D3.2.2 – Environmental Wireless Sensor Network (WSN) prototypes

Final Version – Results of the final iteration of sensors selection and integrated system tests

2019.09.25

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Short Abstract

This document extends the deliverable D3.2.1 - Environmental Wireless Sensor Network (WSN) prototypes describing: i) the outcomes of the final iteration of the sensors selection for developing the environmental monitoring system of NESTORE; ii) the integrated system tests on the selected sensors. The selection followed the recommendations coming from the WP2 activities in terms of needed monitoring variables and unobtrusiveness. The document also presents the chosen technologies and their integration in the system using available off-the-shelf and custom devices by means of the Web of Things paradigm.

Key Words

Environmental Sensors, Web of Things, Bluetooth Low Energy, Ballistocardiography, Smart Scale.

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1 Introduction

One of the main goal of NESTORE is to monitor physiological and behavioural data related to the five domains of wellbeing (i.e., physical, mental, cognitive, social, and nutritional). In order to achieve this goal, we develop a multi-domain unobtrusive monitoring system also relevant for assessing the user profile.

In the WP3 activities, NESTORE will optimize and integrate available technical solutions based on advanced non-invasive monitoring systems, such as wearable and environmental sensors.

Focus of this document is the specification of the environmental monitoring system, including sensors for indirect monitoring of behavioural information related to daily living activities patterns and physical activity.

This document represents the outcome of the task "3.2 – Development of environmental sensors". It is an extension of document D3.2.1 - Environmental Wireless Sensor Network (WSN) prototypes (Preliminary Version – Results of the first iteration of sensors selection).

While the focus of D3.2.1 was the outcome of the preliminary sensors selection, in this document we show the actual devices chosen as the set of environmental sensors of the NESTORE exosystem and the test performed on custom devices, namely Bluetooth Low Energy beacons, developed in the Work Package 3 with the aim of detecting social interactions and the environmental status of the user's vital space (indoor air quality, movements, detection of indoor/outdoor).

1.1 Motivation and rationale

The environmental monitoring system is an ensemble of wireless sensors able to sense the variables indicated by the domain experts in the WP2 activities. Furthermore, it has the aim of detecting the interaction of the user with the environment and monitoring the status of the environment itself, in terms of indoor air quality.

For this reasons, we call *environmental* device any sensor deployed in the user's vital space, while *wearable* the device worn by the user during his daily activities. As further source of information about the user's status, we can derive data as result of computation or fusion strategy of data coming from a direct input of the user, as questionnaires, while interacting with the NESTORE coach. We call the latter *soft* data.

Task 3.2 has as main goal to build the integrated environmental monitoring system. To this end, we first performed a technology selection to satisfy not only the requirements coming from the domain experts related to the user profile (to cover as much variables as possible), but also the ones coming from the co-design activities in terms of unobtrusiveness. The integrated system should be unobtrusive under diverse perspectives: user interaction – the user should not wear additional sensors or explicity interact with the environmental device; number of devices – the user's living environment should not be filled with lot of visible devices; installation and maintenance – it should be easy to deploy and maintain the device without additional effort from the user.

Table 1 describes how the device types (*wearable*, *environmental*, and *soft data*) covers the variables indicated as needed by domain experts for each sub-domain and the frequency of transmission. In particular, for some sub-domains, the actual measurements will be sent with a high frequency (e.g. in the case of structured activities suggested by the coach or in the case of detecting social interactions among the user and his caregivers visiting him at home). Other measurement, like a morning weighing, will have a single transmission. As it can be seen in the table, not all the indicated variables are currently covered. This is due to the fact that the outcome of the WP2 activities is the complete modeling of the user status, but some of these variables can be considered stable during the coaching intervention or measured by specialists in ad hoc medical examinations.

In this document, we will focus on the tecnologies used to cover all the variable that are indicated in Table 1 with the column Device Type: *Environmental* (indicated in bold). Regarding the variables covered by wearable

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device type, we refer to D3.1.1 and D3.1.2 documents for technical specifications. For what concerns soft data variables, insights are available in the D4.1 document.

