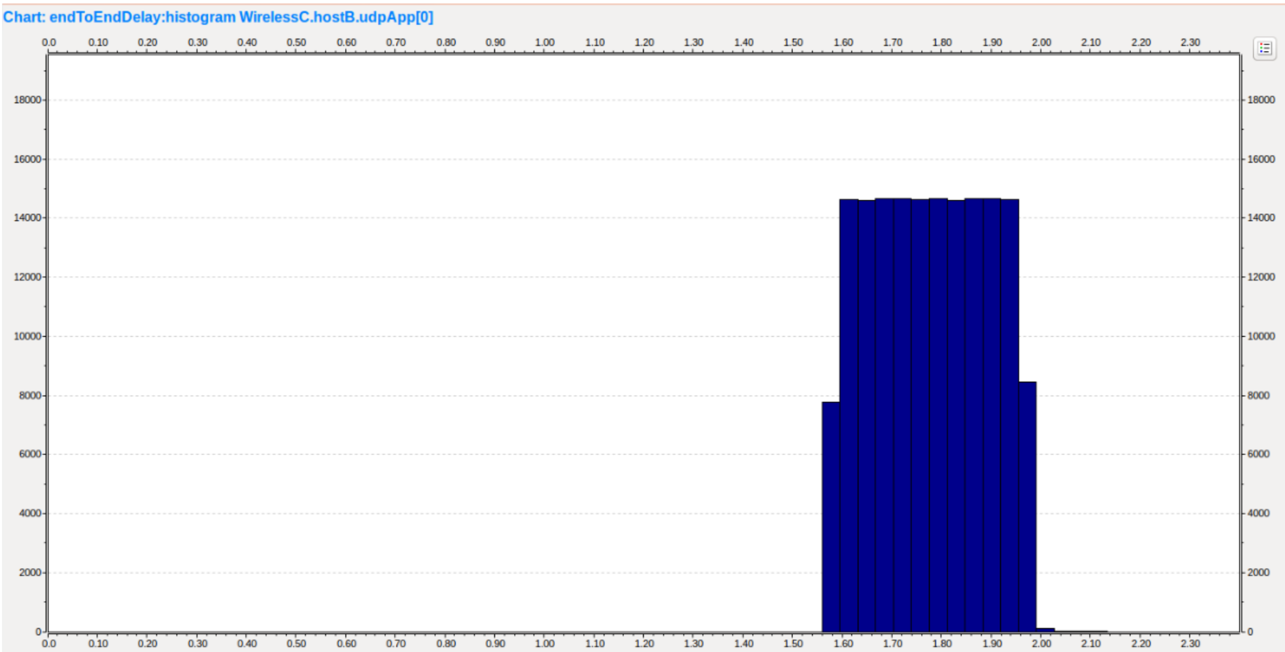

Figure 8 - End to end delay WSN remote area

The Figure 9 shows the Packet error rate of a WSN remote area, each colour represents a node, X-axis shows the number of packets that have the percentage error rate market in the Y-axis.

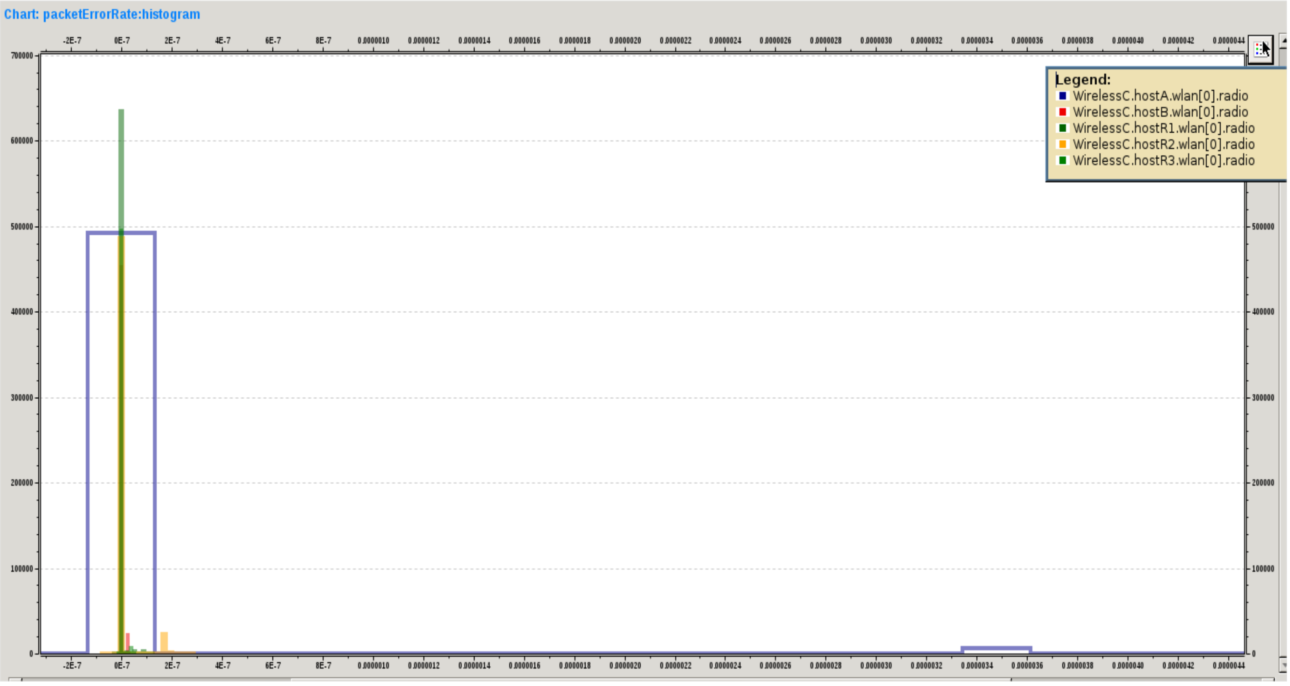

Figure 9 - Packet error rate WSN remote area

4.1.2 WSN stabling area architecture

In the present section the simulation results are presented in the form of graphs exported from the application for the Scenario 2: WSN-based stabling area OCWC.Figure 10 shows a WSN stabling area. In this simulation Green, Yellow, Dark blue and Red lines show the communication flow of each node while teal lines between nodes show the device to device communication.

