Enhanced PHY for Cellular Low power communication IoT

D2.1 Scenarios and Requirements

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Executive Summary

This report presents some applicative scenarios in which low power wide area (LPWA) systems are used to transmit information from a sensor and eventually to an actuator. These scenarios are used to derive the requirements for these links. These requirements are divided into 4 categories: The first is topology, the second is spectrum usage, the third is quality of service and the fourth is cost and size.These requirements will be used as targets for the rest of the project to develop new LPWA links. Key performance indicators are also given to evaluate and compare waveforms and resource radio management propositions. Another input to take into account is the regulation imposed in the frequency bands that will be used. Main regulatory aspects of the ISM bands at 868 and 915 MHz are given.

Contents

1 Introduction

The Internet of Things (IoT) is a large market with huge potential according to most of forecast analysts. Objects could be connected through short range communication systems (Wi-Fi, Bluetooth etc.) or directly connected to the network using e.g. mobile cellular communication systems. Recently, the notion of Low Power Wide Area (LPWA) networks appeared to cover technology enabling low power devices designed to directly connect to the network. Such LPWA systems include proprietary solutions (e.g. Ingenu, Weightless, Sigfox, LoRa) or evolutions of cellular system (e.g. 3GPP Cat-M1 or NB1).

On the one hand there are indeed several solutions offering IoT connectivity. On the other hand there are several types of objects, with possibly very different requirements for the connectivity and leading to many different use cases. We could for instance mention smart city leveraging the presence of sensors to optimize e.g. traffic lights; wildlife surveillance; healthcare; connected cars, or even virtual reality goggles. The number of possible applications conduct to extremely different requirements. In the context of the EPHYL project we will focus on low end devices, possibly battery powered, with low requirements in terms of throughput or data rate. In other words, we will not address the case of virtual reality goggles, surveillance cameras etc.

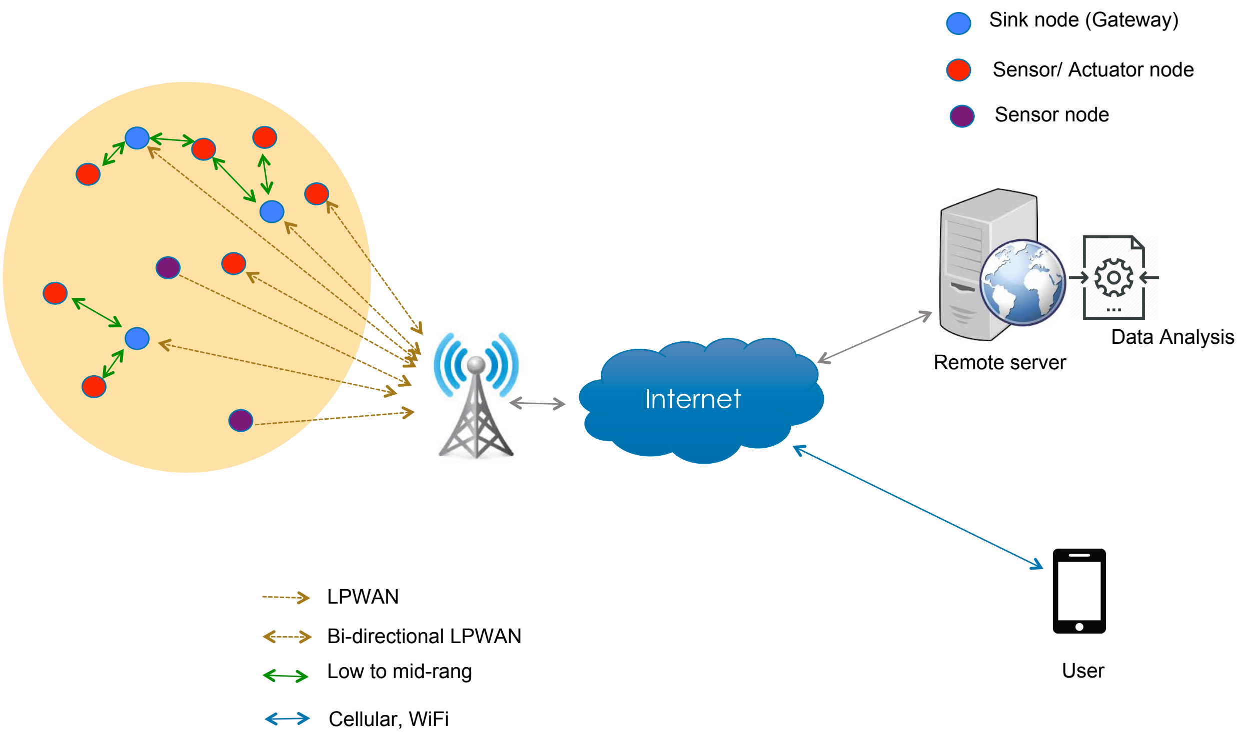

Figure 1: General IoT architecture

The general IoT architecture is depicted in Figure 1. Depending on the intended application, nodes can either simply sense environmental parameters or sense and actuate at the same time. Nodes can be either connected to the Internet through a sink node (or a Gateway) using a short to mid-range communication, or directly connected through a Low Power Wide Area communication technology. For sensing application, the downlink is used to acknowledge the reception of messages and to regularly check if the sensors are alive.

However, bi-directional communications are required for scenarios with sensor and actuator nodes. Data are remotely processed and appropriate actions are transmitted to the actuator nodes. At any time, authorized users access to data stored at the remote server.