Table 1 Relationships between Device Types and Domains variables. In bold, the sub-domains variables covered by Environmental devices.

Domain	Sub-domains	Device Type	Coverage of Vars	Frequency of Transmission
Physical Activity	Physical Activity Behaviour	Wearable	Medium	High (during structured activities)
	Cardiorespiratory Exercise Capacity			
	Cardiovascular System			
	Respiratory System			
	Strength-Balance-Flexibility Exercise Capacity	**Environmental**	**Low**	**Low**
	Anthropometric Characteristics	**Environmental**	**Medium**	**Low**
	Musculoskeletal System			
	Sleep Quality		**High**	**High** (during sleep)
Nutrition	Energy Expenditure	Soft Data (calculated)	High	Low/Medium
	Nutrition Habits	Soft Data (Questionnaires, Games)	High	Medium
Cognitive, Mental, **Social**	Cognitive Status			
	Mental Status			
	Mental Behaviour and States			
	Social Behaviour	**Environmental**	**High**	**High** (during social interactions)

In the next Section, we will explain how the environmental devices can cover the related sub-domain, in terms of use cases and chosen technologies. For each category, we first show the candidate technologies and devices available on the market (form document D3.2.1), then we describe the actual device chosen as part of the NESTORE environmental sensors kit.

In Section 3, we describe the test performed on custom NESTORE devices (i.e. NESTORE BLE beacons) and the obtained results in terms of usability and functional tests.

1.2 Relation with other workpackages

The sensors, whose architecture will be designed on the clinical and utilization requirements provided in WP2 and considered compliant in the co-design phase in WP7, will provide data for the assessment of the user

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profile and habits, needed for the personalization of the decision support system in WP4 and the coach developed in WP5. The interface technical specifications of the sensors platform will be provided to WP6, for its integration to the NESTORE system.

Figure 1 shows a graphical representation of the relationships between WP3 – T3.2 and the activities of the other NESTORE work packages.