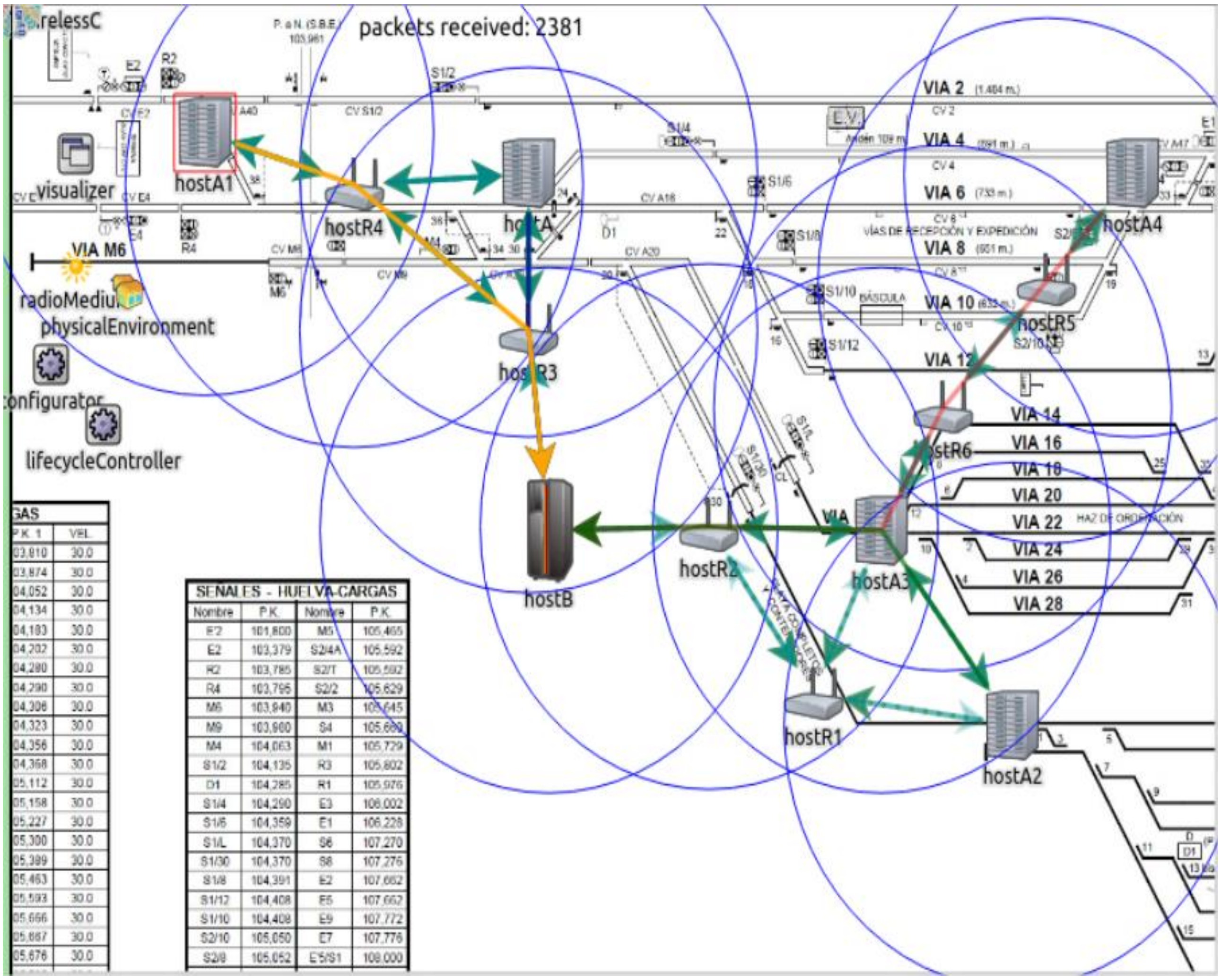

Figure 10 - WSN stabling area

The communication starts for topology discovery and creation, later the sender sends a CSMA message to verify if the channel is available, the next hop of the topology answers saying that the channel is clear and is available, then the sender will start transmitting data and the relay will answer with an acknowledgment to confirm reception. This process will keep going until reaching the interlocking.

Yellow, Dark Green, Red and Dark blue arrows are the possible paths that are actually being employed by AODV protocol in order to reach the sink (HostB), the bidirectional arrows shows the paths that a message can follow (ack and CSMA messages are included).

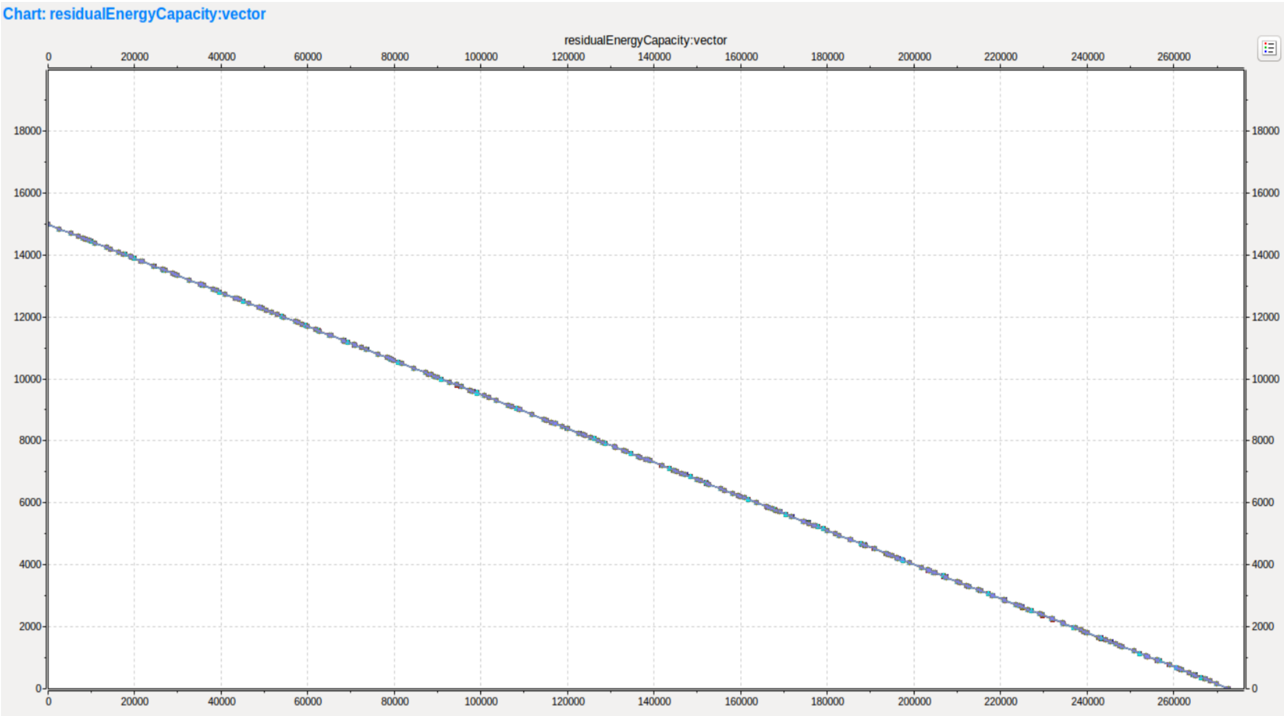

Figure 11 - Energy drawn until depletion

In Figure 11, it is shown a full view of the energy consumption of the HostB which models OCWC attach to a trackside object.

In Figure 12, it is depicted a closed up of Figure 11 representing an instant where the energy goes to depletion. It is shown the instance where each node reaches the value of 0 joules.

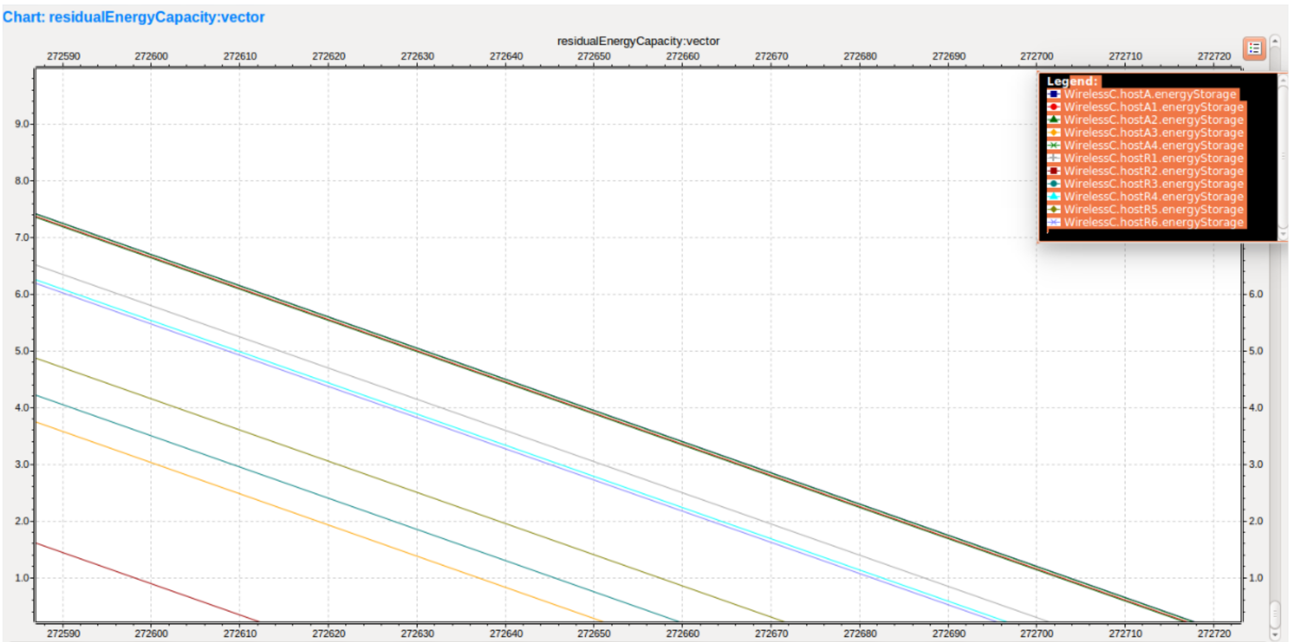

Figure 12 - Depletion of the batteries

In Figure 13, it is shown the exact instant where a transmission between interlocking and the host A1 is occurring. As shown in the image, A1 (Red), R4 (Teal) and R3 (Dark Teal) are communicating. Nodes A (Dark blue) and R2 (Dark red) are able to sense the communication.