The objective of this deliverable as described in the technical annex is to capture the scenarios that should drive the development of the technical activities. It will serve as a basis to align all partners on similar scenarios and objectives.

The document is structured as follows: Section 2 illustrates some typical use cases and provide basic requirements. Then section 3 elaborates a bit further the assumptions that will be used during the technical developments of the project. Similarly section 4 provides Key Performance Indicators (KPI) we like to evaluate through simulation. Then, section 5 briefly discusses about the regulation in the targeted frequency bands and finally section 6 concludes the document.

2 Typical use cases and scenarios and requirements

2.1 Smart parking

Today finding an available parking space in cities is a real issue. It contributes to significant traffic congestion since 30% of the congested traffic in a city is provided by cars that are seeking for free parking spaces (Shoup, 2011). As a consequence, this is a loss of time for parking space seekers but also for other drivers since it induces traffic congestion and as a consequence of the induced traffic congestion, 1 million of barrels of oil is wasted every day in the world causing pollution and costing money.

Smart parking could help to solve these issues. The expected benefits are (the list is not exhaustive):

- Guides residents and visitors to available parking spaces
- Optimizes parking space usage
- Decreases traffic in the city
- Reduces the emission of CO2 (consequence of the first and third points): forecasts are 220000 gallons of fuel savings till 2030 and 300000 till 2050
- Gain of time for users but also for other drivers thanks to the decrease of traffic
- Gain of money for the users due mainly to fuel savings, for the parking managers (or the city) due to optimization of parking space usage, for users and managers due to the possibility of making payment optimization

Starting from the current situation, the evolution towards smart parking will be facilitated under certain conditions. First the cost of infrastructure deployment should be contained. It includes the cost of each parking space sensor and the installation cost. In particular, the amount of roadwork should be limited. Secondly the constraints should be minimized, for example the duration of immobilization of an existing car park to convert it to a smart one should be as short as possible. Thirdly, maintenance should be reduced as much as possible to avoid human interventions. In particular, the lifetime of the sensors even if they are battery powered, must be as long as possible. Lastly, the system must be scalable. It must be easily adaptable to the add or the remove of parking spaces and resistant to breakdown of some equipment.

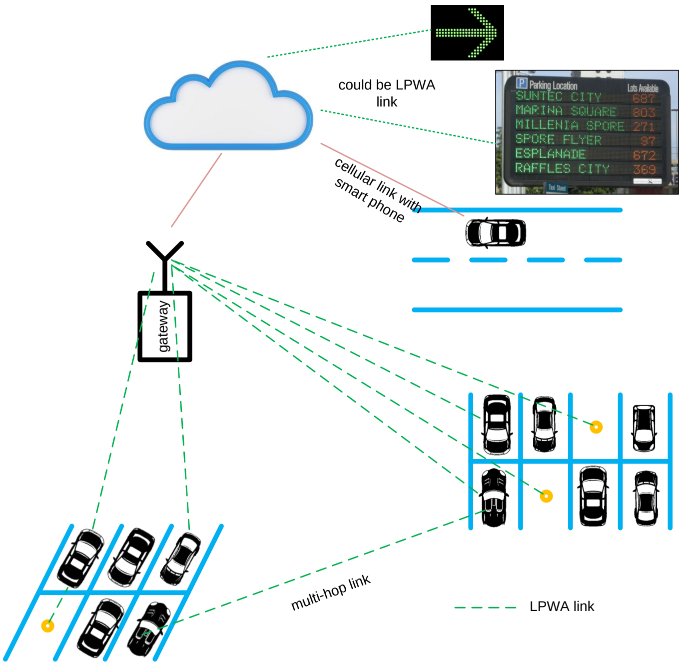

Figure 2: Smart parking scenario.

The smart parking scenario we want to address in the EPHYL project is described in Figure 2. There is one sensor per parking space. This sensor is used to detect if a parking space is empty or occupied. It must be autonomous (possibly thanks to energy harvesting) and as a consequence it must have a low power consumption to target several years of lifetime. This sensor sends its data to a gateway thanks to a wireless LPWA link. Wireless technology is imposed by its relatively low cost of deployment, low power to extend the lifetime of the sensor and wide area to have very little infrastructure (one to a few gateways per city according to the city size). Furthermore car parks can be located underground so the link has to be robust and resilient to the difficult propagation environment introduced by elements such as concrete walls. To extend this range or to get around obstacles causing a very strong shadowing (cars, several underground floors), multi-hops protocols could be considered and in this case transmitter and receiver are necessary at the sensor. Data messages are small, typically: ID + occupancy of the space + eventually position (a few bytes non withstanding overhead introduced by security issues). The gateway sends data to the cloud (database): this link might be a faster data rate link (it could be an LPWA link for small areas, local database, to contain the costs of a specific infrastructure). The cloud dispatches the data to the pices of equipment that need it: to large city display distributed around the city (it could be an LPWA link in some cases), to displays with arrows to guide the drivers to an empty parking space, to users through their smart phones (through a cellular link).

To put some numbers, we take the example of a medium french city: Grenoble. The area of the city is 18.13 km^2 and there is about 50000 parking spaces leading to a density of 2760 spaces/km^2. The peak density is reached inside a car park and it is usually 1 space/25 m^2/floor = 0.04 space/m^2/floor.

