Research by Experimentation
for Dependability on the
Internet of Things

D-4.1 – Report on Use Case Definition and Requirements

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Abstract This document presents four candidate Internet of Things use cases that are going to be analyzed for their dependability requirements. The use cases encompass a range of typical Internet of Things applications designed for different operating environments and dependability requirements: (1) Outdoor Parking Management, (2) Civil Infrastructure Monitoring, (3) Condition Based Maintenance, (4) Ventilation on Demand. We analyze the potential impact of environmental variations on the dependability requirements of each use case, in terms of data loss, latency and operational lifetime. The primary environmental factors we consider are temperature and radio interference.

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Contents

List of Figures

List of Tables

Executive Summary

This deliverable was created in the context of Task 4.2 *Use Case and Requirements* of WP4 *Experimentation and Applications*. It identifies a set of typical Internet of Things (IoT) applications that are exposed to challenging environments and that need to meet given dependability requirements. This deliverable presents four candidate use cases encompassing a range of typical IoT applications designed for different operating environments with different dependability requirements:

1. Outdoor Parking Management,
2. Civil Infrastructure Monitoring,
3. Condition Based Maintenance,
4. Ventilation on Demand.

To facilitate the identification of dependability requirements, we compiled a generic list of characteristics of interest that describes factors that will be taken into account during the design, implementation, and evaluation of the chosen RELYonIT use case implementation.

Based on these characteristics of interest, each of the four applications is studied in detail. The potential impact of environmental variations on the dependability requirements of each use case is analyzed in terms of data loss, latency, and operational lifetime. For each application, we consider a set of different typical climates. The primary environmental factors we consider are temperature and radio interference.

Based on feedback obtained during the first review, the Annexes include a detailed illustration of network components and their expected operation in the chosen use cases, a description of the foreseeable routing topologies, and a discussion of the concrete uses of the corresponding applications. Next, we quantitatively evaluate the characteristics of the use cases in terms of logistic, technical, and business aspects. This exercise drives the reasoning towards the final choice of use case.

1. Introduction

1.1. Purpose of this document

The main purpose of this document is to present a set of industry applications and their respective dependability requirements as possible use cases for the project. These applications operate under a wide variety of environmental conditions that pose different challenges to dependability. We intend to use this document to establish relations between these environmental conditions and the respective dependability requirements.

1.2. Scope of the document

This deliverable is the outcome of Task 4.2 *Use Case and Requirements*. Knowledge gained from this task will serve as the foundation for the generation of models (Tasks 1.1, 1.2, 1.3), protocols (Tasks 2.1, 2.2), and for protocol selection and configuration (Tasks 3.2, 3.3). One of the proposed use cases will later be selected for implementation in Task 4.3 *First Integrated Experiment*.

1.3. Use cases overview

We provide an overview of four industry Internet of Things (IoT) applications, which have diverse dependability requirements and cover a large spectrum of environmental conditions.

The first use case is a *Smart Parking* system, a central component of future Smart Cities. Today, vehicles looking for a free parking spot account for more than 30% of the traffic in EU cities. A smart parking system provides real-time information about free parking spots to drivers, by aggregating spot occupancy information from individual sensors. Road traffic can be reduced considerably if such information can be disseminated to drivers accurately and timely.

The second application is located in the area of *Civil Infrastructure Monitoring*. The market for construction site monitoring is undergoing a major shift to 24/7 solutions. Examples include monitoring of bridges for stress and vibration and monitoring buildings for torsion, deformation, and others properties. Main success factors of a monitoring system include (1) providing a complete, end-to-end monitoring solution; (2) being affordable, thus allowing for large-scale monitoring of critical construction points; and (3) integration of data analysis and prediction tools with data captured from other products, thus providing unprecedented insights into the structures under monitoring.

The third use case we present is concerned with *Condition Based Maintenance*. Due to productivity and cost considerations, maintenance procedures of industry mechanic equipments are ideally carried out just in time before a fatal fault is allowed to occur due to, e.g., metal fatigue. The common current practice is using wired sensors to detect anomalies on running equipments and alerting maintenance staff of an upcoming failure. Such solutions are often based on costly and proprietary licensed technologies. In order to lower costs, we want to use open wireless sensors standards. We therefore need to construct a network that delivers messages at the same high data rate and in a timely matter as the wired system. In addition, real-time comparison of data from multiple sensors is needed.

The last use case is a *Ventilation on Demand* system in residential apartments and industrial factories. Autonomous control of ventilation cycles ensures a healthy and comfortable living environment for inhabitants or workers, while reducing energy use during vacancy periods. This application does not have the same level of harsh environmental conditions and reliability requirements than in the previous case, but has more frequent dynamics in a continuous sensing and actuation control loop.

2. Use Cases Analysis

2.1. Formal Analysis Structure

We analyze the four use cases in a uniform structure. Each use case description comprises: (1) a general functionality overview, (2) a description of typical environmental conditions, (3) a list of characteristics of interest, and (4) a table of specific dependability requirements.

2.1.1. Characteristics of Interest

In spite of the diversity of the candidate use cases, we try to analyze and understand their characteristics using a uniform set of technical features and constraints. The following list comprises factors that will be taken into account during the design, implementation, and evaluation of the chosen RELYonIT use case implementation.

Critical Quality of Service Requirements Any critical QoS requirement, e.g., a maximum latency threshold, which is absolutely needed for the proper operation of the application. Such requirements are prioritized in the design of our dependable IoT.

Impact on Quality of Service We try to identify potential impact by environmental factors, e.g., temperature changes and radio interference on certain quality of service properties. We provide qualitative estimations about which QoS properties will degrade when certain environmental condition occur.

Different Phases of Activity in the Environment Any discernible time pattern whereby certain environment factors alter their level or intensity radically. Certain use cases might involve regular alternations between busy and idle phases, e.g., peak hours of human activities during the day.

Indoor / Outdoor Whether the deployment site is indoor or outdoor often leads to a clear implication about the range of temperature change and intensity of radio interference.

Size (geographical and topological) Deployment size in terms of area and number of nodes. Network complexity tends to be positively correlated to deployment size. A large network thus poses extra challenges to multi-hop routing and reproduction of tests.

Scalability The flexibility of expanding or shrinking the number of nodes while maintaining the same system functionality. A small scale, initial deployment with the flexibility to be expanded later often benefits the development process, because a higher number of design iterations are permitted.

Repeatability Considerations about the repeatability of the environmental conditions (Are they unique for each scenario instance? Are they repeatable?).

Control of environment Means and degree that environmental factors can be controlled. A high degree of control enables precise recreation of environmental conditions across multiple test runs. Accurate control of individual environment factors, e.g., temperature, helps to differentiate impacts brought about by different factors. The IoT system's dependability under certain severe conditions can only be fully tested after the condition is held stable for a long enough time period; therefore a good control of the primary environment factors is needed in order to fulfill the test condition for such stress tests.

Reproducibility in testbeds Feasibility of reproducing a use case's function and environmental conditions in a testbed. This can potentially be used to conduct small scale experiments.

New or existing deployment Whether the use case is going to be deployed from scratch or retrofitted to an existing deployment.

Access to Deployment Site Considerations about the access to the deployment site, as well as working conditions.

Node mobility We assume all or the majority of sensor nodes are static. Special measures might be needed nonetheless, in order to accommodate a small number of mobile nodes, depending on their motion pattern.

IP connectivity per individual sensor Here we consider if the connection with the Internet is going to be only in the gateway or if we need an IP address for each sensor node. A gateway solution puts extra responsibility on the gateway node for protocol translation, while relieving the sensor nodes from running an IP stack.

Available radio spectra Considerations about possible constraints and preferences on radio bands to be used for network communication. The 2.4 GHz ISM band supports higher data rate than the 868 MHz ISM band; but the latter is less congested and usually has a longer communication range.

2.1.2. Dependability Requirements

The requirements are divided into two separate categories. One category contains the requirements related to the reliability of the application while the other category is concerned with the operational lifetime. The specification of the requirements follows the structure presented in Table 2.1.

Table 2.1.: Requirement Template

ID	Alphanumeric identifier
Name	Name
Description	Textual description
Priority	M (must) / S (should) / C (could) / W (won't have)
Failure Effect	Possible consequences if we do not comply with this specific requirement

The ID field is the identification which is going to help us to identify the requirements throughout the document and the project (e.g., in WP4). The first letters of the ID indicate the use case to which the requirement refers.

The description will avoid to say anything about *how* the developer should implement the requirement but instead will describe the desired result.

Traditionally, requirements are divided into functional and non-functional. In this case there is little point in this division, given that such requirements are related to dependability, all of them will be non-functional.

The prioritization employs the MoSCoW prioritization technique [5]. This technique divides the requirements into four categories:

Must. Requirements labeled as *Must* have to be fulfilled by the system to consider the project successful. It can also be considered as an acronym of **M**inimum **U**sable **S**ubse**T**.

Should. Such requirements are still important but are less critical for overall project success. Alternative ways of meeting the specified need may be available.

Could. This type of requirement increases customer satisfaction at little costs but they are not critical for project success.

Won't have. These requirements are not going to be implemented in the current project, but they may be taken into account for further developments.

2.2. Outdoor Parking Management

In the Smart cities context, we target a smart parking solution. Vehicles looking for a free parking spot are responsible for more than 30% of the traffic in EU cities. Autonomous smart parking solutions could significantly reduce the traffic by directly impacting on the users and the ability to easily find a free parking spot.

Parking availability and cars seeking for a free parking spot (known as hustle bustle traffic) are considered as one of the most important actors in traffic congestion in urban areas. However, parking is one of the fundamental services for the inhabitants, commuters or visitors to the city, which has to be taken into account for managing authorities for traffic regulation. Many European cities have been suffering the chronic shortage of parking, especially in the city center. Even now, we can see many public spaces to be occupied by private vehicles for usage as parking lot.