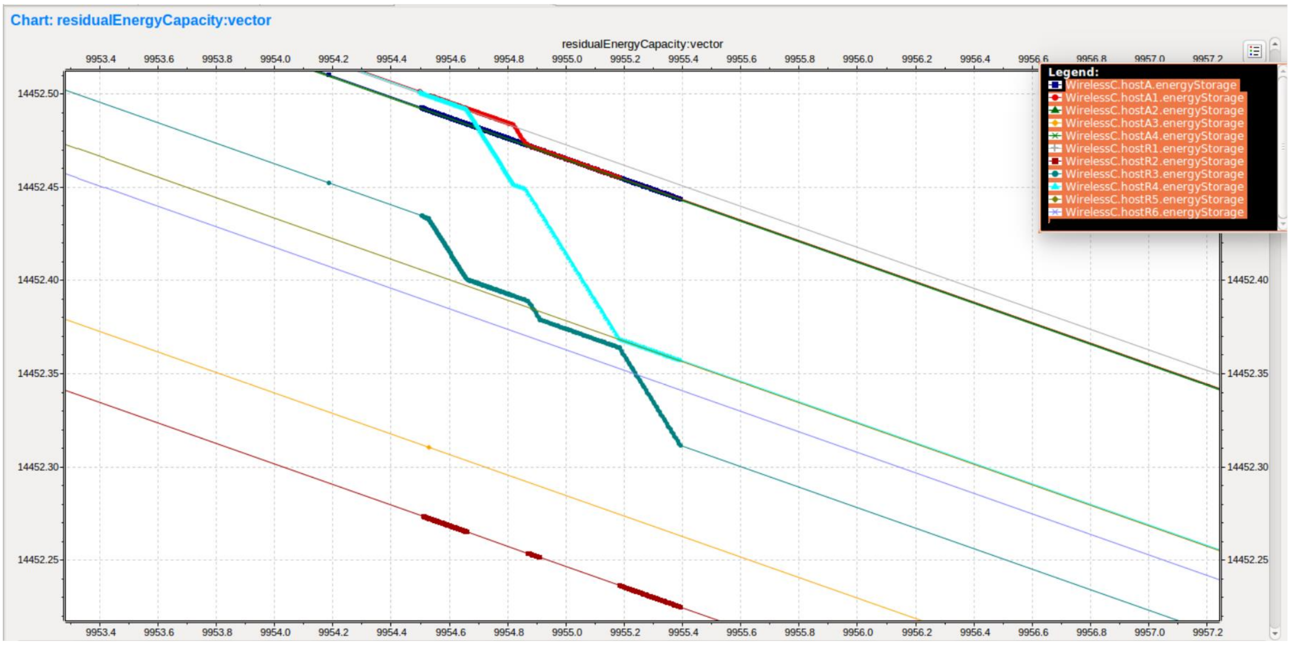

Figure 13 - Transmission of A1 to R4 to R3 to interlocking

As seen in Figure 11 and Figure 12 the nodes kept alive a little bit more than in the remote area due that almost all the consumption is from the idle state of the antenna and only a small part is drowned from the communication.

Unlike the previous case there is no visible difference between nodes until you zoom in the plot. As seen in Figure 12 , Nodes R2, A3 and R3 are the nodes with more energy consumption due its location in the network topology. R2 is in the path of three data flows while A3 and R3 are in two, that is why the battery of these nodes is depleted faster, but with less distance gap than in the remote area between the faster and the slower.

The delay will depend on the location of the nodes and if when a transmission starts another node is transmitting in its communication range, this policy is applied by CSMA/CA protocol.

Figure 14 shows the end to end communication delay for the stabling area. The mean delay of the communication is 1.49 seconds, but some packets, due to the CSMA/CA procedures, will have a higher delay if when the communication starts, another node is transferring data.

Contract No. H2020 – 777576

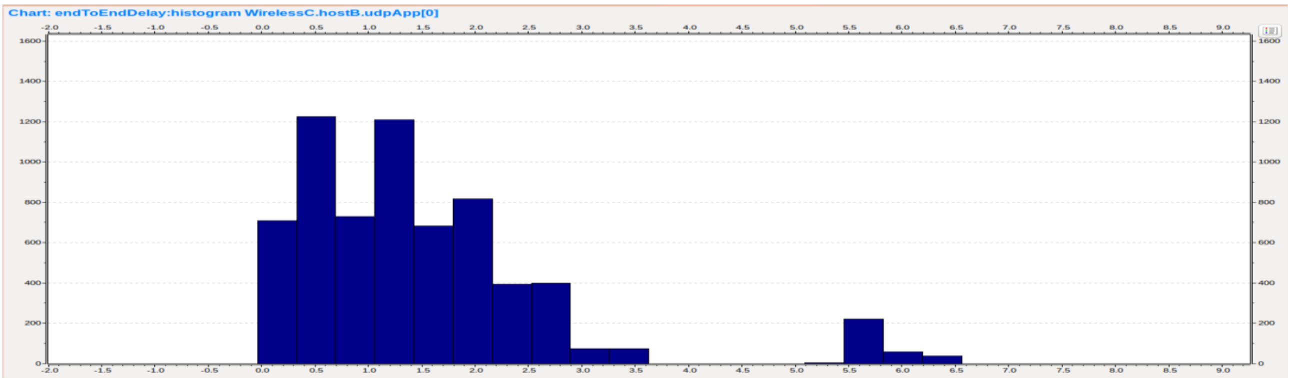

Figure 14 - WSN stabling area end to end delay

Figure 15 shows the packet error rate per node, the X-axis shows the number of packets and the Y-axis the probability of packet error.

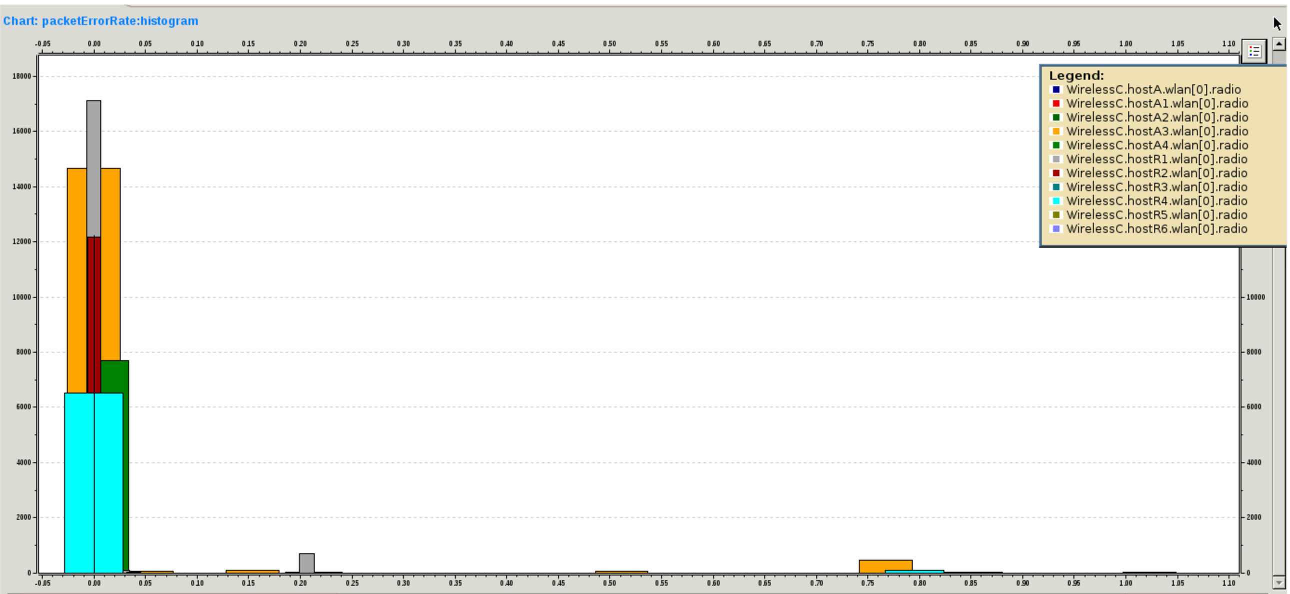

Figure 15 - Packet error rate WSN stabling area

The numerical results are summarized in the form of tables in the Annex1 and Annex 2 at the end of the document.