From the sensor a few bytes are sent per message, one message per event (an event is a change of status of a parking space). At most we have a few tens of messages per day. Periodic messages could also be sent to check if the sensor is still alive and to reinforce the reliability on a several hours basis.

In this scenario, the latency is the time elapsed between an occupancy change of a parking space and the feedback on the displays (panels or smartphones). To be efficient in a dense area, the latency should be below one minute.

The range or the maximum coupling loss should be such that indoor/outdoor link through concrete walls is possible.

No mobility is required for the LPWA link in this scenario.

The main requirements are summarized in the Table 1.

Table 1: Main requirements of the smart parking scenario

Coverage	**Low Power**	**Message size**	**Periodicity**	**Number of nodes**	**Latency**	**Mobility**
Deep indoor	Yes	Low size a few bytes	Event driven <40mess./day	High	<60 s	No

2.2 Trackers

Trackers represent the family of devices that regularly provides location information of the object it is related to. Example of such device can be:

- Asset tracking: valuable objects could be tracked in order to monitor delivery or to prevent robbery.
- People tracking: elderly people or people suffering from illness such as Alzheimer disease may like to be easily positioned in case of emergency. More recently, we see interest in children tracking !
- Pet tracking: similarly to people tracking (or asset tracking ?) people may like to monitor the location of their pets.
- Car tracking: some car lease company or insurance company may see benefit in the possibility to locate (and possibly send some commands) to the car they lease.

All these examples share the same requirements: ability to locate the device (either directly using the radio technology to provide the location), or using alternate technology such as GNSS to provide the location information. Location could be coarse or very precise (e.g. for emergency services). The rate of the update of location may vary for the different use cases: one value per day could be enough for certain scenarios, one value per minutes for others, or reporting the location when certain trigger is met (e.g. not need to report location in case of no location change, but report a new value in case of movement; another example could be to report location only if the object goes beyond a predefined area etc.). Reporting location does not require large messages. So, the size of the packet to be transmitted (in UL) is rather small (few kbytes). However, assistance information could be delivered DL to accelerate the location estimation such as GPS assistance information (e.g. GPS assist data service designed to accelerate a location fix). As a result, DL communication may be required. This is also the case when upon certain circumstance, action should be triggered to the device.

As a summary, requirements for this tracker scenario are:

- Mobility support, ubiquitous coverage (indoor / outdoor)
- Location support
- UL and DL communication
- for the UL small size packet message for location reporting ($<$ 100kbit), although possibly at regular time interval (up to every minute?)
- for the DL: software upgrade capable and limited packets size for triggering basic actions ($<$ 100kbit)
- Battery powered

2.3 Smart Viticulture

Smart viticulture is nowadays attracting a lot of attention in the wine industry sector. Different solutions were adopted in several countries Germany, Spain, California, Slovania etc. One of the main wine-producer challenges is to reduce the costs and to optimize the quality of the grapes. Currently, the vineyards growers face two major problems: the pests and the non-optimized water irrigation. On one hand, the traditional excessive use of pesticides to fight against grape diseases affects significantly the grapes quality. On the other hand, the intuitive irrigation in vineyards is not optimized and may lead to either an excess of irrigation or a non efficient use of water. Sensor networks that collect vineyards environmental factors as air humidity and temperature, soil humidity and temperature, solar intensity, are expected to help wine producer to remotely monitor grape diseases as well as the irrigation process. The benefits brought by the smart viticulture to the wine industry are:

- the prediction of the optimal time of harvest and consequently an optimization in resource management and staffing;
- the supervision of the grape and the leaf diseases;
- the improvement in terms of wine quality by defining the optimal time of irrigation and the use of pesticides;
- the eco-friendly operations that optimize the use of natural resources (water), decrease the pesticide residue as well as the fuel emissions induced by the supervision of multi-vineyards;

As a use case, the EPHYL project will address the Bordeaux vineyards that cover a total surface of 117 200 hectares. The mean density of vines in these vineyard varies from 4 000 to 7 000 vines per hectare. The Bordeaux vineyards is one of the most famous wine producing region in the world and is considered as the third wine producing region in France after the Herault and Aude departments. Considering all the plants in Bordeaux, a massive sensor network should be considered in this case. We will assume that in each surface of radius of 50m, a device containing: a sensor board, a water valve actuator, a radio module, a rechargeable battery and a solar panel. Various sensors are connected to the sensor board to measure different parameters as the temperature, humidity (ambient and soil), leaf wetness, atmospheric pressure, pluviometer, wind, radiation, etc. These measurements are transmitted via the wireless network to a remote server where intelligent algorithms are used to process data and to remotely control the water irrigation, to alert the wine producer of the emergence of vine disease and to recommend appropriate actions. In term of signaling, the plant device should have very low duty cycle and will be sleeping most of the time in order to save battery. The plant device wakes up twice per day to read the sensors parameters and to transmit the information to the controller. The total number of messages sent per device per day is therefore 2 messages per day. Neighboring plants transmit highly correlated information. The correlation between information can be exploited to reduce the interference and to improve accurate values through data processing. The device uses energy harvesting and is powered via a rechargeable battery and a solar panel. Irrigation actions should be activated by the network, and that's why the network should be bi-directional. The existing solutions proposed in smart viticulture are based on a combination of mid-range wireless communication and classical cellular networks. In such architecture, adequately positioned gateways collect the data from the sensors. These relays transmit then the information to a global collector. The global collector transmits the collected data via a long range wireless communication technology. The gateways and the global collectors form an ad-hoc network. Data packets are relatively small, containing the ID of the plant and the sensors measurements (a few bytes). Within the EPHYL project, we will consider low power wide area networks in which plant devices transmit directly their data to the network via licensed or unlicensed Low Power Wide Area Networks (LPWAN). The network is latency tolerant and thus communication can be multi-hop in which different relays are used to collect the data.