2.2.1. Description

We present a general view of the communication infrastructure for a smart parking solution. Normally the sensors for parking detection are embedded into the ground in the center of each parking spot. The sensor nodes should communicate parking space availability to neighboring sensors until they reach the gateway. Multi-hop routing needs to be used when direct contact with the gateway cannot be made.

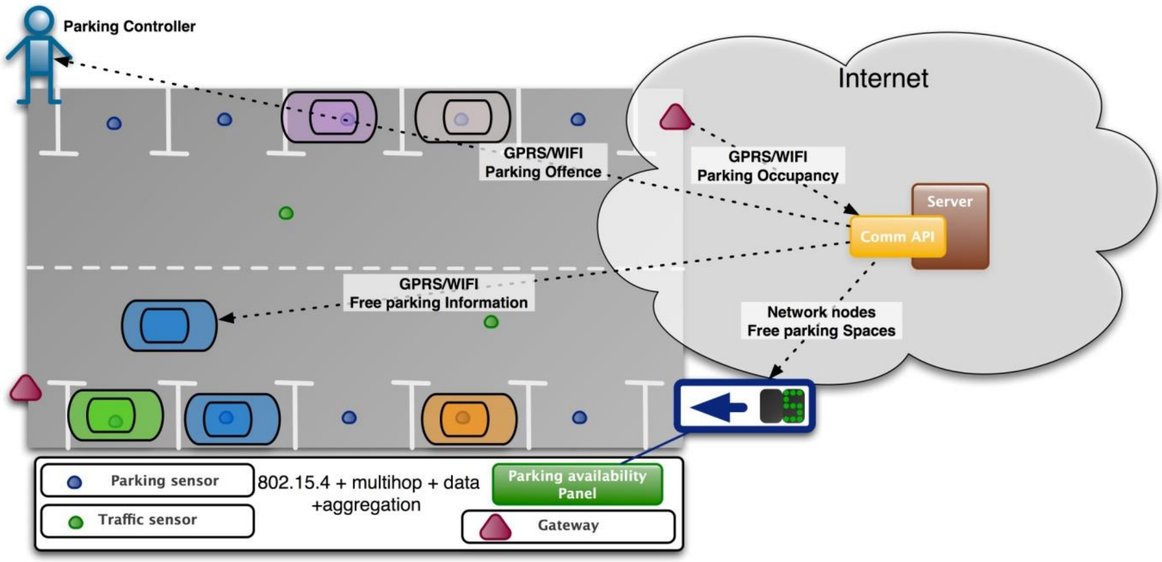

Figure 2.1.: Architecture of the parking space availability control service.

A centralized control system stores and processes all data gathered from sensors resulting information and implemented services are offered to citizens by means of mobile applications and city panels.

The parking control application consists of the following main sensor/actuator systems:

- Sensor Nodes, which are small-embedded devices containing an Anisotropic Magneto-Resistive (AMR) MEMS sensor, a low-power IEEE 802.15.4 wireless interface for communication and a suitable battery pack. These nodes are connected to a self-organizing network, which allows communication among the nodes. As cars will usually cover the sensor and severely impact radio connectivity, redundancy of communication needs to be assured in order to enable reliable communication. The sensor nodes must be fully embedded in the road surface to avoid vandalism and destruction by snow cleaning machines. Sensor nodes are on average separated 5 m resulting in a dense topology. The expected lifespan of the sensors should be above four years in optimal conditions to match the interval in which the tarmac is usually replaced in cities. Nevertheless, customers are currently willing to accept more frequent battery change, if needed. Power considerations, environmental considerations and duty cycling timings are presented in the Table 2.3. Moreover, cost considerations should be taken into account for commercial products.

- Hybrid Gateways collect information about parking availability from sensor nodes on the streets and transmit this information to the centralized urban control. They allow interconnection using different interfaces in order to be easily adapted to different urban scenarios. They might be equipped with 3G modems, 802.11 interfaces, or Ethernet interfaces. Taking the resulting higher power consumptions into account, appropriate energy harvesting solutions may be considered. Gateways are located on traffic lights or trees.

Table 2.2.: Smart parking sensor characteristics

Characteristics	Description
Dimensions (Hx0)	Circular, 130mm x 80 mm (100 mm x 50mm inner)
Antenna type	Fractal matched at 868MHz, SMA connector
Battery type	7200mAh@3.6V
Smart sensor interface	TBD
Frequency of communication	868MHz
Communication range	15 m with car, 50 m without car

Table 2.3.: Power requirements for smart parking solution

Parking sensor component	Power Consumption	Operation time	Duty cycle
Radio transceiver	45 mW-150 mW	1-5 ms	0.1%-1%
μC	12 mW-150mW	1-5 ms	0.1%-1%
Sensor	20mW-30mW	2ms	0.1%

- Information Panels collect parking availability information from the control center and display this information to guide drivers to free parking spots. They may also include appropriate energy harvesting solutions.

The sensor nodes consists of the elements described in Table 2.2. In order to function properly, the system has the power requirements described in Table 2.3. In Table 2.4 the environmental variables potentially affecting the smart parking system scenario are presented.

2.2.2. Environmental Scenarios

Three different sub-scenarios are summarized, each one with different ambient temperatures:

Mediterranean City

Near the Mediterranean sea, a city such as Barcelona usually features an average annual temperature about 20 ℃ during the day and 11 ℃ at night. In the coldest month, typically the temperature ranges from 10 to 17 ℃ during the day and 2 to 10 ℃ at night. In the warmest month, the temperature ranges from 25 to 31 ℃ during the day and about 20 ℃ at night [2, 12].

European Continental City

A European continental city such as Moscow has cold winters and mild summers: Temperature variation between night and day and winter and summer are about -12 ℃ on winter nights to +23 ℃ on summer noon [4, 14].

Desert Climate City

A desert city as Cairo is considered. In this climate, summer is hot and humid with temperatures from 20 ℃ to 40 ℃. Winter temperature ranges from 9 ℃ to 29 ℃ [3, 13].

Table 2.4.: Environmental Conditions for Smart Parking.

Variable	Min	Typ.	Max	Comment
Temperature	-30 °C (we have observed down to -14 °C in Moscow during winter).	0-12 °C Winter, 5-25 °C Autumn, and Spring. 20-50 °C Summer time	+75 °C (we have observed up to +68 °C in south of Spain during summer under direct sun exposure).	-
Vibration&Shock	Streets are subject to constant vibrations centered at around 4-7 Hz, few nm/s.	Cars passing and car motion generates vibrations up to 100 Hz and several mm/s.	Sensors may be subject to impact and shock from cars, load, and unload operations.	-
Magnetic radiation	Small towns and unpopulated areas show no magnetic disturbances.	Urban scenarios show DC magnetic disturbances mainly attributed to Metro and power stations.	In specific areas, very high magnetic noise will be present. Includes DC and AC components. AC are centered at 50Hz, 60Hz, 100Hz.	It effects detection performance and hence battery consumption and processing capabilities.
Humidity	No humidity, very dry dry environments.	45-70%, dry or wet ground.	Snow covering sensors or rain.	We have observed strong effects of water on communications.
Car rotation	During night almost no movement. 1 car per 5h on average.	Normally in central zones we observe 3-4 cars per hour.	We have observed in very central areas, rotations above 10 cars per hour.	It is also important to consider the traffic around sensors. In centric it might be very dynamic

2.2.3. Characteristics of Interest

Critical QoS requirements The most critical requirement in this case is the latency of the network, in terms that an event sent by a mote must arrive at the central server in time of seconds.

Impact on Quality of Service It is expected that most of the variations in environmental variables are going to be changes in temperature and humidity. Added to this we should consider the fact that the node is embedded inside the road surface so the electromagnetic wave has to be powerful enough to trespass the tarmac.

Different Phases of Activity in the Environment Changes in activity will follow a day-night cycle, because usually traffic movement is less frequent at night.

Indoor / Outdoor Outdoor.

Size (geographical and topological) Tens/Hundreds. We can consider aggregations of tens of motes covering house blocks.

Scalability For parking slots, the measures will be independent from each other. But multi-hop radio protocols usually limit the maximal diameter of the network (number of hops a packet can travel).

Repeatability Although cities in the world are located in very diverse climates, we assume that our three different scenarios cover the most typical climates and temperature ranges. It should not be too difficult to have a controlled environment like we presented in the sub-scenarios.

Control of environment We must consider, in addition to the typical conditions of any urban environment, that the motes are below parking slots. Communication is affected by the need for signal transmission through thin layers of concrete and cars, the presence of metal structures, and wet environments (oil, water). Nevertheless, we do not expect any severe problems in controlling these effects in our experiments.

Reproducibility in testbeds We do not perceive any difficulty in reproducing any of the environmental conditions in a lab environment.

New or existing deployment WOS has some deployments in different urban environments and climates suitable to use as testbed.

Access to Deployment Site The access to any mote is guaranteed but usually a city permission is needed to cut streets. In most cases, we could be supported by city employees.

Node mobility We can assume everything is static.

Link to Internet There is no need for the nodes to have their own IP address.

Available radio spectra As the electromagnetic spectrum is very crowded, it is necessary to select an available and suitable frequency for each specific location. The selection is usually limited to the unlicensed industrial, scientific and medical (ISM) radio bands as published by the ITU [6].

2.2.4. Dependability Requirements

ID	SP-1
Name	Latency < 30 seconds
Description	The system has to have a time response in less than 30 seconds. Time response is considered as the time between a car change is detected by a mote and data is received by the Gateway.
Priority	M
Failure Effect	A driver could reach, thanks to the system, to a place that is already occupied losing confidence in system, if this situation recurs.