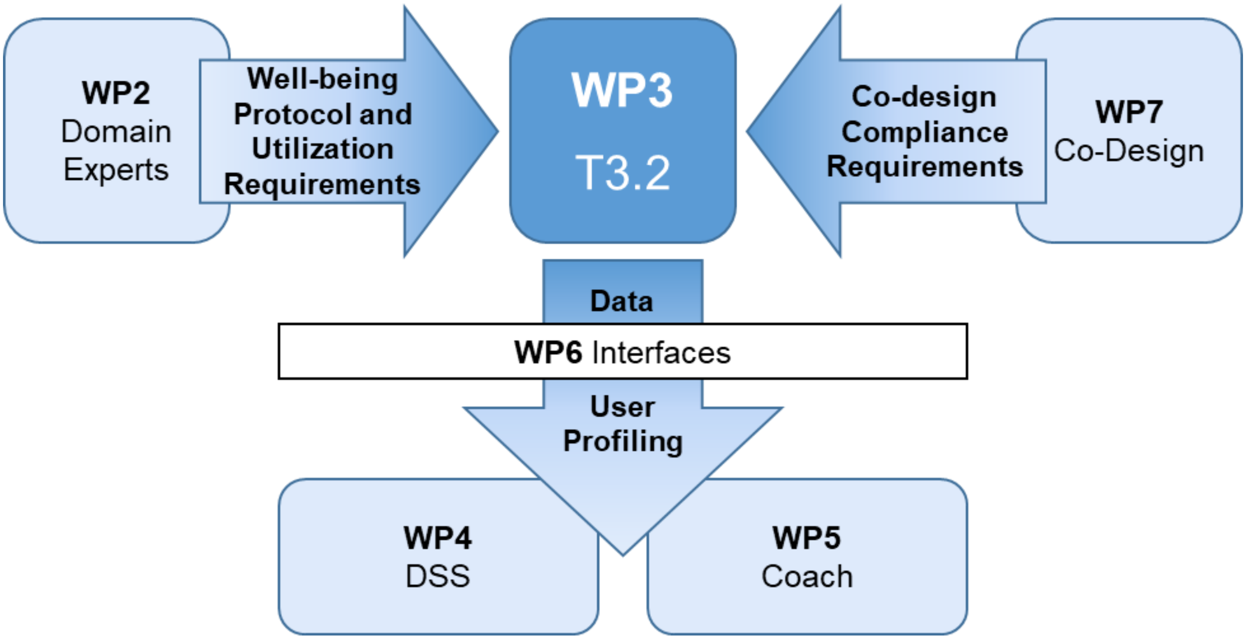

Figure 1 Graphical representation of the relationships between WP3 – T3.2 and the activities of the other NESTORE work packages.

2 Integrated environmental monitoring system – Final sensors selection

The main goal of task 3.2 is to build an integrated environmental monitoring system able to monitor, mainly using off-the-shelf devices, the environmental data, such as users' house air quality, and the users' behavioural data, such as movements in the house, sleep quality, interactions with point-of-interests in the house and other people.

For each domain, we investigated the possible technologies to be used considering the unobtrusiveness requirements derived from the activities of other work packages. Table 2 shows, for each subdomain, the variables that can be monitored with the chosen technologies.

For anthropometric characteristics and musculoskeletal system, we chose a smart scale able to detect weight and body composition, in terms of percentage of fat mass, muscle mass, water, and bone mass. Regarding the sleep quality, the variables to be monitored (details on the motivations behind these choices can be found in D2.1) are: perceived calm sleep; sleep efficiency; total sleep time; sleep onset and offset; time in bed; sleep onset latency; wake after sleep onset; number of awakenings. We identified in the ballistocardiography (BCG) the best candidate technology for sleep quality assessment, thanks to its easiness of installation, the peculiarity to be contact-less with the user's body, and good accuracy in detecting physiological raw data during sleep.

For social behaviour, we will use Bluetooth Low Energy (BLE) beacons to detect social interactions among primary users and their relatives (bringing with them keyfobs equipped with mobile BLE tags), monitoring their duration, function, location, and frequency. We will exploit the capability of calculating the proximity between BLE devices from Received Signal Strenght Indicators (RSSIs) also for detecting the interaction of the user with

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the furnitures in the house on which fixed beacons are deployed, giving us insights on the user's level of sedentariness.

The possibilities offered by BLE beacons of customizing their hardware and firmware will allow us to advertise, from fixed beacons, additional information like motion (to increase the level of accuracy in detecting interactions with point of interests in the house) and temperature and humidity (to calculate the indoor air quality indicator [1]). Details on each technology are given in the following subsections.

Table 2 Variables monitored with the identified technologies.

<table>
<tr><th>Domain</th><th>Sub-domains</th><th>WP2 Variables</th><th>Technology</th></tr>
<tr><td rowspan="3">Physical Activity</td><td>Anthropometric Characteristics</td><td rowspan="2">Weight
Fat Mass %
Muscle Mass %
Water %
Bone Mass %</td><td rowspan="2">Smart Scale</td></tr>
<tr><td>Musculoskeletal System</td></tr>
<tr><td>Sleep Quality</td><td>Perceived Calm Sleep
Sleep Efficiency
Total Sleep Time
Sleep Onset
Sleep Offset
Time in Bed
Awakenings
Sleep Onset Latency (SOL)
Wake After Sleep Onset</td><td>Ballistocardiography</td></tr>
<tr><td>Social</td><td>Social Behaviour</td><td>Interaction Duration
Interaction Function
Interaction Locations
Social Interactions Detection
Total Number of Interactions</td><td rowspan="3">BLE Beacons</td></tr>
<tr><td>Air Quality</td><td rowspan="2">T3.2 Activities</td><td>Humidity
Temperature</td></tr>
<tr><td>Sedentariness</td><td>Proximity</td></tr>
</table>

From the architectural and deployment point of view, in order to reduce the effort needed by the end user to install and use the environmental sensors, we chose to adopt a Web of Things (WoT) approach. WoT is a computing concept that describes an environment where everyday objects are fully integrated with the Web. The prerequisite for WoT is for the "things" to have embedded computer systems that enable communication

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with the Web. Such smart devices would then be able to communicate with each other using existing Web standards.