2.4 Alerts for critical applications

The naming "alerts for critical applications" gathers scenarios of monitoring, threshold detection and alarm trigger, where the alarm or the data to be transmitted has to be taken into account in a very short time. Indeed, in addition to its mandatory effective reception in order not to miss any data, this information would not have any signification if arriving at destination with a long delay, which is even more accurate in case of alarm signals.

As an example, critical applications relate to the contexts of :

- home, industrial and urban temperature, gas, water, air, etc. metering and control;
- incident signalizing such as fluid leakage, fire, pollution or traffic alarms (for accidents, dysfunctional traffic lights, and other disturbances);
- medical sensing and monitoring;
- vehicular communications...

The later has a potentially high data rate (and/or Peer-to-Peer) communication scheme so, as already stated in the introduction, we are not dealing with this type of use cases. The cases of strict metering communications, referring to a more or less periodic activity, is addressed in the above scenario of smart viticulture; therefore, we will focus on the alarm signals of the previously mentioned use cases, which are about sporadic communications.

Indeed, the typical sporadic traffic scheme of these use cases is based on the rare characteristic of the monitored events. These alarm events are rare both in time and space since the managed environment has a large scale, i.e. there is a very large amount of nodes whose communication activity is very low. Therefore, this scenario is dealing with dense networks and sporadic communications.

Furthermore, the packets size will be short since the information to transmit comprise either only an identifier or if needed an identifier together with an additional data such as a sensed value above a threshold. This leads to consider that the size of the packets' payload does not exceed a few bytes.

Depending on the use case, nodes may have to be deployed in inaccessible places or may be mobile. Consequently, powering these nodes would be constraint and embedded, as such, their communications require energy efficiency and reliability even though they are situated in a highly unfavorable environment.

As an example, the context of forest monitoring and wildland fire detection described in (Molina-Pico, Cuesta-Frau, Araujo, Alejandre, & Rozas, 2016) is a typical case where deploying a sensor network for fire alarm signalization is required. In this article, a hierarchical wireless sensor network is built by disseminating sensor nodes every 25m approximately, together with central nodes for access points at a larger distance. In that network, the sensed data has to be relayed through several central nodes before reaching the control centre since the network has a tree hierarchy. In case of fire alarm, this architecture introduce latency although dealing with critical information. Therefore, in order to remove this relay constraint, the EPHYL project will consider similar sensor node spreading, but those nodes would use direct LPWA uplink communications.

To sum up this scenario, alerts for critical applications require overall a very high reliability, but also a low latency for ensuring a short delivery delay of the real-time monitoring. The communication network must satisfy a long range coverage, for outdoor as well as deep indoor, and support the possible mobility of its dense population of nodes, which are communicating sporadically with short packets.

2.5 Smart grid case

The increasing development of renewable energy resources, the cost of power failures and the need for optimization is driving electricity operators towards the development of new functions for the real-time management of the electrical grid. These improvements change the traditional electrical grid into the so-called Smart Grid (SG).

Three functions are generally proposed to manage the smart distribution grid: the advanced metering infrastructure (AMI), the distribution automation (DA) and the management of distributed energy resources (DER) (Brown, 2008). Furthermore, the management of a smart grid is carried out through smart sensors and actuators deployed all along the grid. One of the main roles of these devices is to provide an overall view of the state of the grid as continuously as possible. This cannot be done without an efficient communication system.

Each of the functions developed for the management of the grid has its own constraints in term of throughput, latency, security and reliability (U.S. Department of Energy, 2010). As a consequence, the design of the smart grid communication infrastructure is one of the key point in Smart Grid deployment.

A variety of LPWANs standards have recently been proposed. These standards can be sorted in two categories. On the one hand, the NB-IoT standard (Ratasuk, Vejlgaard, Mangalvedhe, & Ghosh, 2016) designed by the 3GPP is used for long range communications are slotted protocols. On the other hand, the LoRaWAN standard (Anteur, Deslandes, Thomas, & Beylot, 2015) or the protocol used by Sigfox based on Ultra Narrow Band (UNB) (Abramson, 1970) communications are unslotted (or pure) ALOHA based protocols (Semtech, 2015). In these unslotted protocols, the signalling is reduced to diminish the end-device energy consumption and transmissions are asynchronous and event-driven. Furthermore, in order to limit the impact of the acknowledgement on the end-device energy consumption, the receive window during which the end-device waits for an acknowledgement has to be shortened. To do that, the acknowledgement can be sent at the same moment. In other words, the receive delay between the end of the uplink packet and the transmission of the acknowledgement is constant. With this simple mechanism, the end-device senses the channel during a very short time to detect the preamble of the downlink packet. This solution is used in the LoRaWAN standard (Semtech, 2015), (Sornin, Luis, Eirich, Kramp, & Hersent, 2016). Indeed, in this standard an acknowledgement is sent in the channel used for the uplink transmission one second after the end of the reception of the uplink packet (Semtech, 2015).