ID	SP-2
Name	Latency < 10 seconds
Description	The system should have a time response in less than 10 seconds. Time response is considered as the time between a car change is detected by a mote and data is received by the Gateway.
Priority	S
Failure Effect	A driver could reach, thanks to the system, to a place that is already occupied losing confidence in system.

ID	SP-3
Name	Data loss < 10%
Description	The system does not lose more than 10% of the events
Priority	M
Failure Effect	System could give wrong information too often.

ID	SP-4
Name	Data loss < 5%
Description	The system should not lose more than 5% of the events
Priority	S
Failure Effect	System could give wrong information sometimes.

ID	SP-5
Name	Data loss < 1%
Description	The system could not lose more than 1% of the events
Priority	C
Failure Effect	System could not have reduced quality of service.

The previous information allow us to establish the following requirements regarding the operational lifetime:

ID	SP-6
Name	Battery Life > 6 months, Mediterranean city climate
Description	Battery has to last for at least 6 months in a climate as described for a Mediterranean city.
Priority	M
Failure Effect	System could not be installed due to the effort required in maintenance.

ID	SP-7
Name	Battery Life > 4 months, European continental city climate
Description	Battery has to last for at least 4 months in a climate as described for a European continental city.
Priority	M
Failure Effect	System could not be installed due to the effort required in maintenance.

ID	SP-8
Name	Battery Life > 3 months, desert city climate
Description	Battery has to last for at least 3 months in a climate as described for a desert city.
Priority	M
Failure Effect	System could not be installed due to the effort required in maintenance.

ID	SP-9
Name	Battery Life > 1 year, Mediterranean city climate
Description	Battery should last for at least 1 year in a climate as described for a Mediterranean city.
Priority	S
Failure Effect	System could not be competitive enough due to maintenance cost.

ID	SP-10
Name	Battery Life > 8 months, European continental city climate
Description	Battery should last for at least 8 months in a climate as described for a European continental city.
Priority	S
Failure Effect	System could not be competitive enough due to maintenance cost.

ID	SP-11
Name	Battery Life > 6 years, desert city climate
Description	Battery should last for at least 6 year in a climate as described for a desert city.
Priority	S
Failure Effect	System could not be competitive enough due to maintenance cost.

ID	SP-12
Name	Battery Life > 2 years, Mediterranean city climate
Description	Battery could last for at least 2 years in a climate as described for a Mediterranean city.
Priority	C
Failure Effect	System could not be the ultimate one.

ID	SP-13
Name	Battery Life > 1.5 years, European continental city climate
Description	Battery could to last for at least 1.5 years in a climate as described for a European continental city.
Priority	C
Failure Effect	System could not be the ultimate one.

ID	SP-14
Name	Battery Life > 1 year, desert city climate
Description	Battery could last for at least 1 year in a climate as described for a desert city.
Priority	C
Failure Effect	System could not be the ultimate one.

2.3. Civil Infrastructure Monitoring

The Spanish normative regulation "Código Técnico de la Edificación" (Technical Building Code) states that the goal of civil infrastructure monitoring will be to detect any damage or abnor-

Figure 2.2.: Application of stress on a rafter.

malities at an *early* stage, in order to take appropriate measures for mitigating risks before an unwanted event occurs [7].

When we want to monitor the effect of specific conditions on a structure under construction, there are mainly two types of test procedures: in testbeds and directly on the structure. The measurement can be done by piezoelectric gauges embedded into the concrete. In place monitoring with embedded sensors can, for example, be used as a safety system. The stresses to which a structure is subjected at the time of construction are constantly measured and compared with a theoretically determined maximal threshold. If this threshold is reached, the operation can be stopped before any accident might happen. As a concrete example, we can consider the monitoring of the load on the pillars, when the bridge deck is sliding on these, during the construction process.

In contrast, testbed experiments do not directly measure the effects in situ, but replicate measured forces to which the structure is subjected on a similar specimen in a lab. The replicated specimen can be a simple sample of material inside a testbed or a full replica of the original part. To generate meaningful results, the material of the replica must be the same as the one of the structure (e.g., the same concrete). To ensure this, the replica are usually manufactured simultaneously with to the original (Figure 2.2).

2.3.1. Description

When we monitor a structure, we should consider that the structure perhaps is currently surrounded by an urban ecosystem (with some of the features to take into account that are the same as in the *Smart Parking System* case).

A need to in parallel monitor the construction parts as well as the surrounding structures is not uncommon, for example, in metro works, slope stability monitoring, bridge monitoring, and tunnels monitoring. In the specific case of metro works (Figure 2.3), partner WOS offers a particular product. A scenario in which this product can be applied is the following: The route of a new metro network is located close to a street at the bottom of a natural escarpment, with many old historic buildings. In such a construction project located in a densely populated urban

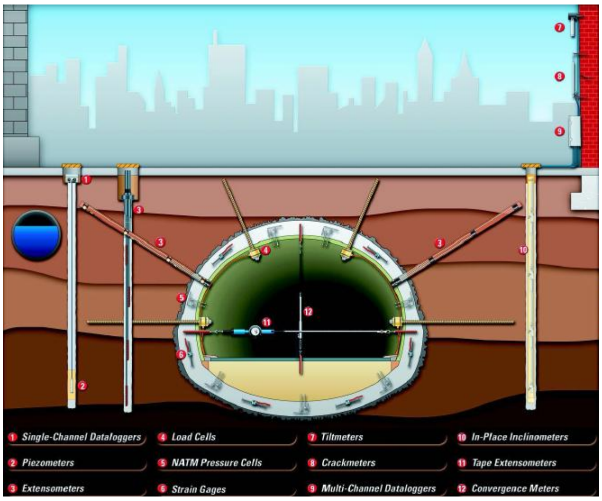

Figure 2.3.: Underground infrastructure monitoring.

area with multiple independent private properties to be monitored, a conventional hardwired system would not be practical, so the novel wireless loggers are key to the success. These wireless loggers consist of tilt meters and crack meters connected to wireless Loadsensing (LS) dataloggers. The LS dataloggers communicate every few minutes with a gateway sited nearby, which automatically transmits the data via a 3G modem to a computer running user-friendly LS software at the client's offices. The data is also transmitted to a web site at regular intervals, enabling instant data access to any member of the contract team, without the need for the client to have either a dedicated computer or engineer. In the event that pre-set limits are exceeded, nominated personnel can be alerted by SMS text message and email. This kind of monitoring requires two types of artifacts:

- Wireless multi-channel LS dataloggers in each building and in each tunnel section.
- Gateways to collect, store, and send the data via 3G or Wi-Fi. One in the affected street for dataloggers at buildings, and one at each end of the tunnel for the dataloggers inside of the tunnel.

The expected environmental conditions for this use case are described in Table 2.5.

2.3.2. Characteristics of Interest

Critical QoS Requirements In this scenario, typically not the sensor value itself but the gradient between sensor values are of interest. Thus, it is of paramount importance not to lose measurements in order not to make wrong decisions. The latency of the system, although it is desirable to be low, it is not of paramount importance, given that we need to anticipate the events long before they happen. With low latencies, the monitoring system could also be used as an emergency alert system.

Table 2.5.: Environmental Conditions for Smart Infrastructure.

Variable	**Min**	**Typ.**	**Max**	**Comment**
Temperature	-40 °C (we have observed down to -27 °C in Austria during winter).	0-12 °C Winter, 5-25 °C Autumn and Spring, 20-50 °C Summer time.	+85 °C (we have observed up to 70 °C in Qatar during summer under direct sun exposure).	Temperature range depends on the region of interest. Rapid temperature changes may occur if a sensor under direct sunlight exposure is covered. Note that temperature effects shows day-night cycles.
Vibration&Shock	Sensors are exposed to civil works risks. Normally they are subject to constant vibrations and shocks as well as wind gusts.	Sensors installed in bridges, slopes, or structures might be affected by wind, structure vibration.	In extreme situations such mining or tunneling, sensors may suffer strong impacts during tunneling operations.	–
EM radiation	No EM radiation effects.	EM radiation form DC and AC sources such power lines and machinery.	In harbors, airports, mines radiation from Radars, frequency jammers and Wi-Fi and radios may interfere with communications.	It affects detection performance and hence battery consumption and processing capabilities.
Humidity	No humidity, very dry environments. Might have effects on electronics.	45-70%, dry or wet normal operation.	Snow covering sensors or strong rain or flooding.	Strong effects of water on communications have been observed.

Impact on Quality of Service Although distances between sensors usually do not vary during the deployment time, there may be cases in which changes in the environment might affect connectivity. These changes are planned in advance, so that is is possible to place nodes *a priori* at suitable locations to limit negative effects. Regarding temperature, concrete can reach temperatures up to 70 °C while being forged. If we want to embed nodes in the concrete, the nodes must withstand such temperatures, but nodes could be split into a sensor and a detached communication device to mitigate the issue.

Different Phases of Activity in the Environment If we look at the daily cycle, we do not assume phases with lower activity as such constructions sites usually operate 24 h a day in shift operation. If we look at the construction lifecycle, activities and schedules differ from one construction site to another, but these characteristics are well defined at the beginning of the construction.

Indoor / Outdoor We have to take into consideration that a typical infrastructure construction site could span both environments, as can be seen in Figure 2.3. sometimes two separate systems (or at least two different networks) are needed – one for the infrastructure itself and one to monitor the surroundings.

Size (geographical and topological) At a typical site, we can assume networks of ten nodes for each task and we can assume approximately three different monitoring tasks at a time. Looking at the geographical size, we can assume extensions of less than 100-200 m^2, due to the fact that a bigger extension will require the monitoring of more than one structure. An average distance between nodes of 5-10 m can be expected.