Considered a subset of the Internet of Things (IoT), WoT focuses on software standards and frameworks such as REST, HTTP and URIs to create applications and services that combine and interact with a variety of network devices. The key point is that this doesn't involve the development of new communication paradigm because existing standards are used [2][3].

As result of the first iteration of sensor selection, we plan to deploy in a typical NESTORE environment the following devices:

- Fixed BLE beacons installed in meaningful point of interests in the user's home (e.g., fridge, TV, closet, door, table) able to detect the proximity of the user, if the object on which the beacon is installed is moving (useful to detect a opened/closed doors), relative humidity, and temperature.
- Mobile BLE beacons to be provided to secondary users (i.e. caregivers, relatives and friends of the user) in form of keyfobs in order to detect social interactions.
- A smart scale for body composition analysis.
- A ballistocardiograph device for sleep quality analysis.

As depicted in Figure 2, BLE beacons' advertisements will be collected by the smart wristband of the user and then sent to the cloud by means of a WoT agent running on the user's smartphone via WiFI, when indoor, or via mobile connection, when outdoor. The smart scale and the BCG device will send data to the cloud backend via WiFi. Further architectural detail can be found in the D6.3.1 document.

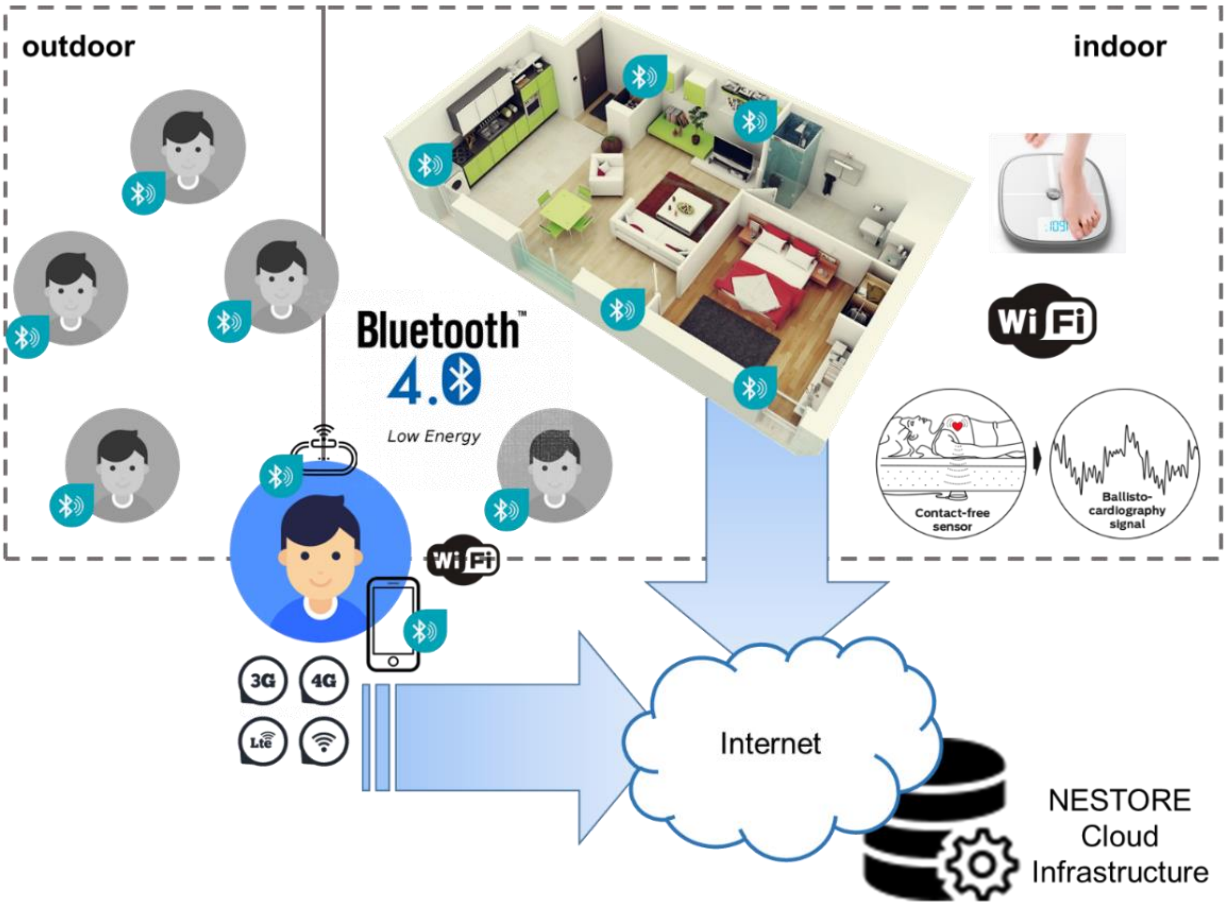

Figure 2 The WoT approach for environmental devices.

2.1 BLE beacons

A beacon, in wireless technology, is the concept of broadcasting small pieces of information. The information may be anything, ranging from ambient data (temperature, air pressure, humidity, and so forth) to micro-location data (asset tracking, retail, and so forth) or orientation data (acceleration, rotation, and so forth).

The transmitted data is typically static but can also be dynamic and change over time. With the use of Bluetooth low energy, beacons can be designed to run for years on a single coin cell battery. This application report introduces the concept of beacons and how to get started with implementing a beacon solution. Naming conventions throughout this document can be summarized as Beacons that broadcast information by using advertisements with Bluetooth low energy technology that could be branded as Bluetooth low energy.