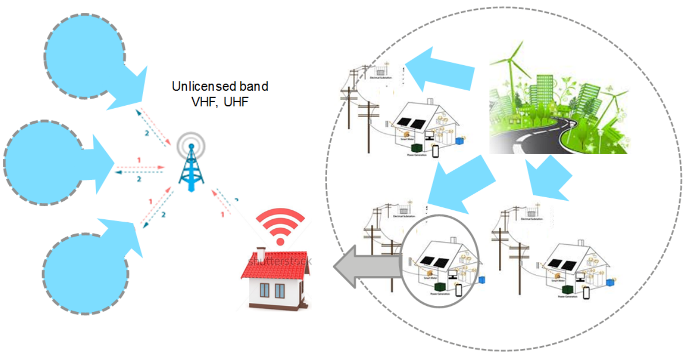

Figure 3: IoT-Smart grid scenario.

In previously mentioned LPWANs, the channel used for the uplink transmission is chosen by end-devices. These networks operate in unlicensed bands. However, the end-devices can have different behaviour or capabilities which depends on their manufacturers and on the requirements of their applications (temperature sensing, smart grid monitoring, etc.). This can create an imbalance in the number of communications in channels and consequently an imbalance in the probabilities of collision. Thus, if an end-device can access to several channels, it can use intelligent frequency access schemes to reduce its packet loss ratio and reduce the latency of its communications.

In this scenario, we focus on the communications between aggregators and the LPWAN base station. First of all, compared to most of other Smart Grid communications, the AMI communications has less tight constraints. According to (U.S. Department of Energy, 2010), the maximum latency of AMI communications should be between 2-15s and a 99 reliability (in term of packet delivery ratio) is sufficient. Consequently, unslotted ALOHA LPWANs can be used for AMI backhaul. Moreover, compared to other devices that will use LPWANs, aggregators are less constrained in energy consumption and will have the possibility to use several channels. Therefore, they will be able to use intelligent frequency access schemes to reduce both their packet loss ratio and latency. In this scenario, we only consider interferers which use the same standard. We suppose that the packet length is the same for all devices.

The focuses in smart grid scenario will be on:

1. Analyse the latency of AMI communications for different frequency access schemes.

2. Introduce cognition and learning mechanisms to enhance the LPWAN channel selection as Upper Confidence Bound algorithm (UCB), and reduce the collision percentage.

2.6 LTE-MTC case

In this scenario, we explore the opportunity opened by the combination of LTE links for supporting low rate low power machine type communications (MTC) or Devices (MTD). We motivated our system model by on body sensing MTC devices which can be characterized (Ratasuk et al., 2016), as having contained battery life, for non-threatening life conditions to be delay tolerant and, due to the ubiquitous cellular coverage, to be in close proximity of a smart phone. The considered setup is presented in figure 4. In this scenario, the MTDs (labelled as M in figure 4) send the body sensed information to the user equipment (LTE compliant) devices. The MTDs information will be relayed throught the users' uplink communication resource blocks (RB) to transmit the information. Different access modes and resource mapping are envisaged to ensure the best coexistence between the MTD information and the pure LTE data traffic (standalone or in-band). Higher coverage and data rate MTDs (i.e., NB-IoT or LTE machine-to-Machine) can be considered in this scenario with direct transmission capability to base station.

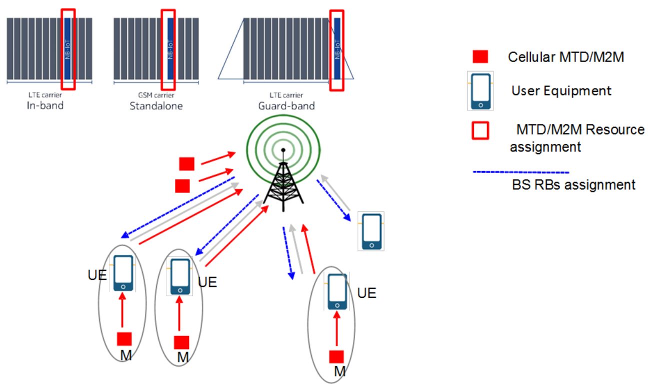

Figure 4: LTE-MTC scenario.

Main focuses in this scenario will be to propose solutions on network assisted machine type device solution that enables the cooperation between the short range (and cellular MTDs) and normal cellular devices, while reducing the outage of the machine-type communications and maximizing the combined cellular system rate. One of the main performance objectives is the outage probability for a given low fixed rate for the Machine-Type communication versus rate maximization for the cellular broadband traffic.

2.7 IoT in TVWS case

Studies have quantified the amount of spectrum available that could be used by IoT in bands as VHF, UHF and millimeter frequencies in the order of 30GHz (Ofcom, 2015). The possible use of the UHF band, currently destined to DVB, raises a very interesting solution to consider the deployment of IoT technologies. This band offers good propagation characteristics and low implementation costs. In 2015 at the World Radio Conference (WRC-15) was agreed to keep allocation in the 470-694MHz band to DVB as a primary service, and the possibility of being used for broadband services only in downlink (always accomplishing the quality of the primary service). However, studies are required for 2025 when the future use of this band will be discussed with the possibility of being used as dedicated or shared spectrum with other wireless technologies (Lamy, 2013). Nowadays there are very limited studies evaluating candidates of IoT technologies adapted to share the digital TV band (Digital Video Broadcasting-Terrestrial-DVB-T).