4.2 LTE BASED ARCHITECTURES

In Figure 16 a remote area scenario for LTE is simulated, the black line in the figure represents a real railway line in Spain. HostA models the OCWC while eNode models the interlocking.

In this case in order to simulate the trains passing through the controller a traffic interval has been defined between 1 minute to 3 minutes. Static routing has been configured and the user equipment has a direct wireless connection to the eNode. Acknowledgement messages are inserted in the protocol to check whether the packets arrive correctly. The maximum packet size, as mentioned in previous section, is set to 1500 Bytes (ETALON D2.2).

Specific protocols of LTE Machine to Machine (M2M) communication suitable for railway environment have not yet been developed and their definition is not in the scope of ETALON project, so some generic features have been assumed for the communications from OCWC to eNode.

For this simulation the values from the energy consumption were taken from reference values for M2M communications in [2].

Below is shown the extract from simulation code.

The following lines correspond to the static routing and the message length of the LTE remote scenario:

```
*.hostA*.udpApp[0].destAddresses = "eNode"
*.hostA*.udpApp[0].messageLength = 1500B
```

These lines show energy consumption depending on the state of the antenna:

```
**.hasStatus = true
*.host*.wlan[0].radio.energyConsumerType = "StateBasedEpEnergyConsumer"
*.host*.wlan[0].radio.energyConsumer.offPowerConsumption = 0mW
*.host*.wlan[0].radio.energyConsumer.switchingPowerConsumption = 1mW
*.host*.wlan[0].radio.energyConsumer.receiverIdlePowerConsumption = 111mW
*.host*.wlan[0].radio.energyConsumer.receiverBusyPowerConsumption = 240mW
*.host*.wlan[0].radio.energyConsumer.receiverReceivingPowerConsumption = 240mW
*.host*.wlan[0].radio.energyConsumer.transmitterIdlePowerConsumption = 111mW
*.host*.wlan[0].radio.energyConsumer.transmitterBusyPowerConsumption = 300mW
*.host*.wlan[0].radio.energyConsumer.transmitterTransmittingPowerConsumption =
300mW
```

For both LTE scenarios, the same parameters of energy consumption are configured. The major part of the energy consumption comes from the idle state of the antenna, since it is the state in which the antenna mostly remains.

As seen from the results below, this scenario setup has a low latency in the communication between OCWC and eNode.

In the LTE stabling area scenario, the end-to-end latency is similar to remote are use case due to the bandwidth capacity of the network.

4.2.1 LTE-based remote area OCWC architecture

In the present section the simulation results are presented in the form of graphs exported from the application for the Scenario 3: LTE-based remote area OCWC. The numerical results can be consulted in the Annex 1 and Annex 2.

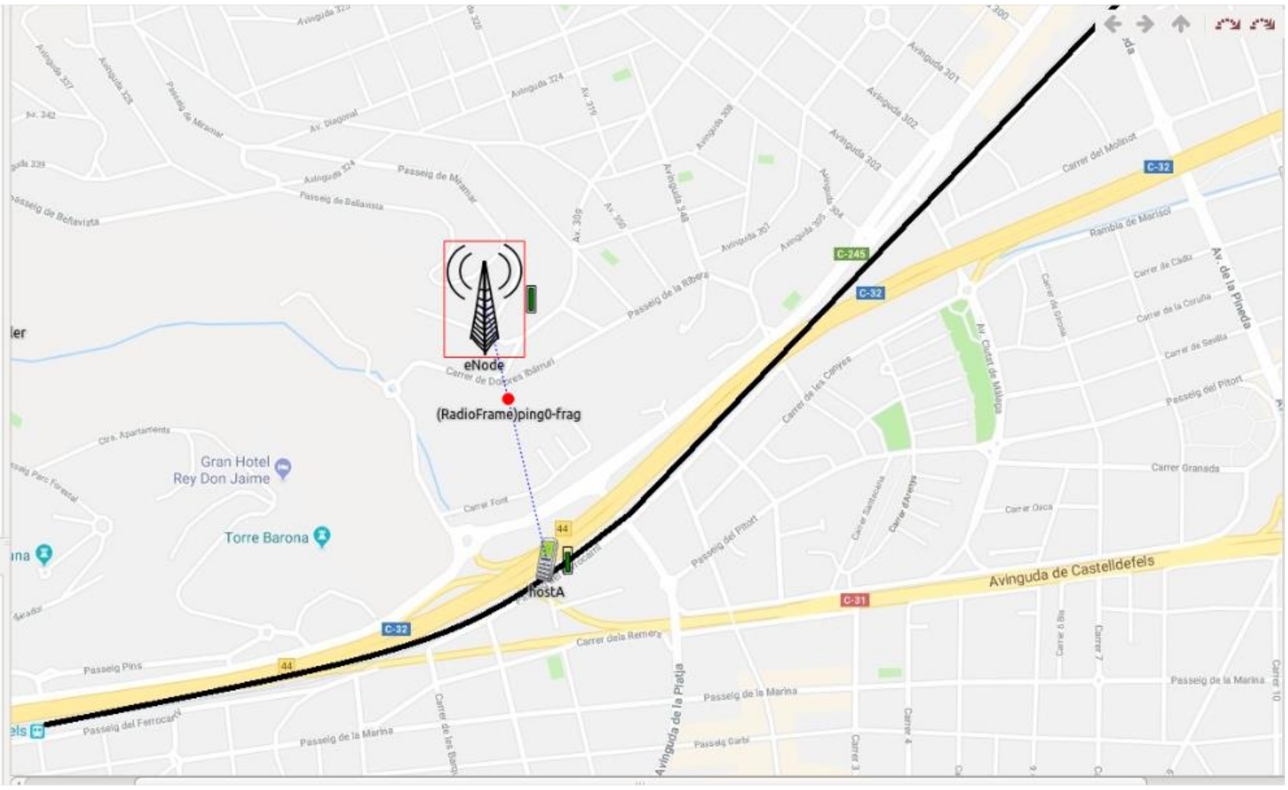

Figure 16 - LTE remote area scenario

In Figure 17, it is shown a full view of the energy consumption of HostA which models the User equipment of the LTE network, the simulated battery has a duration of 1day, 13hours and 46 minutes, which adds up to approximately 136.000 seconds. The total amount of energy stored in the battery is 15.000 Joules. The Y-axis shows the remaining energy of the battery in Joules while X-axis shows the time in seconds.

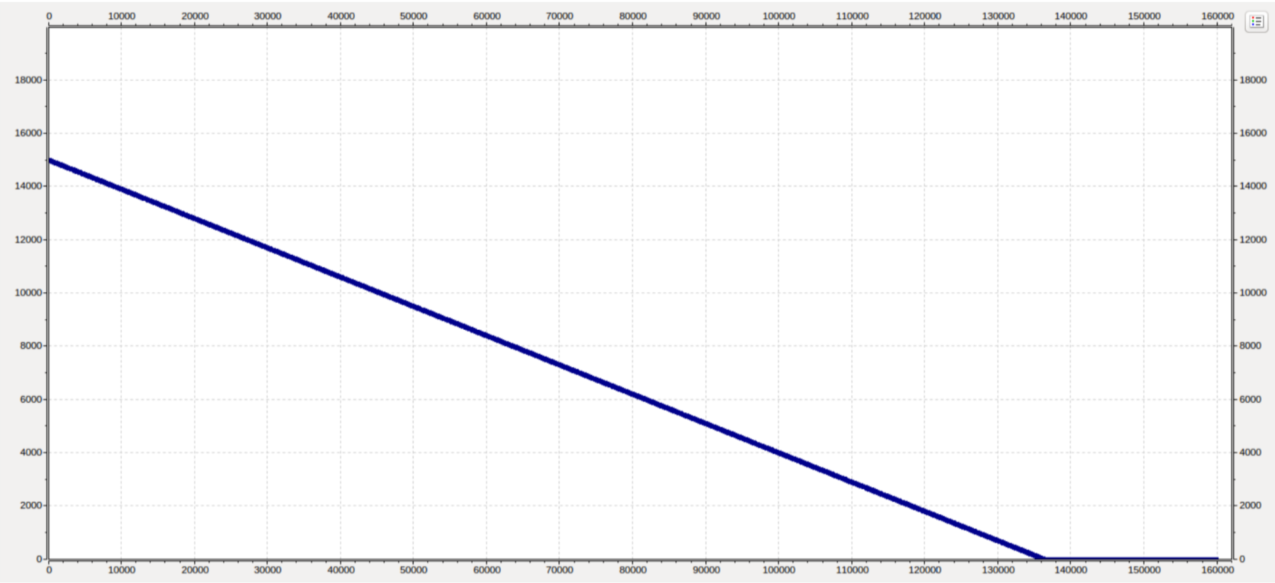

Figure 17 - Full view of Energy consumption of LTE simulation

Figure 18 shows the exact instant of a transmission. The major part of the battery is drained from the idle state of the antenna. The Y-axis shows the battery energy amount in joules, while the X-axis shows the time.