Scalability The actual construction sites could be as large as 200 m^2. The length of one dimension it is rarely more than 50 m. Usually, only part of the construction site needs to be monitored at a specific time interval.

Repeatability Despite the fact that there are not two identical infrastructures, we can assume that the phenomena we have to monitor are quite similar. It should not be too difficult to have an useful and controlled environment for each phenomenon.

Control of environment To reproduce the conditions that we can find in a civil infrastructure project, we need to have extensions of around tens of meters. We also need to reproduce the presence of large concrete blocks, heavy vehicles with large metal components, and low frequency interference from heavy machinery.

Reproducibility in testbeds The previous factors suggest that the lab environment could only be an outdoor one. Despite there being indoor infrastructures constructions which need to be monitored (tunnels), it will be easier to deal with the aforementioned components in an outdoor environment and such environments are also more common.

New or existing deployment We have the possibility to use one new deployment as it is the most comfortable way to include new technologies envisioned.

Access to Deployment Site It is expected that full access to the monitored parts, at least during the construction, is possible. In many cases the node will be lost after the battery is drained as the recovery is usually not economically worthwhile.

Node mobility Although there are situations that require mobility for the monitored element (for instance the arm of a crane), we can assume almost fully static situations in most cases.

IP connectivity per individual sensors There is no urgent need for the nodes to have IP connectivity, but this could be used for additional commercial purposes.

Available radio spectra The activity sometimes will take place outside, so that one has to consult the specific legislation of each country [6]. Moreover, we should consider that there will be electrical motors which can cause interference, mainly in lower frequencies. At the same time, we need to keep in mind that the electromagnetic wave will go through (reinforced) concrete pieces, which limits the suitable range of the electromagnetic spectrum.

2.3.3. Environmental Scenarios

The main environmental factors to be considered are temperature and humidity. We can identify the following different climates:

Cold

This climate is the one we can, for example, find in Russia or Austria. This climate is characterized by temperatures that can oscillate between −20 ℃ and up to 30 ℃, with a daily thermal oscillation of less than 10 ℃. The relative humidity in Moscow oscillates from 60% to 85%.

Temperate climate

This climate can be found in the Mediterranean (it is also known as cold Mediterranean). This climate can have thermal oscillation from −13 ℃ up to 45 ℃ during the year, and a daily oscillation of 10-15 ℃. We can consider relative humidity similar to the previous one, an oscillation from 65% to 85%.

Warm desert climate

Saudi Arabia is an example of this. Here we can find temperatures from 18 ℃ up to 50 ℃. In these environments, we can usually find daily temperature oscillations of around 30 ℃. Humidity in Saudi Arabia goes from 11% of average on July to 46% on December, but sometimes humidity can reach 70%.

2.3.4. Dependability Requirements

ID	CI-1
Name	Latency $<$ 5 minutes
Description	The system has to have a time response of less than 5 minutes. Time response is considered as the time between a measurement is made and it triggers a warning signal.
Priority	M
Failure Effect	The need for detecting dangerous situations in time to avoid any damage could not be satisfied. 5 minutes is the minimum time to evacuate any work place.

ID	CI-2
Name	Data loss $<$ 2%
Description	The system must not lose more than the 2% of the measurements.
Priority	M
Failure Effect	In case more data is being lost, we could be overlooking a dangerous situation.

ID	CI-3
Name	Latency $<$ 1 minute
Description	The system should have a time response of less than 1 minute. Time response is considered as the time between a measurement is made and the triggering of a warning signal.
Priority	S
Failure Effect	We could be unable to fix the problem because of degradation of one specific part.

ID	CI-4
Name	Data loss $<$ 1%
Description	The system should not lose more than 1% of the measurements.
Priority	S
Failure Effect	We could be unable to study the cause of the collapse.

With the previous requirements in mind we consider the following requirements:

ID	CI-5
Name	Battery Life > 6 months, temperate climate
Description	The system has to last for at least 6 months in a temperate climate.
Priority	M
Failure Effect	We would not meet the safety period required for leaving the infrastructure with confidence.

ID	CI-6
Name	Battery Life > 4 months, cold climate
Description	The system has to last for at least 4 months in a cold climate.
Priority	M
Failure Effect	We would not meet the safety period required for leaving the infrastructure with confidence.

ID	CI-7
Name	Battery Life > 4 months, warm desert climate
Description	The system has to last for at least 4 months in a warm desert climate.
Priority	M
Failure Effect	We would not meet the safety period required for leaving the infrastructure with confidence.

ID	CI-8
Name	Battery Life > 1 year, temperate climate
Description	The system has to last for at least 1 year in a temperate climate.
Priority	C
Failure Effect	We could not add a quality mark.

ID	CI-9
Name	Battery Life > 6 months, cold climate
Description	The system has to last for at least 6 months in a cold climate.
Priority	C
Failure Effect	We could not add a quality mark.

ID	CI-10
Name	Battery Life > 6 months, warm desert climate
Description	The system has to last for at least 6 months in a warm desert climate.
Priority	C
Failure Effect	We could not add a quality mark.

2.4. Condition-Based Maintenance

The goal of condition-based maintenance is to anticipate the occurrence of a fault in advance in order to be able to pro-actively prevent future malfunctions. To achieve that, a predictive maintenance system measures component vibrations, temperatures, or flow rates. With this information, the system can give appropriate hints to prevent a failure.

Condition-based maintenance can enable significant savings in energy (thanks to improvements in spare part logistics) and money (due to a reduction of holding time). In addition, it is possible to increase the efficiency of the machinery and to reduce the need for periodic maintenance.

The advantages of condition-based maintenance are especially effective for large machines like the ones found on commercial vessels (Figure 2.4).

2.4.1. Description

The most useful technique for condition-based maintenance is the vibration measurement and analysis. The main advantage in comparison to other approaches such as ink penetration, X-ray, and ultrasound, is the possibility to record measurements while the machines are running.

At coarse-grained approach could use vibration measurements from the external surfaces of the machines, for example, provided by capacity displacement sensors in conjunction with accelerometers. Based on this data, different approaches to detect a future rupture are available. Some significant ones are:

Spectral Analysis The essence of the spectral analysis is to decompose the vibration signal into frequency spectrum components. This allows to correlate vibrations with the forces acting within the machinery. If there are some new, unforeseen spectral components, a future rupture could be predicted.

Waveform Analysis For example, a sharp peak or a pulse and a continuous signal that varies at random may have spectra that look the same, although the waveforms are completely different. In engine vibration, the peaks are usually caused by mechanical impact, and random noise can be caused by the degradation of bearings in an advanced stage.

Vibration Phase Analysis This refers to the analysis of phase difference between horizontal and vertical vibration or between different axial vibrations of the machine support system. It allows to determine the relative motions in the machinery. If something new is seen, it might indicate a future rupture.

Typical devices that may need to be monitored on a vessel can be:

Figure 2.4.: *Ciudad de Sevilla* Engine Room.

- main and auxiliary diesel engines,
- exhaust gas piping,
- alternators,
- electric appliances and lighting,
- boilers,
- steam and condensate piping, and
- tanks

Large engines are usually located in engine rooms that have the effect of a Faraday cage (Figure 2.4). This makes wireless communication with the outside difficult to impossible. In typical scenarios, most wireless communication will take place inside the engine room. Within these rooms it is possible to find a multitude of metal pieces, in which the electromagnetic wave dissipates upon contact. To make communication possible, it might be necessary to either increase the signal strength (with consequent reduction of battery life) or to take this effect into account when planing the network, so that transmissions could avoid spaces occupied by large metal objects.

Regarding temperature, it is important to consider that, despite the machinery being designed to operate at reasonable temperature values as well as not to heat the surrounding environment too much, in emergency situations – when the measurements are most needed – temperature could rise significantly. Approximately 3% of the machine power is dissipated as heat. This fact can be mitigated using detached probes instead of directly placing the node in intimate contact with the surface of the machinery. As an example, we can consider the *Wärtsilä 46 lubricating oil pump* which has a specified operational temperature of 100 °C [9].

As stated in the paper "A Long-Term Study on the Effects of Meteorological Conditions on 802.15.4 Links" [11], humidity can also have a significant effect on wireless communication.

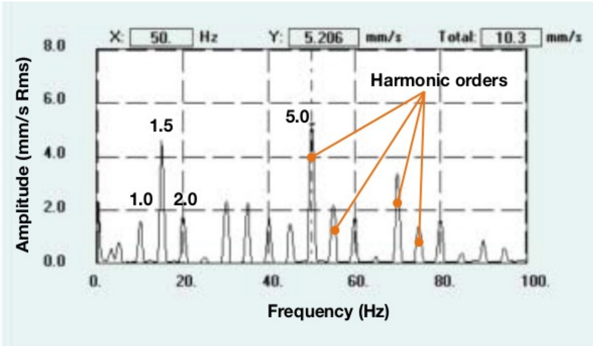

Figure 2.5.: Typical displacement of a Diesel engine [10].

This is especially relevant at ships, where we can find significant humidity levels. For example at the injectors coolers, we can find relative humidity of 80% at 35 ℃ [9]. We cannot assume that the humidity just depends on temperature, but we can establish a distinct relationship for each part of the ship.

Environmental requirements of this use case are summarized in Table 2.6.

2.4.2. Characteristics of Interest

Critical QoS requirements As we need to consider relationships between the measurements, it is mandatory to have precise knowledge of the time of recording for each measurement. This can be either reached by establishing a tight time synchronization among the nodes and time-stamping each measurement, or with a low latency delivery of measurements. Data loss needs to be reasonably low in both approaches.

Impact on Quality of Service It seems that the main factor that will affect communications is the presence of large metal components. The network might also be exposed to water vapor and sudden significant temperature changes.