In this scenario, the main target is to use the white spaces of the DVB band (TV-White Space) through spectrum sharing between DVB and IoT networks. The proposed scenario considers a DVB network offering fixed rooftop reception as a primary service and NB-LTE network IoT as a secondary service. Several representative scenarios to deploy IoT will be evaluated, both uplink and downlink modes will be considered. The aim is to study and evaluate whether the coexistence of both technologies in co-channel or adjacency is possible by determining the margins of protection and Equivalent Isotropic Radiated Maximum Power (EIRP) that could transmit base stations and IoT devices. The objective is to satisfy the spectrum requirements for IoT technologies through the sharing of the digital TV band. It also assesses an important candidate for IoT technology defining the power requirements to be met for coexistence with DVB-T systems. The narrowband nature of the IoT technology may offers efficient use of the radio spectrum that would allow better use of frequency with better adaptation to the spectrum available.

The scenario under analysis evaluates the coexistence of DVB-T network offering fixed rooftop reception as a primary service, and an NB-IoT small cell giving coverage as a secondary service. The DVB-T useful signal occupies a bandwidth of 8 MHz (the European Channelling) and the NB-IoT interfering signal has a bandwidth of 200 KHz for both uplink and downlink. It is considered that the digital TV signal uses 47 channel (678-686 MHz) and the IoT NB-LTE signal transmits in co-channel or adjacency channel 48 (686-694 MHz). Line of sight is assumed and the propagation losses are the smallest possible between the NB-LTE uplink and downlink and the digital TV receiver antenna (worst case). Furthermore, the receiving digital terretral TV antenna is located to a typical height of 10 meters above ground level.

3 Main assumptions

This section summarizes the network assumptions used in each scenario. The topology, the spectrum usage, the quality of service, the cost and size used in each scenario will be detailed in the following.

3.1 Topology

The topology in each scenario is described by the following parameters:

- Propagation environment: it corresponds to the environment in which the radio propagation occurs.
- Communication range: indicates the furthest distance in km between the nodes and the LPWAN stations.
- Mobility: specifies if the LPWAN network should handle or not the mobility of the nodes.
- Network topology can be star, tree or mesh topology. In a star topology, all nodes are individually connected to a central connection point. In a tree topology, each node is connected to a central connection point but, if necessary, through other nodes. In a mesh topology, each node is connected directly or indirectly to all other nodes.
- Nodes density indicates the number of nodes per km^2.
- Maximum number of nodes per cell.

	Smart Parking	Trackers	Smart Viticulture	Critical Applications	Smart Grid	LTE-M (TVWS)
Propagation	(deep) indoor and outdoor	Indoor and outdoor	outdoor	(deep) indoor and outdoor	outdoor	outdoor
Range	10 km	30 km	10 km	50 km	10 km	10 km
Mobility	No	Yes	No	Yes	No	No
Topology	Star or Tree	Star (cellular)	Star or mesh	Star or mesh	Star	Star
Nodes density	3000/km^2	10-100 nodes/km^2	128 nodes/km^2	500 nodes/km^2	5-50/km^2	-
Maximum number of nodes	50000	-	40 thousand/cell	4 thousand/cell	up to 5000/cell	-

Table 2: Scenarios topology

3.2 Spectrum usage

The spectrum usage of each scenario is described with the following parameters:

- Peak bit rate of one node : it corresponds to the maximum throughput of information send by a single node in number of bit per second.
- Message size : it measures the total length of a message in byte.
- Periodicity : this parameter characterizes how often a node sends a packet to the network, it is also a measure of the duty cycle and corresponds to the elapsed time between 2 communications in the cases of regular activity, otherwise its average.

  One can therefore obtain the daily network load by multiplying the message size by the number of nodes (see the previous table) by the periods in 1 day.
- Traffic breakdown (UL/DL): it describes the type of spectrum allocation between Uplink and Downlink communications and specifies if one of the traffics' amounts is dominant.
- Interference topology : this feature specifies the kind of Medium Access planned for each use case to deal with competitive communication.
- Spectrum type : this parameter specifies whether the communications occur over an unlicensed or a licensed spectrum band.

	Smart Parking	Trackers	Smart Viticulture	Critical Applications	Smart Grid	LTE-M (TVWS)
Peak bit rate of one node	< 1kbps		50 kbps	<1kbps	50 kbps	1 kbps-1 Mbps (0.1 kbps-200 kbps)
Message size	a few bytes	50 bytes	20 bytes	a few bytes	200 bytes	(few bytes)
Periodicity	Event driven (<40 messages / day)	minute - hourly reporting (1440/day - 24/day resp.)	twice per day	rare event driven (<1/day)	Once every 15, 30 or 60 minutes (96, 48 or 24/day)	-
Traffic breakdown (UL/DL)	mainly UL traffic	Mostly UL	Bi-directional: UL & DL	mainly UL	mainly UL	mainly UL
Interference topology	ALOHA		Aloha access	Non Orthogonal Direct Access	ALOHA	Orthogonal direct access (ALOHA)
Spectrum type	Unlicensed	Unlicensed /Licensed	Unlicensed	Unlicensed /Licensed	Unlicensed	licensed (LSA)

Table 3: Scenarios spectrum usage

3.3 Quality of service

In this section are given the considered assumptions linked to quality of service.

- Traffic priority management: is there a requirement for a two tier service with priority managements.
- Latency: end-to-end latency measures the duration between the transmission of a data packet from the source node and the reception to the destination node.
- Reliability rate (target of packet delivery ratio): requirement on the amount of transmitted packed successfully received by the receiver.
- Flexibility of QoS: different data services may require different optimization of the QoS (Latency, Network Reliability and Rate).