A Bluetooth low energy device can operate in four different device roles. Depending on the role, the devices behave differently. The first two roles are connection-based: *peripheral* - device is an advertiser that is connectable and can operate as a slave in a connection; *central* - device scans for advertisers and can initiate connections. The other two device roles are used for one-directional communication: *broadcaster* - a non-connectable advertiser, for example, a temperature sensor that broadcasts the current temperature; *observer* - scans for advertisements, but cannot initiate connections. This could be a remote display that receives the temperature data and presents it [4].

The two obvious device roles for beacon applications are Peripheral and Broadcaster. Both of them send the same type of advertisements with the exception of one specific flag that indicates if it is *connectable* or *non-connectable*. The low-power consumption of BLE is achieved by keeping the transmission time as short as possible and allowing the device to go into sleep mode between the transmissions.

In the NESTORE ecosystem, we will use non-connectable beacons (BLE devices in broadcasting mode) that simply transmit information that is stored internally. Because the non-connectable broadcasting role does not activate any receiving capabilities, it achieves the lowest possible power consumption by simply waking up, transmit data and going back to sleep. This comes with the drawback of dynamic data being restricted to what is only known to the device. In particular, we will broadcast temperature, humidity, and information regarding the movement of the device in the last time window (using a threshold on embedded accelerometer). The data transmitted by a BLE device is formatted according to the Bluetooth Core Specification [5] and is comprised of the parts shown in Figure 3 and Figure 4.

The first three bytes of the broadcasted data defines the capabilities of the device. When using Manufacturer-Specific Data, the 0xFF flag is used to indicate so. The first two bytes of the data itself are the company identifier code. For non-connectable undirected advertising (ADV_NONCONN_IND), maximum length of the Manufacturer-Specific Data is 28 bytes. The Manufacturer-Specific Data can contain any user-defined information. This will be the case of our solution, being the information that we want to advertise application-specific.