Different Phases of Activity in the Environment Changes in activity are not expected during operation of the machines.

Indoor / Outdoor Indoor, usually inside a Farady cage.

Size (geographical and topological) A high density of nodes is expected. A plausible number could be 5 nodes in $20m^2$.

Scalability Different parts and components of a vessel can usually be monitored largely independent, so that a modular design can be considered.

Repeatability Exactly similar conditions are usually difficult to replicate for complex machinery. The fact that a large vessel usually has several components of the same type might allow the parallel study of different approaches under roughly comparable conditions.

Control of environment Environment conditions are almost entirely determined by the state of machinery, thus we have limited control over it.

Table 2.6.: Environmental Conditions for Condition-Based Maintenance.

Variable	**Min**	**Typ.**	**Max**	**Comment**
Temperature [9]	10 °C (minimum outside temperature could be 0 °C).	In the specification for ventilation in machine “Wärtsilä 46” it is said that “it is recommended to consider an outside air temperature of not less than 35 °C and a temperature rise of 11 °C for the ventilation air”.	50 °C (in emergency cases, the machine is designed to work with incoming air temperatures up to 50 °C).	If the temperature rise over 50 °C, the problems in the combustion would be far greater than a lack of communication among measuring devices.
Vibration&Shock	Sensor is not exposed to vibrations.	5 mm/s RMS (50 Hz).	10 mm/s RMS (50 Hz).	Data extracted from Guidelines to engine dynamics and vibration (Hannu Tienhaara). It is taken at 50 Hz which is the biggest vibration component. [10]
EM radiation	No EM radiation effects.	EM radiation form DC and AC sources such power lines and electric motors.		It effects detection performance and hence battery consumption and processing capabilities.
Humidity	20-30%	50-60%	80%	We have observed strong effects of water on communications.

Reproducibility in testbeds Limited reproduction of the environment in a lab is possible by using smaller comparable machinery, for instance, the Diesel engine of a car. Nevertheless, the size of the machine can have a considerable effect on the results. The full environment is difficult to reproduce in a lab.

New or existing deployment Possible deployment sites do not currently employ any wireless sensors.

Access to Deployment Site There may be situations in which monitoring is required for inaccessible engine parts and where deployment requires a disassembly of the engine. These situations should be avoided by trying to monitor only parts with easy accessibility, for example, to ease battery replacements. Otherwise, a condition-based maintenance system might require more work than manual maintenance.

Node mobility We can assume that all nodes are static.

IP connectivity per individual sensor An Internet connection is not constantly available (at least offshore). IP connectivity on the individual nodes is not needed.

Available radio spectra As explained above, in most situations the equipment will be located in Faraday cages so that a less constrained selection of frequencies might be possible.

2.4.3. Environmental Scenarios

We can consider two separate environments, one representing legal conditions for a working place, and another without this restriction. In these two types of environments, the variation between day and night is small due to the sea cushion effect.

With conditions for the stay of a human being

These conditions are as described in most legal documents as temperature between 14 and 25 ℃ and humidity between 30% and 70%.

Without the need to support human comfort

In this case, the environmental conditions could be more extreme. It is not unusual to find temperatures from 5 up to 80 ℃ on items that need to be measured. Humidity is usually the same as in the previous case, between 30% and 70%.

2.4.4. Dependability Requirements

ID	CB-2
Name	Data loss < 10%
Description	The system does not lose more than 10% of the measurements.
Priority	M
Failure Effect	We could be overlooking a dangerous situation

ID	CB-3
Name	Latency $<$ 10 seconds
Description	The system should have a time response of less than 10 seconds. Time response is considered as the time between a measurement is made and the moment this information is processed by the gateway.
Priority	S
Failure Effect	We could be unable to detect the failure causes

ID	CB-4
Name	Data loss $<$ 5%
Description	The system should not lose more than 5% of the measurements.
Priority	S
Failure Effect	We could be unable to detect the failure causes.

ID	CB-5
Name	Data loss $<$ 1%
Description	The system could not lose more than 1% of the measurements.
Priority	C
Failure Effect	We could be unable to detect the failure causes with accuracy.

With the previous requirements and considering the operation in a vessel, we consider the following lifetime requirements:

ID	CB-6
Name	Battery Life $>$ 3 months, conditions suitable for human
Description	The system has to last for 3 months with the same batteries inside an environment with conditions for the stay of a human being.
Priority	M
Failure Effect	The attention the system would need, will render it impractical.

ID	CB-7
Name	Battery Life > 6 months, conditions suitable for human
Description	The system should last for 6 months with the same batteries inside an environment with conditions for the stay of a human being.
Priority	S
Failure Effect	The system could be used, but not extensively.

2.5. Ventilation on Demand

One of the biggest challenges for any European construction company is to comply with the directive 2002/91/EC [8] that states:

> Article 4: Setting of energy performance requirements (...) These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation, as well as local conditions and the designated function and the age of the building. These requirements shall be reviewed at regular intervals which should not be longer than five years and, if necessary, updated in order to reflect technical progress in the building sector.

Focusing on ventilation, one of the most efficient approaches is *ventilation on demand*. Using this approach, it is possible to save up to 30% of the energy used in climatisation by reducing the heat exchange between the outside and inside air (Figure 2.6).

2.5.1. Description

The relation between comfort and CO_2 level is well-known as well as the fact that an over-ventilation does not provide any further benefit but produces a huge amount of energy waste.

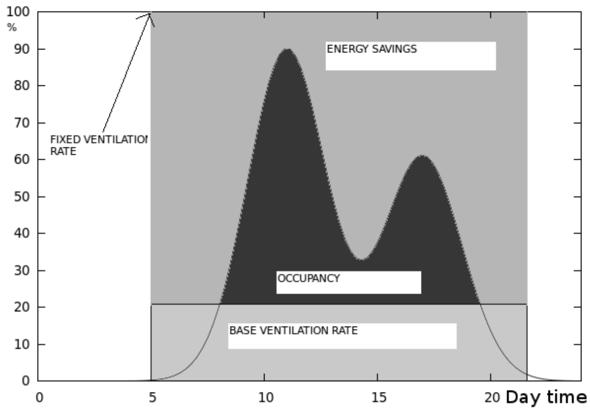

Figure 2.6.: Energy savings due to a ventilation on demand system.

Ventilation should have a good compromise between CO_2 concentration and energy savings. In order to reach the compromise, we can use a pair of sensor/actuator in which the sensor analyzes the CO_2 level, and if the threshold has been reached, the actuator opens the ventilation gate. In this use case we can consider the interference due to domestic equipment as the main obstacle for communication. Table 2.7 summarizes the environmental conditions for the ventilation on demand use case.

2.5.2. Characteristics of Interest

Critical QoS requirements The most critical factor is data loss. If the system is able to deliver most of the data, we can consider the possibility to use it for safety-critical detection of toxic agents.

Impact on Quality of Service It has to be considered that an interference source can initiate its activity during a crucial moment (e.g., when a critical CO_2 level is reached or when a toxic agent is released).

Different Phases of Activity in the Environment The activity phases that we can encounter inside a house usually are identified with human behavior or with the usual industrial schedule.

Indoor / Outdoor Indoor.

Size (geographical and topological) two or three nodes per room. The diffusion of gases ensures that levels get equal in a closed space quickly.

Scalability The same as in condition-based maintenance. We can assume that scalability should not be a problem as the sub-networks in the individual rooms are largely independent.

Repeatability We do not foresee any severe problem in repeating the experiments under similar conditions.

Control of environment We can expect to have full control over the environment.

Reproducibility and in testbeds No issues are expected in this regard.

New or existing deployment ACCIONA has several ventilation on demand systems that are being monitored. Nevertheless, a new one is to be preferred for the sake of flexibility.

Access to Deployment Site Trivial.

Node mobility It is expected that all nodes are static.

IP connectivity per individual sensor There is no need for the nodes to have IP connectivity, but it might enhance the user experience.

Availale radio spectra Unfortunately, the 2.4GHz is used by Wi-Fi connections. Despite being the most desirable frequency band, it could be the one with most interference. Anyway, we should consider the specific regulation for each country [6].

Table 2.7.: Environmental Conditions for Ventilation on Demand.

Variable	**Min**	**Typ.**	**Max**	**Comment**
Temperature	17°C	22°C	27°C	Legal values for permanent work places.
EM radiation	No EM radiation effects.	EM radiation form DC and AC sources such as power lines and electric motors.	Domestic equipment (Wi-Fi routers, Bluetooth, etc.).	It effects detection performance and hence battery consumption and processing capabilities.
Humidity	No humidity, very dry environments. Might have effects on electronics.	20-30%	50-60%	These values are those allowed by ASHRAE 55-1981 [1].

2.5.3. Environmental Scenarios

For this use case we can identify two typical environments, each with its specific environmental conditions and needs:

Domestic environment

In this environment the main agent to be measured is the CO_2 emitted by people. A daily temperature oscillation from 15 ℃ up to 25 ℃ is expected. The main factor to consider is the interference emitted by domestic equipment such as Wi-Fi routers, Bluetooth devices, and microwave ovens.

Industrial environment

This environment usually has higher latency requirements and there is a possibility for a wider variety of agents to be measured, for example, CO, NH_3, and suspended particles. The daily temperature variation is wider than in the domestic environment. It is determined by the law for each country (in most of the cases temperature is between 14 and 25 ℃ and humidity between 30% and 70%.). It is expected to encounter less interference sources, but we should also consider heavy machinery as in section 2.4.