- Adaptative rate: is there a requirement to provide different level of rates depending on the application?
- Duplexing: half-duplex or full-duplex operation. LPWA applications are expected to be half duplex for all scenarios.

	Smart Parking	Trackers	Smart Viticulture	Critical Applications	Smart Grid	LTE-M (TVWS)
Traffic priority management	No	No	No	Yes	No	No
Latency	< 60 s	No real time constraint	30 s	a few sec.	2-15s	-
Reliability rate	99%	99%	99.9%	99.9%	99 - 99.99%	99.9% (99%)
Flexibility of QoS	No	-	Yes	No	Yes	Yes
Adaptative rate	No	-	Yes	No	Yes	Yes
Duplexing	Half duplex	Half-duplex	Half duplex	Half duplex	Half duplex	Half duplex

Table 4: Scenarios quality of service

3.4 Cost and size

In this section we introduce the assumptions related to cost and size of the device. As previously, we focus on the device part, not so much on the network side.

- Battery lifetime. This represents the maximum duration of operation of the device in normal operation mode. Most of the scenario consider indeed devices that are battery powered and that aim at no being maintained during their lifetime.
- Maximum transmitter power. This parameter represents the maximum transmit power of the device. This parameter is directly linked with the UL range as well as with the battery lifetime, since transmission is one of the main consumer of the battery. An interesting outcome of the work could be to define power consumption models that could take into account this maximum transmit power but especially key characteristics of the LPWA waveform (modulation efficiency, DRX cycles, etc.)
- Size. This parameter gives an indication of the size of the device. It is purely indicative.
- Complexity. This parameter should represent the complexity of the device. Actually, when discussing LPWA system, it is inherently assumed that the device has low complexity in order to be low cost (and also long battery lifetime). The complexity could be evaluated based on "visual inspection" (e.g. supporting 1 band would be less complex that to support multiple bands) or based on more precise analysis such as for instance the number of operations per time unit, the memory size required, the number of interfaces offered etc..

	Smart Parking	Trackers	Smart Viticulture	Critical Applications	Smart Grid	LTE-M (TVWS)
Battery lifetime	5-10 years	10-15 years	rechargeable (solar panel)	limited or not (embedded, harvester)	not limited (the sensor is on the electrical grid)	battery lifetime
Maximum transmitter power	14 dBm	14-23dBm	14-21 dBm	30 dBm	14 - 21 dBm	23 dbm (14-21 dBm)
Size	small size	small size	small to medium	small	medium	medium to cellular (small to medium)
Complexity	Low	Low	Low	Low	Low	Medium (low)

Table 5: Scenarios cost and size

4 Key Performance Indicators (KPI)

Hereunder is a list of criteria which will be taken into account for the evaluation of our propositions.

- Reliability. It deals with the delivery rate of the incoming information. It can be measured with different units such as Packet Error Rate or Bit Error Rate (ratio of received packets over sent packets, respectively bits).
- Capacity. This criterion gives a measure of the maximum information rate.
- Coverage. This indicator presents achieved coverage.
- Latency. This indicator quantifies the time delay from the beginning of the emission process until the successful reception at the receiver side.
- Power Consumption. This criterion can be measured in Joule/bit for evaluating the communication's energy efficiency.
- Throughput. It indicates the achieved information rate, measured as number of delivered information bits per second (or another unit of time).

- Goodput. The throughput and the goodput both indicate information rates. The difference between the two lies in the considered incoming bits : the throughput takes all incoming bits into account whereas the goodput only focuses on high-layer information bits, which can be called "useful information bits" in the application perspective, i.e. it does not count low-layer headers for instance. Therefore, the goodput measures the amount of useful bits that the network delivered per unit of time.
- Energy efficiency of high layer useful information. In the same lines, this criterion measures the efficiency of useful information bits, in Joule/useful bit.
- Spectral occupancy. It corresponds to the spectrum band usage of a communication (in Hertz). Dividing the throughput by this spectral occupancy gives the spectral efficiency of the communication (in bit/s/Hz).
- Sensitivity. It indicates the lowest received power for which the packet error rate is below a predefined level. The measure is in dBm.
- Network outage. A network event occurs when there is no more available radio resources in the network. This network dimensioning criteria is used to indicate the capacity of the network to handle all the nodes traffic.
- Peak to average power ratio (PAPR). It indicates the ratio (generally in dB) between the peak power of the transmitted signal and its average power. This is an important parameter for the design of a transmitter since it is an indicator for the class of power amplifiers that can be used and thus the power consumption.

5 Spectrum regulation

5.1 868 MHz band

The 868 MHz band is only available in Europe. The equivalent band in USA is 902-928 MHz (commonly abbreviated as the 915 MHz band, see next section).

In Europe, 2 documents detail the regulation for 868 MHz band: (CEPT Electronic Communications Committee, 2016) and (ETSI, 2012).