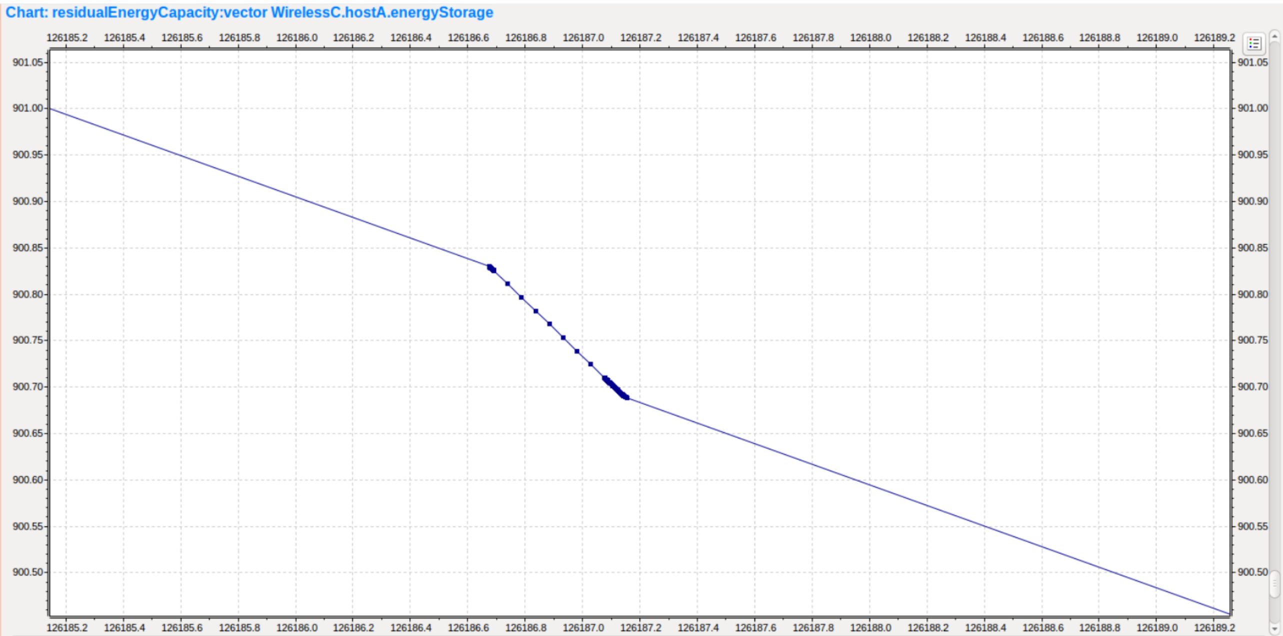

Figure 18 - Transmission of data

In Figure 19 the delay from Node A to eNode is shown. All generated packets reach between 50 ms and 80 ms the eNode. The X-axis represents the delay, while the Y-Axis represents the number of packets.

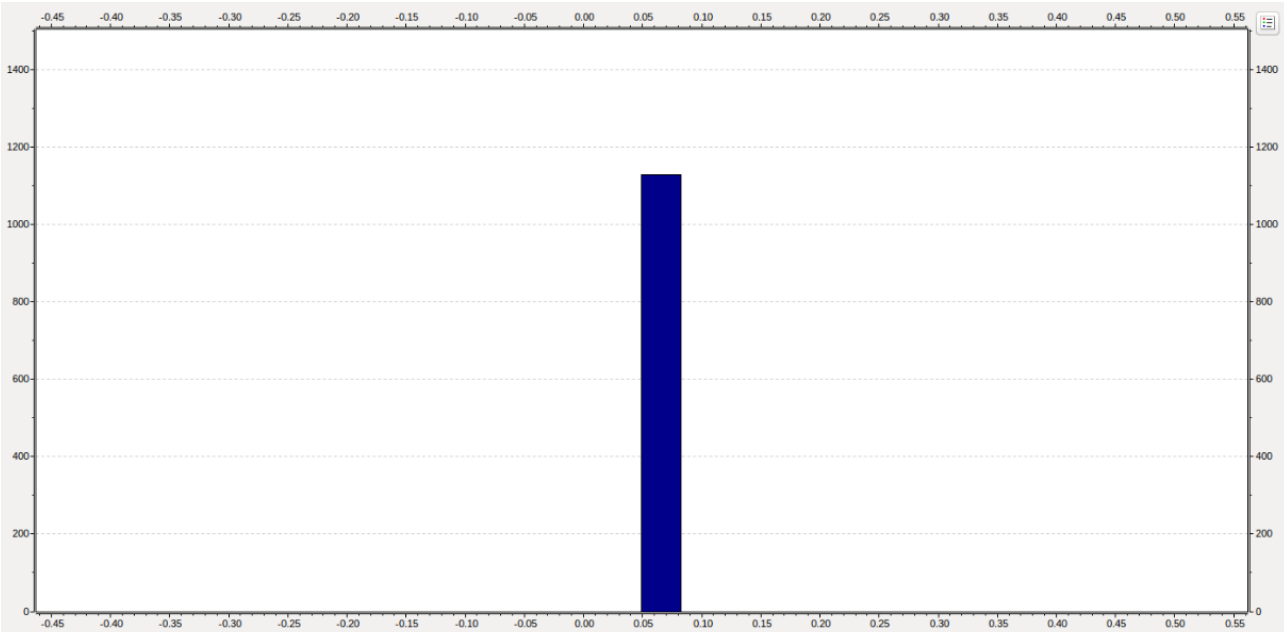

Figure 19 - End to end delay in eNode

4.2.2 LTE-based stabling area OCWC architecture

In the present section the simulation results are presented in the form of graphs exported from the application for the Scenario 4: LTE-based stabling area OCWC. The numerical results can be consulted in the Annex 1 and Annex 2.

In the scenario reported in Figure 20, Railway stabling area is simulated. All hosts from A to A4 represent a Railway OCWC or User Terminal of an LTE network, having an interval of traffic defined between 7000 seconds to 10000 seconds. The idea of this definition of traffic is to try to simulate different profile for railway traffic (irregular one with simultaneous links established from SCC to trackside during a defined period of time with inactive periods in between). It is assumed that the links are triggered by SCC on the train approach to corresponding trackside objects.