2.5.4. Dependability Requirements

ID	VD-1
Name	Data loss $<$ 25%
Description	The system does not lose more than 25% of the measurements.
Priority	M
Failure Effect	The user could prefer traditional solutions (e.g., open a window)

ID	VD-2
Name	Latency $<$ 5 minutes
Description	The system needs to have a response time of less than 5 minutes. Response time is considered to be the time between a CO_2 measurement and the gate opening.
Priority	M
Failure Effect	The user could prefer traditional solutions (e.g., open a window)

ID	VD-3
Name	Data loss < 10%
Description	The system should not lose more than 10% of the measurements.
Priority	S
Failure Effect	There could be situations that would not be treated as needed (e.g., the detection of a toxic agent).

ID	VD-4
Name	Latency < 1 minute
Description	The system should have a time response in less than 1 minute. Response time is considered as the time between a CO_2 measurement, and the gateway noticing the measurement.
Priority	S
Failure Effect	User could initially not feel comfortable after entering the room or the danger of a toxic agent could not be avoided by this system.

ID	VD-5
Name	Data loss < 5%
Description	The system could not lose more than 5% of the measurements.
Priority	C
Failure Effect	There could be situations that would not be treated as needed (e.g., the detection of a toxic agent).

The previous information allows us to establish the following requirements regarding the operational lifetime:

ID	VD-6
Name	Battery life > 6 months, domestic environment
Description	Battery should last for at least 6 months in a domestic environment.
Priority	S
Failure Effect	User would need to change batteries more frequently.

ID	VD-7
Name	Battery life > 8 months, domestic environment
Description	Battery could last for at least 8 months in an industrial environment.
Priority	C
Failure Effect	Industry will be reluctant to use it because of its high maintenance costs.

ID	VD-8
Name	Battery life > 1 year
Description	Battery could last for at least 1 year in a domestic environment.
Priority	C
Failure Effect	User would need to change batteries more frequently.

ID	VD-9
Name	Battery life > 1 year
Description	Battery could last for at least 1 year in an industrial environment.
Priority	C
Failure Effect	Industry does not consider the ventilation on demand system as an alternative because of its high maintenance costs.

3. Conclusions

Four different use cases have been described in this document. These include outdoor parking management, structure supervision at constructions sites, condition-based maintenance on vessels, and ventilation on-demand in buildings. At the first stage, these use cases were chosen because they are exposed to challenging environmental conditions and need to meet stringent dependability requirements.

As a result of the work carried out, several dependability requirements have been identified. Special attention has been paid to the possible environmental conditions and their possible effect on the requirements. In order to facilitate the evaluation of the architecture in the coming months, the requirements have been classified in terms of priority.

The requirements defined in this document will be the basis for the activities to be carried out in the remainder of the project.

IV. Annex

IV.1. Updated Use Cases

We describe next a detailed illustration of network components and their expected operation in the chosen use cases, a description of the foreseeable routing topologies, and a discussion of the concrete usage of the corresponding applications.

IV.1.1. Parking Management

Network Components, Topologies, and Configurations

WOS Parking Management leverages multi-hop networks based on a TSCH (Time Synchronized Channel Hopping) radio links. This radio strategy synchronizes all motes in a network and assigns different time slots to each node. The assigned time slot is the only opportunity a node has to send or to receive information. Channel hopping indicates a change in the transmission frequency used for every transmission. This is used to avoid interference or environmental noise.

The different components in this use case are:

Sensor Nodes. Devices with magnetic and temperature sensors, data processing and decision algorithms, and a 802.15.4-like wireless communications module. They are battery powered. They are buried in the tarmac of the deployment, one in every parking spot.

Repeaters. Devices with radio modules that can receive from Sensor Nodes or other Repeaters and send the data to other repeaters or to the Gateway. They can be powered off the grid or be battery powered. They are placed in high points like on lampposts, traffic signal poles, and traffic lights to provide better radio coverage.

Gateway. A device acting as sink for the network. It receives data from all nodes and forwards them to the central server in the cloud using different Internet connections (Urban WiFi, Ethernet, Optical Fiber, GPRS/3G). This device is powered off the grid.

Regarding the network configuration, the routing topology is not fixed a priori, but the network itself needs to self-organize and to build a tree-shaped routing topology dynamically. This adaptability is needed by the nature of the application: because drastic variations in the quality of radio links may happen (a car on top of the node, new obstacles, etc.), the routing must adapt to these changes. The change of the routing tree is performed every time a node receives feedback from the link with other nodes. The routing topology used in the Parking Management is limited to a maximum of eight hops between any node and the sink (i.e., the gateway).

Figure IV.1 shows two different topologies adapted to different scenarios in a Parking Management application. Each side of the street has different radio links caused by different cars

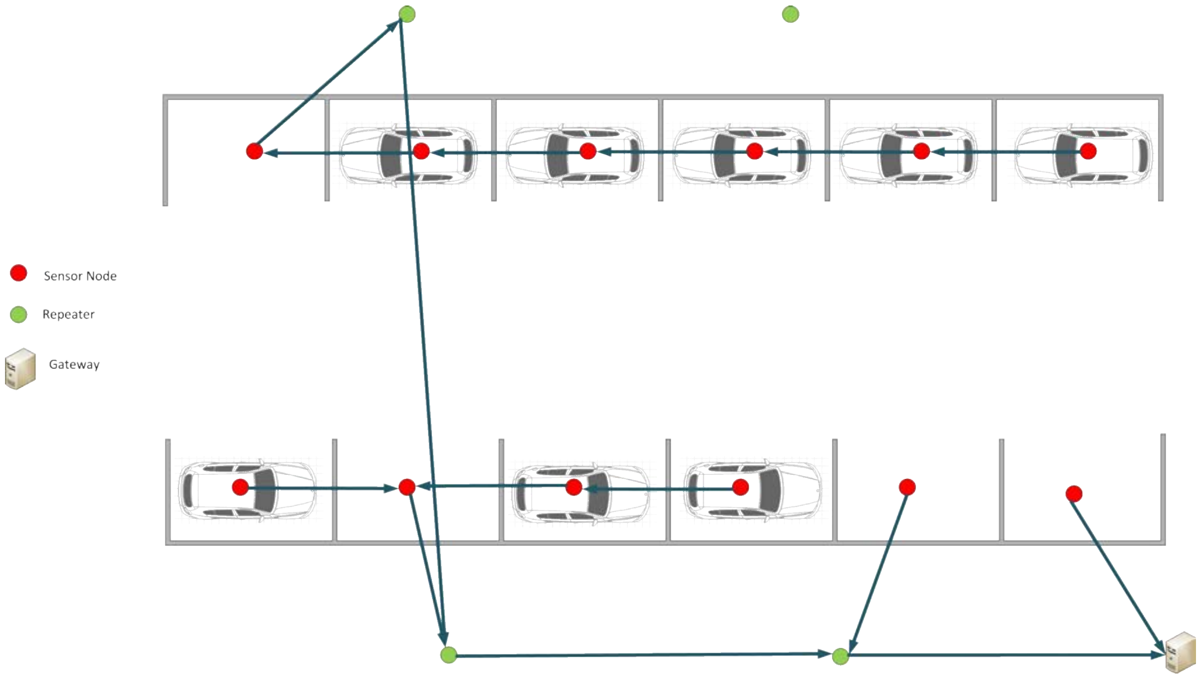

Figure IV.1.: Different topologies adapted to two different situations in the Parking Management Scenario. The top row shows a scenario with several occupied parking spots and a long multi-hop topology. The bottom row shows a scenario with some free spots and hence fewer hops to the gateway. In this situation, no mote is connected via the top right repeater.

parked, hence the routing topology is different for each side of the stree. Red circles represent sensor nodes and green circles represent repeaters.

Although repeaters use the same routing algorithms to reach the final sink nodes, usually their radio environment is not variable and hence the routing paths from repeaters to gateways usually do not vary significantly.

Deployments and Usage

WOS has installed more than 5,000 sensor nodes in Moscow city center, a second phase is running in order to install 10,000 more. Meanwhile, the first phase is being used by citizens. The system has been audited by Russian authorities. Traces from this deployment, e.g., regarding temperature changes and vehicle parking patterns, are available to the partners of the consortium.

In the Barcelona area, WOS has two pilot deployments installed, one in Barcelona city in the "22@ zone", and one in downtown Sant Cugat (a small city near Barcelona). The 22@ deployment is a pilot consisting in 30 sensor nodes, 10 of which can be used for engineering tests. These 10 sensor nodes are installed on two corners between two streets with a repeater and a gateway nearby. This zone is a loading/unloading zone, where cars and trucks can only be parked for at most 30 minutes at a time. This zone is a good testbed because of its high parking rotation. The parking zone in Sant Cugat has about 20 sensor nodes with 4 repeaters and one basestation. It is also a "blue zone" with a 2 hours parking limit. Again, high car rotation is a good feature for testbeds.

Future deployments are on-going and in the pre-design or pilot stages. These include Central America cities, European medium cities (100,000 to 500,000 inhabitants), and other Russian cities.

IV.1.2. Civil Infrastructure Monitoring

Network Components, Topologies, and Configurations

The LoadSensing product by WOS is designed to use multi-hop networks similar to how the Parking Management application does.

Sensor Nodes. Devices with circuitry to read different sensors, digital converters, along with a 802.15.4-like wireless communication module. They are battery powered and only occasionally powered off the grid.

Repeaters. Devices with radio modules that can receive from Nodes or other Repeaters and send the data to other repeaters or to the Gateway. They can be powered off the grid or battery powered. They are placed in strategic spots in order to offer better radio coverage; because repeaters are not sampling any sensor, installers enjoy greater flexibility to choose a location for them.

Basestation. This device collects all data from all Nodes and, depending on the installation, either pre-processes the data to offer *in-situ* information or sends the data to cloud servers to offer the data to external entities. A basestation can use several Internet connections like: WiFi, Ethernet, Optical Fiber, and GPRS/3G. This device can be powered by batteries or off the grid.