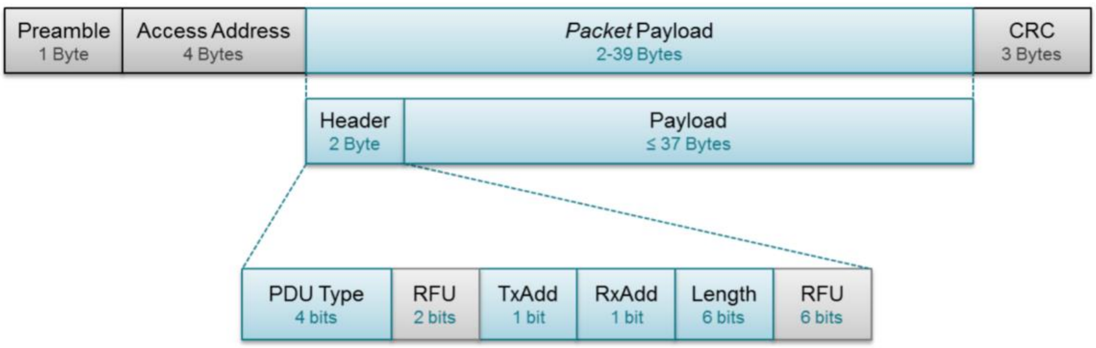

Figure 3 The BLE data packet.

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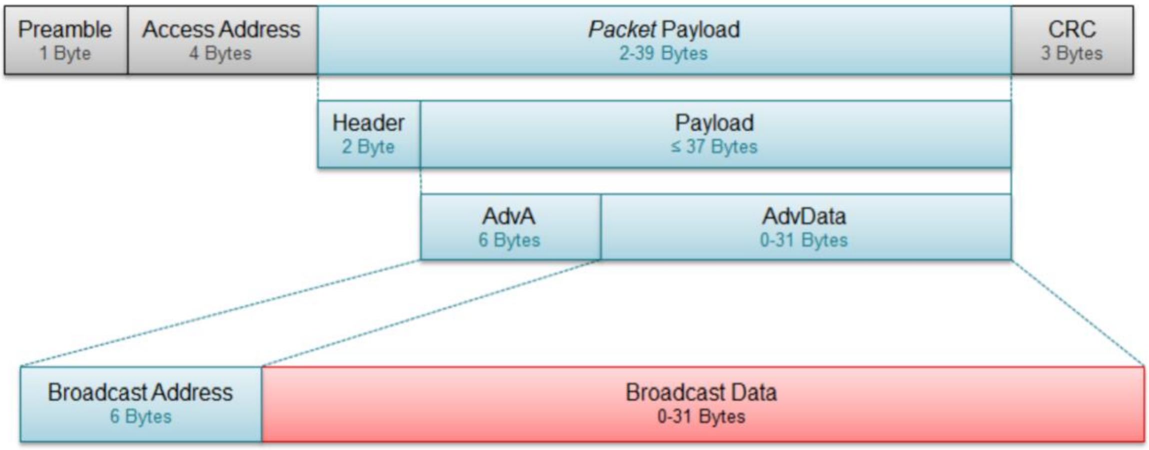

Figure 4 The BLE payload.

The broadcasted data can also be formatted in a standardized way, such as iBeacon from Apple, AltBeacon from Radius Networks, and Eddystone from Google. iBeacon is protected by the MFi license and is interoperable with all iOS devices. AltBeacon and Eddystone are instead open standards and their specification can be downloaded at [6] and [7], respectively.

The sensor selection process considered the capabilities offered by the available BLE beacon manufacturers in order to guarantee the possibility to exploit standard protocols for socialization events interactions (using BLE beacons in form of key fobs) and to modify the AdvData to include air quality information and movements of the beacon itself. Table 3 shows the considered manufacturers in terms of protocol used, possibility to customize the HW and the FW of the beacon, and the price. This analysis lead us to chose as testing platform the Global Tag manufacturer offering the most customizable BLE solution at a lower price for standard tags, with additional costs for firmware and hardware customization.

This platform has been used as reference architecture for the development of custom BLE beacons (developed by the partner FLEX) that are able to expand the capabilities of Globalt Tags in terms of information about temperature, humidity, and thresholds on embedded accelerometers to detect the interaction of the user with the furniture on which the beacon is attached.