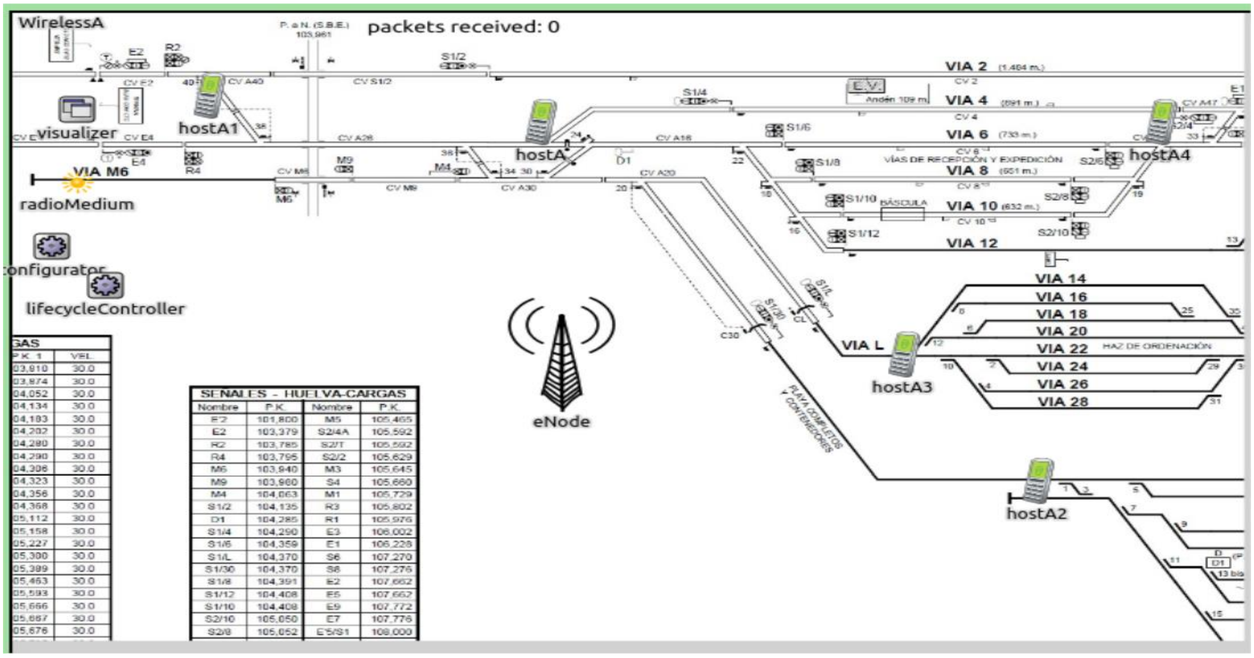

Figure 20 - Stabling area LTE scenario

In Figure 21 a complete view of energy depletion of all nodes, Host A3 will stand 1 day, 10 hours and 9 minutes (123000s), while Host A4 will stand 1 day, 3 hours and 46 minutes (100000s). In this figure X-axis represents the time and Y-axis the total amount of energy. All nodes start with the same amount of energy at instant 0.

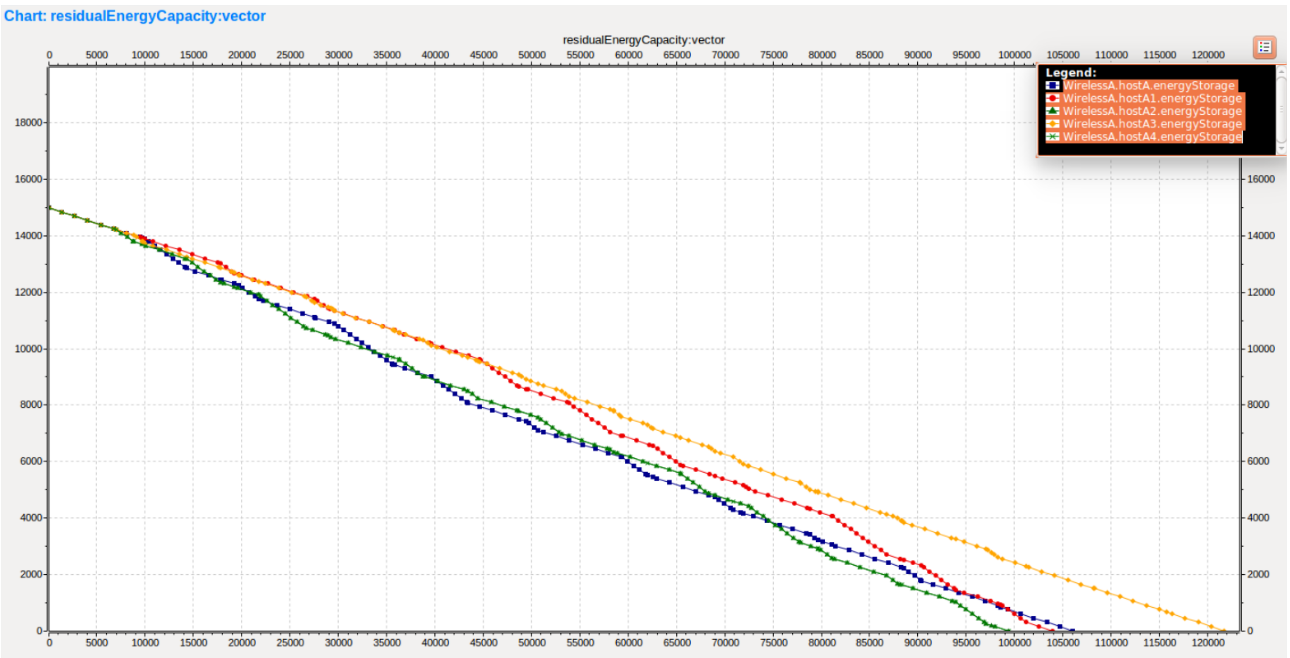

Figure 21 - Full view Of Energy Consumption LTE

From Figure 22 could be seen the different activation intervals of different nodes and its consumption, these intervals are defines as previously described in a random manner.

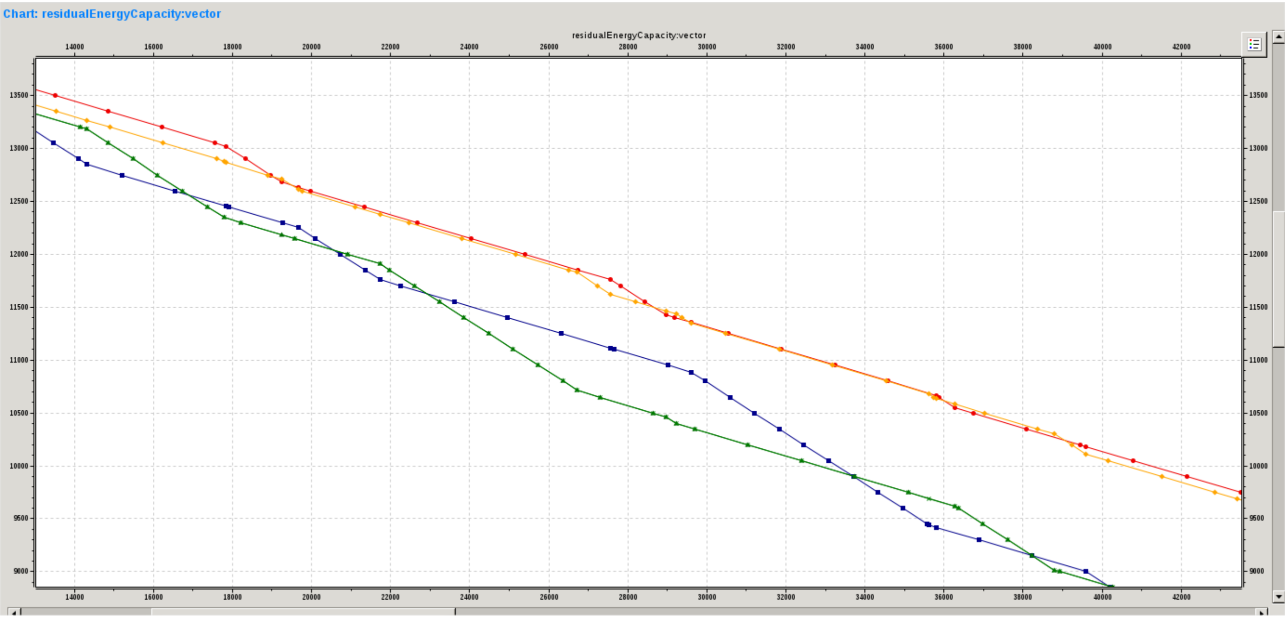

Figure 22 - Energy Consumption Zoom interval

In the Figure 23, the end to end delay from Node B to eNode is shown. All generated packets reach between 50 ms and 85 ms the eNode. The X-axis represents the delay, while the Y-Axis represents the number of packets.