Usually there are only a few nodes in these kinds of deployments, but usually separated by long distances (up to tenths of meters). Hence, the routing topology for these types of deployments is usually very flat (i.e., only 1 or 2 hops) and a wide routing tree typically forms where most of the nodes can communicate to the basestation directly, as seen in Figure IV.2.

In these deployments, the environment is usually harsh in terms of electromagnetic noise, due to the presence of electric motors and other wireless devices. These issues are typically solved by channel hopping. In some cases, when the deployment is outdoor, the temperature conditions can vary notably, as illustrated in Section 2.3.

With similar routing topologies, the latency of the network can be very small, enabling applications like alarm and warnings when some sensor read unusual or pre-specified warning values.

Deployments and Usage

ACCIONA Infrastructure carries a legacy of more than one hundred years' experience of construction activity. Today, it stands at the leading edge of R&D and Innovation (RDI) and ranks among the world's foremost construction companies, with a proven ability to respond

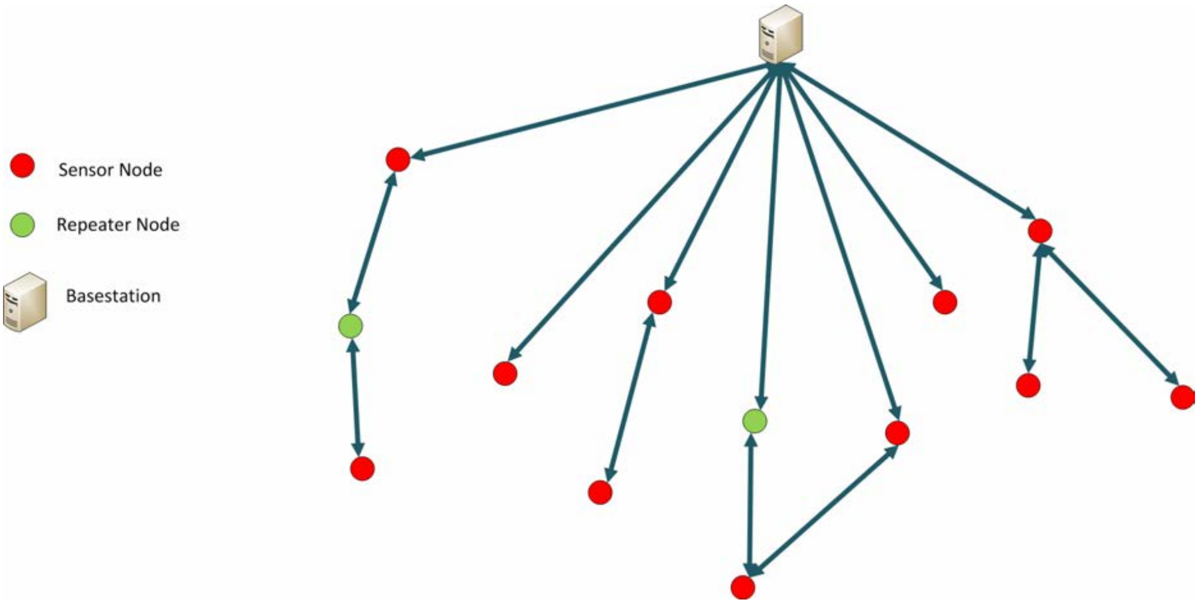

Figure IV.2.: Typical tree topology for Civil Infrastructure Monitoring.

with cutting-edge, ground-breaking construction methods and technologies. ACCIONA Infrastructure is capable of taking on all kinds of construction projects and to meet all kinds of needs, from engineering to works execution and maintenance, as well as public works concessions, especially in transport infrastructures, e.g., roadways, railway lines, and buildings such as hospital service and knowledge center concessions.

In every project, the company has always used the most advanced construction techniques that meet sustainability criteria that include economic, social, and environmental aspects. One of the technologies that are increasingly present are smart embedded wireless sensors. Construction sites are continuously changing as the project evolves, so it is not advisable to deploy wires for making the nodes communicate. If we take the example of a medium-sized airport construction site of and we pick one possible application, for instance, one dedicated to monitor the concrete maturity, it is necessary to deploy hundreds of humidity and temperature sensors. All these sensors will indicate when the concrete maturation process is over and it will allow to finalize this stage earlier.

At this very moment, ACCIONA Infrastructures has 138 international projects pending to be accepted, which represents 27.199.572.012,62 € of budget.

IV.1.3. Condition-based Maintenance

To exemplify this use case, a vessel maintenance system was selected because of the potential it has for ACCIONA. If the reliability of using an embedded network of sensors is guaranteed and high enough, it can be possible to include the Condition-based Maintenance into the "Integrated Management System" currently used in Trasmediterranea. This can lead to great cost and environmental savings for ACCIONA due to the improvement in the logistics associated with vessel maintenance.

Network Components, Topologies, and Configurations

ACCIONA's monitoring system for Condition-based Maintenance will be composed of the following components:

Sensor Nodes. Wireless equipment consisting of one or several types of low power sensors (accelerometer, displacement sensors, temperature, humidity, etc...), a wireless communication module (802.15.4-like) and a power supply module. Sensors can be placed in measurement zones, and communication modules can be installed in safe zones, not exposed to high temperatures, harsh environments, or potential damages. If possible, nodes can leverage the power grid; in other cases, batteries will be used.

Gateway. Equipment responsible to collect vibration, temperature, humidity, etc. data from sensors connected to nodes. If possible, all this information is sent to a central storage point at the company premises or in the cloud; if not possible, the gateway will store the data. The gateway installation can be done in any place of the monitored area or nearby the sensor nodes to favor communication with them. Network interfaces available in the gateway can be adapted for the application: Ethernet, Wifi, HSDPA or serial are usually present. The power grid should be used to provide power to the gateway.

The wireless network is a 2.4 GHz multi-hop network: depending on the size and harshness of the area, sometimes nodes cannot communicate directly with the gateway. In these situations, nodes will transmit data to the "best" neighbor available, forming a tree-shaped routing topology. In addition, if any link breaks or is not reliable enough, the network shall adapt the routing topology to the new situation, changing and establishing new links with other nodes to maintain the communication in the whole network.

Metal surfaces, humidity, and wireless communications do not mix well. To get efficient communications, repeaters or redundancy nodes may also be installed to avoid connectivity issues. In this specific scenario, due to the expected communication problems, the resulting routing topology will include many hops between sensor nodes and the gateway.

Deployments and Usage

ACCIONA Trasmediterranea is Spain's largest passenger and cargo shipping line and one of the biggest in Europe. The fleet, consisting of 25 vessels, is among the most modern and best-equipped in Europe, with cutting-edge safety and security technology and top-quality service on-board. The fleet features high-speed, comfortable ferries designed to make the journey a central part of the passenger's vacation experience. In addition, large, cutting-edge cargo vessels offer express service and ensure the quick and safe delivery of goods.

The maintenance work needed for each vessel heavily depends on the age. Older vessels require greater monitoring. Although the majority of the vessels have been built after year 2000, ACCIONA Transmediterranea is studying the suitability of improving the maintenance process, including Condition-based Maintenance, especially for the vessel's engines.

IV.1.4. Ventilation on Demand

It is estimated that controlled ventilation can save up to 30% of the energy used in air conditioning of a building. A monitoring/actuating system with a proper performance/reliability could make the installation and maintenance of Ventilation on Demand systems affordable and suitable in low to medium cost buildings because of the ease of use, installation, and maintenance a low-power sensor network would have. ACCIONA is undergoing efforts to make these solutions part of its technology portfolio. In order to achieve that, the staff that is going to be trained is going to have RELYonIT results into their syllabus.

Network Components, Topologies, and Configurations

An ACCIONA monitoring system for Ventilation on Demand will be composed of the following components:

Sensor Nodes. Wireless devices composed by one or more types of low-power ambient gas sensors (CO_2 or any other needed), a wireless communication module (802.15.4-like) and a power supply module. Sensors can be installed in walls, in false ceilings, or safe zones not exposed to human activity. Nodes can use batteries or be connected to the grid if possible.

Actuator Nodes. These nodes have the same wireless interface and power supply possibilities than sensor ones, but they will be placed near the ventilation equipment to control, and hence it is probable that the power grid will be available at these locations. Actuators will be installed near ventilation devices and communication interfaces can be hidden in the same way as sensor nodes.

Gateway. The gateway will be similar to the previous description for the Condition-based Maintenance use case, having the same functionality and similar interfaces. The installation can be carried out in any convenient part of the building: electric boxes, false ceilings, and the like.

The network deployed is the same illustrated in previous use case. In this specific situation (indoor monitoring), we expect the resulting topology to include many nodes able to communicate directly with the gateway, or in a few hops at most, as seen in Figure IV.3.

Deployments and Usage

The mission of ACCIONA Facility Services, a leading company in the integrated management of company infrastructures, is to respond to customer requirements by developing innovative and creative solutions permitting reductions in costs. ACCIONA Facility Services offers an integral management service for all energy flows present in any property asset. Some example activities include management of electricity, gas, water, fuel supply, etc. The division uses its energy engineering experience to offer energy consumption management and the supply and selection of the best energy source in each case, in an effort to optimize consumption and to achieve efficient energy use. The goal is to ensure the reliability, availability, profitability, and duration of facilities.