- Bands h1.1, h1.2 and h1.3 between 863 MHz and 870 MHz
  - The power is limited to 25 mW (14 dBm) and the duty cycle is limited to 0.1% or listen before talk (LBT) and adaptive frequency agility (AFA)
    * For frequency hopping spread spectrum (FHSS), the maximum occupied bandwidth must be lower than 100 kHz for 47 or more channels. The preferred channel spacing is 100 kHz allowing for a subdivision into 50 kHz or 25 kHz.
    * For direct sequence spread spectrum (DSSS) and other wideband techniques, the maximum occupied bandwidth is not specified. The power density is limited to -4.5 dBm/100KHz but can be increased to +6.2 dBm/100 kHz and -0.8 dBm/100 kHz, if the band of operation is limited to 865-868 MHz and 865-870 MHz respectively. For wide-band techniques, other than FHSS, operating with a bandwidth of 200 kHz to 3 MHz, the duty cycle can be

increased to 1% if the band is limited to 865-868 MHz and power to 10 mW e.r.p (10 dBm).
    * For Narrow /wide-band modulation, the maximum occupied bandwidth can be lower than 300 kHz.
  - Duty cycle may be increased to 1% if the band is limited to 865-868 MHz.

- Band h1.4 between 868 MHz and 868.6 MHz for Narrow /wide-band modulation: The power is limited to 25 mW (14 dBm) and the duty cycle is limited to 1% or LBT+AFA. No spacing, for one or more channels
- Band h1.5 between 868.7 MHz and 869.2 MHz for Narrow / wide-band modulation: The power is limited to 25 mW (14 dBm) and the duty cycle is limited to 0.1% or LBT+AFA. No spacing, for one or more channels
- Band h1.6 between 869.4 MHz and 869.65 MHz for Narrow / wide-band modulation: The power is limited to 500 mW (27 dBm) and the duty cycle is limited to 10% or LBT+AFA. No spacing, for one or more channels
- Band h1.7 between 869.7 MHz and 870 MHz for Narrow / wide-band modulation
  - The power is limited to 5 mW (7 dBm) without requirement on duty cycle
  - The power is limited to 25 mW (14 dBm) and the duty cycle is limited to 1% or LBT+AFA without requirement on duty cycle

Recently in Europe, (CEPT Electronic Communications Committee, 2016) proposes to extend h band:

- Band h2 is between 870 MHz and 876 MHz. The power is limited to 25 mW (14 dBm) and the duty cycle is limited to 0.1%. The maximum occupied bandwidth is limited to 200 kHz. For ER-GSM protection (873-876 MHz, where applicable), the duty cycle is limited to $\leq$ 0.01% and limited to a maximum transmit on-time of 5 ms each 1 s.
- Band h2.1 is between 870 MHz and 875.8 MHz. The power is limited to 25 mW (14 dBm) and the duty cycle is limited to 1% between 870 MHz and 873 MHz. The maximum occupied bandwidth is limited to 600 kHz. For ER-GSM protection (873-875.8 MHz, where applicable), the duty cycle is limited to $\leq$ 0.01% and limited to a maximum transmit on-time of 5 ms each 1 s.

5.2 915 MHz band

In the US, the frequency band of 902-928 MHz is one of the ISM bands, commonly abbreviated as the 915 MHz ISM band. In this band, there are no restrictions to the application or the duty cycle. FCC section 15.249 allows 50 mV/m of electrical field strength at 3 meters distance in the frequency band of 902–928 MHz. This corresponds to an EIRP of –1.23 dBm.

Nevertheless, in FCC section 15.249 for applications using digitally spread techniques, the EIRP is limited to 36 dBm. Moreover, some limitations are defined in FCC section 15.247 for applications using frequency hopping spread spectrum techniques:

- If the channel bandwidth is less than 250 kHz, the system must use at least 50 hopping frequencies and the average time of occupancy at any frequency (dwell time) must not be larger than 0.4 seconds within any 20 second period. The power is limited to 36 dBm.
- If the channel bandwidth is larger than 250 kHz, the system must use at least 25 hopping frequencies and the average time of occupancy at any frequency (dwell time) must not be larger than 0.4 seconds within any 10 second period. The power is limited to 30 dBm.
- It is not permitted to synchronize transmitters of different frequency hopping systems to each other. This could lead to a super system that occupies individual frequencies for more than the allowed 0.4 seconds in the 10s or 20s period.

Recently in Europe (CEPT Electronic Communications Committee, 2016) has proposed to re-allocate a part of 915 MHz band, unfortunately, these recommendations are not available in all European countries.

5.3 Licensed bands

Cellular IoT is by nature for cellular deployment. As such, it is reasonable to think that the traditional cellular ecosystem would like to address this promising market. As a result, it is expected that the operated spectrum will be also used to serve cellular IoT. This is the case typically of solutions defined by the 3GPP such as the cat-M and NB1 as well as their evolutions. This spectrum is licensed to a given operator and not shared. The rules driving the use of this spectrum are defined by 3GPP and depends on the given band. 3GPP and local regulation interacts as such that the 3GPP defines a global solution, valid in theory worldwide.

6 Conclusion

The first deliverable of the EPHYL project gives some applicative scenarios where LPWA link would be necessary or would give a capital gain compared to existing technology. These scenarios have been described to show the interest of the LPWA link and to derive some preliminary requirements. Then we derive detailed targets divided in four categories: Topology, spectrum usage, quality of service and, cost and size. The solutions we will propose concerning the waveforms and the radio resource management will be confronted to these targets and evaluated thanks to the key performance indicators that we listed.

We also have to take into account the constraints coming from the regulation, in particular in the sub gigahertz ISM bands at 868 MHz (Europe) and at 915 MHz (USA).

As a consequence this deliverable will be used all along the project to keep all the partners aligned with the objectives we have just targeted.

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