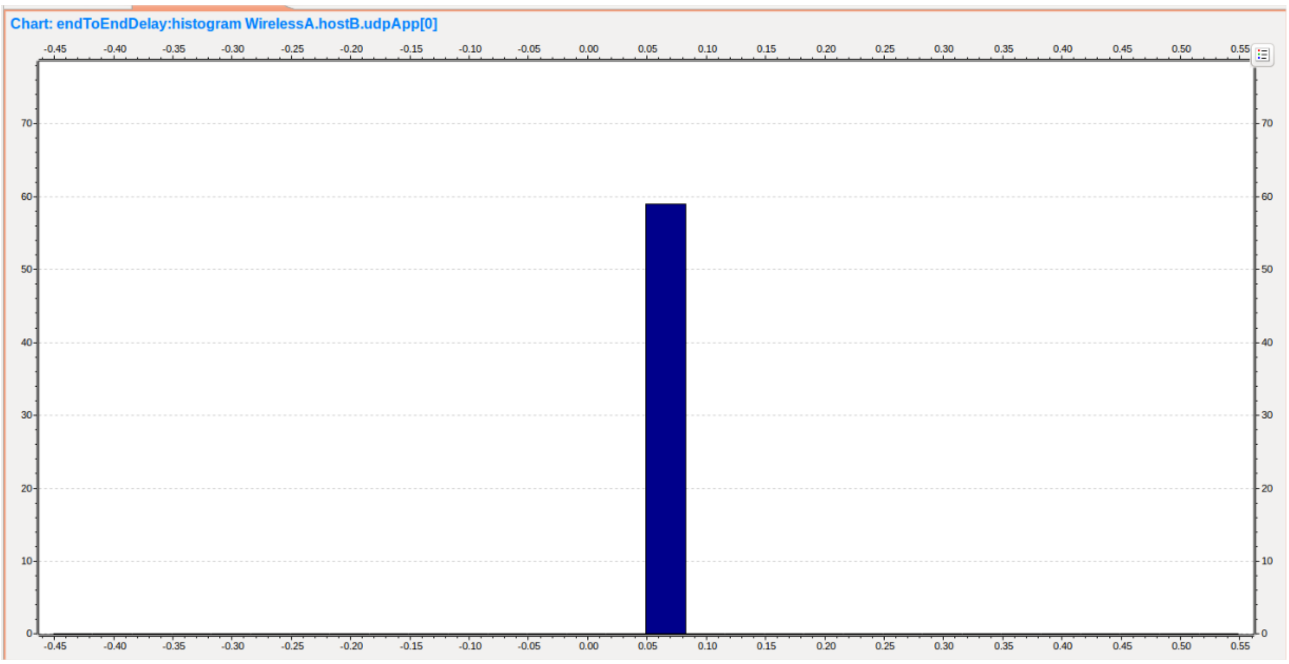

Figure 23 - End to end delay LTE stabling area

Figure 24 shows the packet error rate of each node in the stabling area, X-axis shows the percentage of error and Y-axis shows the number of packets that have this percentage.

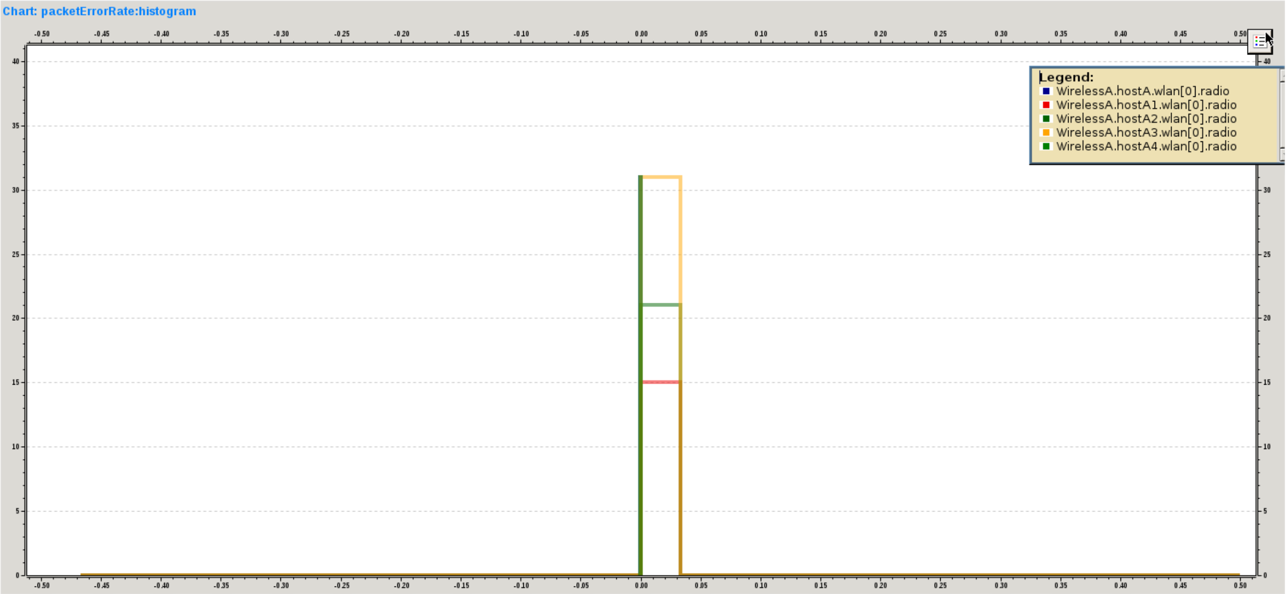

Figure 24 - Packet error rate LTE stabling area

5. POWER REQUIREMENTS

This section shows a summary of the numerical results extracted from the graphs presented in the chapter 4 divided in energy consumption parameters and quality of service parameters

5.1 ROBUSTNESS, AVAILABILITY, RELIABILITY AND MAINTAINABILITY FOR TEH

The TEH (Trackside Energy Harvesting) supplies power to the communication system of the field objects. The functional characteristics of the TEH must guarantee that rail traffic operations can be performed without interruptions due to insufficient power.

It is important that the TEH provides the designed supply respecting the admissible deviations of the rating for the communication system. The TEH is working in an open environment with variable ambient conditions: in front of the variation of the design parameters it must be able to provide the requested supply (see D2.1 §3.3.3 and EN 50125-3).

We expect that the power supply isn't the main contributor for the unavailability of the communications with the field objects. In any case, we can assume that the reliability of the TEH is comparable to the reliability of the transmission system of the object controller: if we consider the apportionment of the unavailability of the field object communications, we can assign half to the transmission system and half to the harvesting system. In this way the requirements for the performances of TEH aren't unnecessarily high but are comparable to the other elements of the communication system.

Since the TEH is a component installed with the field objects, its characteristics of maintainability have to be standard and easy: the detection of the fault should be immediate and a TEH should be rapidly substituted without the necessity of tests and regulations, i.e. require a MTTR (Mean Time To Repair) less than 0,5 hours.

Under these assumptions, we can expect for an energy harvesting device a reliability with MTBF (Mean Time Between Failures) of at least 10^5 hours and an intrinsic unavailability less than $5*10^{-6}$. Taking into account this value, the failure of TEH must not lead to a hazardous event: the hazardous consequences shall be treated and mitigated by the end devices and the loss of communication must be safely managed by the SCC and not lead to an accident (see D2.1 §3.3.1).

The performance of each TEH, which converts environmental energy sources as well as being susceptible to environmental effects that change performance (contamination of mechanical parts, dirt on solar panels, variability of environmental energy sources such as wind and sun) will vary significantly from one site to another. Even mechanical energy harvesters will be susceptible to changes in track stiffness and clearances etc. Some technologies will perform better at different times. Improved reliability under normal, defect free conditions therefore benefits from a diversity of technologies being used across a given Signalling and Control area. This could be implemented from multiple connections to common communication equipment, or from separate communication equipment having overlapping coverage areas. Further improvements to reliability can be achieved by increasing the capacity of each harvester relative to the projected demand, or in critical applications by having a backup supply from conventional primary batteries (normal life vs. installation life).

With regards to maintainability, it may be convenient to design the housing of the TEH and signalling electronics as a modular system, to facilitate upgrades and replacement of electronic components without disturbing a running harvester that may be attached to the rail. Conversely, if the TEH can be changed, this will eliminate reconfiguration of electronic modules for re-joining the network or recovering local status information.

Availability of the system will be determined by a combination of the diversity and redundancy achieved across the system, and by using conservative estimates of communication rate required over time when energy is available and when energy is not available. The duty cycle (energy supply and demand) and energy storage must both be understood, and components sized accordingly to allow sufficient safety margin and avoid service disruptions in all foreseeable load conditions.

6. CONCLUSIONS

In the present report the results of the simulations of OCWC behaviour are presented, the simulations have been provided for four scenarios:

Scenario 1: WSN technology based OCWC deployed in railway remote areas

Scenario 2 WSN technology based OCWC deployed in railway stabling areas

Scenario 3: LTE technology based OCWC deployed in railway remote areas

Scenario 4: LTE technology based OCWC deployed in railway stabling areas

The purpose was to provide a comprehensible and justified comparison of the performance of the two different proposed technologies in two different operational use cases. The parameters chosen to characterize the performance are related to energy consumption and to QoS of the communication network (end-to-end delay and packet error).

After comparing the results, it can be concluded that in terms of energy savings, WSN based devices consumes around 50% less energy than LTE based devices, but from the communication performance point of view, WSN technology has critical disadvantages since it doesn’t comply with QoS requirements for safety-critical communications (ETALON D2.2).