Monitoring the CO_2 concentration with the appropriate sensors and automatically controlling the ventilation system through actuators of a non-residential building could bring many benefits in terms of energy efficiency, as it was explained previously in this document. ACCIONA

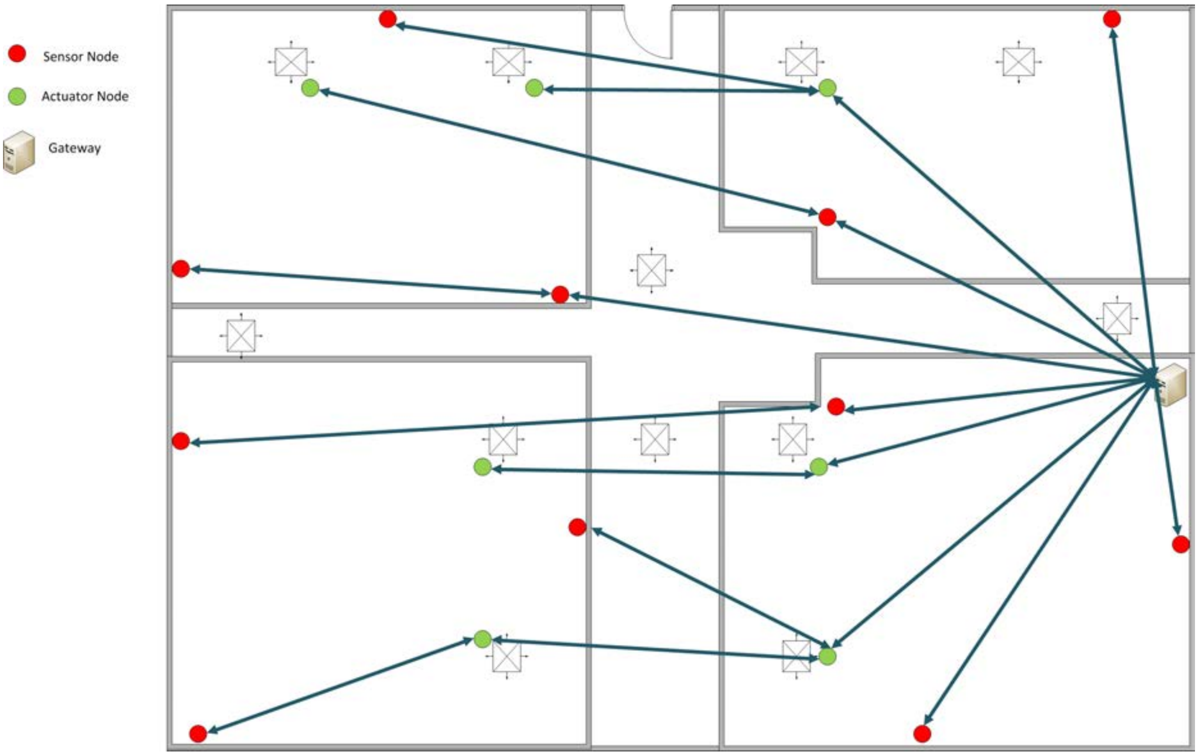

Figure IV.3.: Routing topology for the Ventilation on Demand use case.

Facility Services manages all kind of buildings, but it is mainly focused on public buildings. For instance, we can mention six hospitals all around the world.

IV.2. Use Case Selection

This section describes the process of the selection of the use case the project will implement. We start by describing the underlying selection criteria. Then we define the decision matrix from which we derive the choice of the use case.

IV.2.1. Selection Criteria

In this section, we define the selection criteria for the decision matrix. In order to define meaningful selection criteria, the list of criteria should not be too long but should contain the items necessary to make an informed decision.

We decided to use the following three main criteria since they summarize the most important issues:

1. Business: evaluates the business aspects, e.g., the financial impact on a company's operation, and the economical added value.
2. Technical: evaluates the suitability of the use case to demonstrate the technical aspects and main technical challenges of the project. For example, how well the required quality of service requirements of the use case match the technical challenges of the project.
3. Logistics: evaluates the complexity of the logistics. We want to minimize the overhead of the logistics. Hence, we would favour a deployment site that is easy to get access to, over one where time-consuming security measures are required.

IV.2.2. Features of Interest

Each selection criteria presented above comprises several features of interest. In Section 2.1, we have already derived a number of characteristics of interest, which we associate to the main criteria in Table IV.1.

The criteria described in Table IV.1, however, focus on technical characteristics and characteristics related to logistic. In Table IV.2 we present business-related characteristics.

IV.2.3. Decision Matrix

The discussion in the previous section leads to the decision matrix shown in Table IV.3. For the selection process we use a score ranging from 1 to 5 for each one of the categories of the matrix described in the previous sections. A brief explanation is associated with each estimation.

The decision matrix in Table IV.3 shows that the **outdoor parking management use case is the most suitable use case for our project and this thus selected for prototyping in WP4**. The individual scores are justified below.

Outdoor Parking Management

The business score for this use case is high because high reliability on communications can enable other uses and markets for this product, like automatic enforcement and easing the access to public tenders. Automatic enforcement can be enabled by RELYonIT techniques

Critical Quality of Service Requirements	technical
Impact on Quality of Service	technical
Different Phases of Activity in the Environment	technical
Indoor / Outdoor	technical
Size (geographical and topological)	technical
Scalability	technical
Repeatability	technical
Control of environment	technical
Reproducibility in testbeds	logistics
New or existing deployment	technical
Access to deployment site	logistics
Node mobility	technical
IP connectivity per individual sensor	technical
Available radio spectra	technical

Table IV.1.: Assignment of characteristics of interest to selection criteria

and protocols because communications certifications are required by public authorities. These certifications are based on no packet loss on communications networks and low latency of the entire network. These features are the RELYonIT initial objectives and, hence, they are in line with the expected results for the RELYonIT project.

The time to market for this use case is immediate, because WOS is already producing and installing these applications and once validated, changes can be applied to the final product very quickly. Also the market size can be increased, allowing WOS to sell its products in countries with extreme weather conditions like Middle East, Africa, Far East, and China, where cities (and corresponding markets) are growing very fast and the same cities have major congestion traffic problems. The adaptation of WOS' Smart Parking product to the new technology and techniques developed in the RELYonIT project can be done quickly, because WOS has been working on these kind of networks since years. Therefore, this use case aligns perfectly with the company's strategy.

Also the technical score is high, mainly because the use case can demonstrate the right functionality of the new implementation in outdoor conditions. In particular, there are critical QoS requirements in terms of latency. Further, the environmental variations, in particular related to temperature changes, allow to demonstrate the technical achievements very well. The score for the logistics dimension is medium-high because even though access to the deployment sites is easy (WOS has 2 pilots in Barcelona that could be used), municipality permissions are required.

Civil Infrastructure Monitoring

The business score is high due to the relatively small time to market and potential in saving costs. Nevertheless we cannot ignore the fact that a full solution needs an individual approach for each construction site, so a development process during the whole life cycle of each product is required. Finally, it is important to remark that the application of the RELYonIT approach would not impact the core activity of this use case (that is, of course, build all kind of civil infrastructures) but could bring important savings in term of money and time. Anyway, as we said before, these savings will depend heavily on the kind of infrastructure that we are dealing with.

The technical score is high because this use case can demonstrate completely the functionality of the RELYonIT implementation in very adverse conditions. The demand for low packet latency makes the critical QoS requirements challenging.

The score in logistics for carrying out a pilot with this use case is so small because of the difficulty of acquiring access for a time period that is long enough for making proper tests in a real construction site.

Condition-based Maintenance

The score for the business part of this evaluation has been set to 3 because of the fact that despite the potential for great savings in logistics, some effort is needed to integrate this approach in the already existing maintenance infrastructure (engine workshops, etc.) in order to take advantage of the RELYonIT technology. Nevertheless, since the potential is high, this only partially limits the value of the business side. Nowadays, vessels have a strict schedule for maintenance. The possibility of an engine malfunction is not that high. Anyway, important savings in terms of money and logistics could be achieved if these unexpected breakdowns approach zero.

The technical score is set to 4 since there is a need for either very tight time synchronization or low latency. For the logistics, the score is low because of the difficulty and cost of having the persons aboard a ship long enough to make realistic experiments in the field.

Ventilation on Demand

Focusing on the business part of the ventilation on demand the score of 2 is set because it is difficult to make profit from the business model that the reliability for this use case would enable. Anyway, this use case has a big potential as key enabler for getting into business opportunities (as can be licitations, tendering processes. . .). Also, it would allow the owners/managers of buildings to obtain important savings in terms of energy expenditures. The technical score is a little bit lower than for the other use cases since the QoS requirements are not as critical as for the other three use cases. The value of logistics for this use case is high because of the easy access to the deployment sites. It is pretty easy to get access to the deployment site (e.g., a room in a building) for the time needed for the experiments.

Time to market	Considering development time. How fast can one put the product into production and make profits?
Time for returning the investment	Considering lifetime cycle costs. How fast can we get the investment return? How fast can the product be profitable enough to cover the investment?
Scalability	The product production ability to be enlarged for accommodating to a market which has grown.
Compliance with standards and laws	How well is the product able to conform to existing rules such as a specification, policy, standard or law in order to get legal safety?
Market size	The number of individuals in a certain market who are potential buyers and/or sellers of a product or service.
Previous experience	Familiarity with a skill or field of knowledge acquired over a period of time.
Potential grow	How well is it envisioned that the market size is going to grow?
Providers dependence	How high is our independence on specific providers? The ability to change providers.
Alignment with company strategy	How does this product help accomplish the company strategy agenda?
Lack of (potential) competition	How well can we manage the competition with potential competitors?
Synergies with other company business lines	How well can we foster another business line into the company with this product?
Adaptability to market changes	How well can the product adapt to unexpected changes?

Table IV.2.: Business-related characteristics

	Outdoor parking management	Civil infrastructure monitoring	Condition-based maintenance	Ventilation on Demand
Business	**4**	3	3	2
Technical	**4**	4	4	3
Logistics	**3**	1	2	4
Sum	**11**	8	8	9

Table IV.3.: Decision Matrix

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