WSN performance could be potentially improved with a specific protocol for network topology and with the suppression of the CSMA/CA principle, main responsible for the increased delay, although another, more efficient protocol/function will still be required to avoid collisions between packets.

Also, is should be noted that the CSMS/CA principle has not been applied to the LTE simulation, since the number of nodes is limited, but in case of a denser network, specific protocols shall be employed including collision avoidance functionality.

Furthermore, it is important to highlight that a specific protocol shall be developed for railway operational conditions to meet the requirements of the railway infrastructure and further improve performance and efficiency for the solution.

Taking into account the above considerations, it can be observed that LTE technology is the solution that has greater potential for safety-critical railway applications also in light of future migration of train-to-wayside radio communication system.

Since LTE based OCWC have more stringent requirement to power the source, a further analysis of potential energy harvesting solution shall be done to determine the most suitable TEH type. The TEH candidates can be integrated in the simulations replacing fix batteries that are currently implemented to obtain data regarding OCWC-TEH system viability. For this purpose, the behaviour of harvesters in each use case (remote areas and stabling areas) will be defined in the ETALON WP4 and then simulated.

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[2] Reducing Energy Consumption of LTE Devices for Machine to Machine Communication by Tuomas Tirronen, Anna Larmo, Joachim Sachs, Bengt Lindoff, Niclas Wiberg and Ericsson Research, Published in: 2012 IEEE Globecom Workshops.

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[5] http://simulte.com/install.html

[6] https://github.com/boulis/Castalia

[7] https://inet.omnetpp.org/

[8] X2Rail-1 Deliverable D3.1 User & System Requirements (Telecommunications), Sept 2017

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[15] Design of an Antenna for a Wireless Sensor Network for Trains, Malkolm Hinnemo, Uppsala Universitet, December 2011

[16] Machine-to-Machine communication in LTE-A, Yu Chen, Wei Wang, 2010 IEEE.

[17] A high-efficiency self-powered wireless sensor node for monitoring concerning vibratory events, Dacheng Xu, Suiqiong Li, Mengyang Li, Danpeng Xie, Chuan Dong and Xinxin Li, 2017.

ANNEX 1: ENERGY CONSUMPTION

The energy storage unit (battery) introduced in the simulation has capacity of 15000 Joules and in the tables below the time that each node takes to completely consume this energy is shown.

Scenario 1 WSN remote area

Node	TIME
Node A	272309 s
Node R1	268337 s
Node R2	268989 s
Node R3	268772 s

Table 5 - WSN remote area energy depletion

Scenario 2 WSN stabling area

Parameter	WSN stabling area
Node A	272722.2 s
Node A1	272721.8 s
Node A2	272720 s
Node A3	272640 s
Node R1	272615 s
Node R2	272610 s
Node R3	272640 s
Node R4	272721s
Node R5	272671s
Node R6	272690 s

Table 6 - WSN stabling area energy depletion

Scenario 3 LTE remote area

Node	TIME
Node A	135047 s

Table 7 - LTE remote area energy depletion

Scenario 4 LTE stabling area

Node	TIME
Node A	105050 s
Node A1	103007 s
Node A2	99998 s
Node A3	123247s
Node A4	99997 s

Table 8 - LTE stabling area energy depletion

ANNEX 2: QUALITY OF SERVICE

In the present section the numerical results for Quality of Service parameters are presented. These parameters correspond to:

- Average end-to-end delay;
- Packet error rate (corruption and packet lost).

Scenario 1 WSN remote area

End-to-end delay

Packets affected by delay (% of total)	Average delay
5,103%	1,58s
8,96%	1,62s
8,97%	1,65s
8,96%	1,68s
8,96%	1,72s
8,95%	1,75s
8,97%	1,79s
8,94%	1,84s
8,93%	1,88s
8,95%	1,91s
8,97%	1,94s
5,3%	1,97s
0,025%	2s
0,006%	2,2s
0,006%	2,3s

Table 9 - WSN remote area delay

Packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
491745	98.82%	0%
5864	1.178%	3.4*10^-4%

Table 10 - Node A packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
634648	99.06%	0%
1758	0.27%	1.9*10^-6%
2034	0.32%	5.3*10^-6%
2253	0.35%	8.9*10^-6%

Table 11 - Node R1 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
485203	95.31%	0%
22792	4.48%	1.7*10^-6%
1076	0.21%	2*10^-6%

Table 12 - Node R2 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
497505	98.83%	0%
5865	1.17%	4*10^-6%

Table 13 - Node R3 packet error rate

Scenario 2 WSN stabling area

End-to-end delay

Packets affected by delay (% of total)	Average delay
10.57%	0-0,35s
18.88%	0,36s-0,7s
11.02%	0,71s-1,1s
16.31%	1,11s-1,4s
10.42%	1,41s-1,7s
12.84%	1,71s-2,2s
6.04%	2,21s-2,5s
6.59%	2,51s-2,9s
1.12%	2,91s-3,3s
1.12%	3,31s-3,6s
0.32%	5,1s-5,4s
3.54%	5,41s-5,9s
1.29%	5,91s-6,2s
0.80%	6,2s-6,5

Table 14 - WSN stabling area delay

Packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
9164	97.62%	0%
1	0.01%	4.710^-2 %
212	2.26%	5.2* 10^-2 %
10	0.11%	5.5* 10^-2 %

Table 15 - Node A packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
3805	94.44%	0%
12	0.3%	7.72*10^-8%
212	5.26%	6.62 *10^-8%

Table 16 - Node A1 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
10719	82.37%	0%
110	0.85%	3*10^-3%
1336	10.27%	1*10^-2%
433	3.33%	1.7*10^-2%
17	0.13%	2*10^-2%
384	2.95%	5.4*10^-2%
15	0.12%	2.7*10^-2%

Table 17 - Node A2 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
14647	95.33%	0%
65	0.42%	5%
96	0.62%	15%
47	0.31%	50
3	0.02%	70%
473	3.08%	76%
11	0.07%	82%
4	0.03%	92%
18	0.12%	100%

Table 18 - Node A3 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
7714	0%	0%

Table 19 - Node A4 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
17115	95.65%	0%
17	0.1%	1%
3	0.02%	7%
6	0.3%	8.5%
717	4.01%	20,5%
13	0.07%	22%
23	0.13%	24%

Table 20 - Node R1 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
12166	99.36%	0%
40	0.33%	1.2%
3	0.02%	2.3%
12	0.10%	3.5%
1	0.01%	11.5%
3	0.02%	12.4%
19	0.16%	20%

Table 21 - Node R2 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
8579	97.90%	0%
2	0.02%	2*10^-3%
2	0.02%	4*10^-3%
34	0.39%	9*10^-3%
3	0.03%	1.6*10^-2%
1	0.01%	2.4*10^-2%
33	0.38%	2.9*10^-2%
101	1.15%	3.4*10^-2%
8	0.09%	5*10^-2%

Table 22 - Node R3 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
6538	97.95%	0%
5	0.07%	17%
101	1.51%	77%
31	0.46%	85%

Table 23 - Node R4 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
5135	99.84%	0%
1	0.02%	17%
1	0.02%	77%
6	0.12%	85%

Table 24 - Node R5 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Error rate
12252	93.63%	0%
433	3.31%	3*10^-8%
17	0.13%	4.5*10^-8%
384	2.93%	1.15*10^-7%

Table 25 - Node R6 packet error rate

Scenario 3 LTE remote area

<u>End-to-end delay</u>

Packets affected by delay	Average delay
100%	50ms

Table 26 - LTE remote area delay

<u>Packet error rate</u>

Node	Error rate
Node A	0%

Table 27 - LTE remote area error rate

Scenario 4 LTE stabling area

End-to-end delay

Packets affected by delay	Average delay
100%	50ms

Table 28 - Delay LTE stabling area

Packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Mean error rate
31	91.17%	0%
3	8.82%	3.65*10^-7%

Table 29 - Node A packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Mean error rate
15	0%	0%

Table 30 - Node A1 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Mean error rate
21	0%	0%

Table 31 - Node A2 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Mean error rate
31	0%	0%

Table 32 - A3 packet error rate

Number of packets affected	Percentage of affected packets in respect of a total	Mean error rate
31	67,4%	0%
15	32,6%	3,7*10^-4%

Table 33 - A4 packet error rate