Table 3 Manufacturers selection indices

Manufacturer	Protocol	FW/HW Customization	Price
Radbeacon	iBEacon, Eddystone, AltBeacon	No	$
BlueCats, kontakt	iBeacon, Eddystone	No	$$
BlueSense, Estimote, Glimworm, Gimbal	iBeacon	No	$$
Global Tag, BlueUp	iBeacon, Eddystone	Yes	$ ($$ for customization, depending on number of units)

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Figure 5 shows the beacons used in our testings for indoor socialization detection, further details about the algorithms used is available on D4.1 document, while the results from the testing phase in terms of data rates and impact of the custom developed beacons is be described in Section 3 (preliminary results can be found in [8] while the description of the adopted technology is detailed in the next subsection).

Figure 5 BLE beacons used as environmental sensors and for detecting social interactions. On the top: the GloblTag testing platform; on the bottom: the custom NESTORE beacon developed by Flex.

2.1.1 The custom NESTORE beacons

The Nestore beacon (developed by FLEX) is an embedded device that is able to report periodically with a broadcast BLE message its battery level state, the temperature and humidity of the environment in which it is located, and the information related to movements detection of the object on which it is mounted.

These functionalities of the beacon can be resume in the following high-level tasks:

- It shall acquire data from an accelerometer;
- It shall acquire data from a temperature-humidity sensor;
- It shall acquire the battery voltage level;
- It shall send a non-connectable BLE advertising message containing information about movement detection, temperature, humidity and battery percentage level

In the system, it is also expected a watchdog timer able to reset the microcontroller in case of malfunctionalities. The FW shall manage also the timer resetting to prevent it from elapsing.

These tasks are executed considering that the overall system has critical constrains in terms of power consumption. The microcontroller implements these features consuming less energy as possible: the target consists of covering 1 year of continuous usage with a CR2032 coin cell battery. Microcontroller achieves the lowest possible power consumption by simply waking up, resetting the watchdog timer, collecting and transmitting the data and going back to sleep.

Furthermore, it also a downgraded version of this FW has been developed that doesn't integrate the reading of the accelerometer and temperature-humidity sensors. This second version of the beacon FW, therefore, sends periodically a broadcast BLE message with only its battery level state.

2.1.1.1 Embedded sensors: Accelerometer - LIS3DH

The triaxial accelerations of the object on which the beacon is mounted are used to understand the movement changes of the object itself. Generally, a thresholding method on the magnitude value of the x, y and z components of the accelerometer permits to understand easily a motion event.

Nevertheless, to reduce power consumption, the microcontroller avoids to continuously read the accelerometer raw data, but it takes advantage of the motion detection hardware feature of the LIS3DH sensor or the LIS3DH internal FIFO buffer to limit its reading intervention.

The information to report to external world consist of just a Boolean that indicates the presence or the absence of a movement detection.

2.1.1.2 Embedded sensors: Temperature-humidity sensor - SHT3x-DIS

The temperature and humidity provided by the sensor is calibrated using the calibration data stored in the sensor non-volatile memory.

The system updates temperature and humidity each: TEMPERATURE_HUMIDITY_SAMPLING_PERIOD.

The temperature is reported in °C, while the relative humidity in %.

To reduce power consumption, accelerometer and temperature-humidity sensor are placed on the same I2C peripheral.

2.1.1.3 Battery Voltage level

The system acquires the battery voltage level each; BATTERY_SAMPLING_PERIOD.

The microcontroller samples multiple values for a short time window and then take the average to reduce the signal noise level.

The voltage level sampling shall occur when the device is in a low power state: no transmission of the BLE advertising message and no sensor data reading. This should avoid the reading of battery voltage oscillations due to the sensor and BLE management load.

The voltage raw measure read shall be converted in percentage value with respect to the maximal battery voltage level.

2.1.1.4 BLE management

The device acts as a simple BLE broadcaster sending a non-connectable advertising message every: ADVERTISING_PERIOD.

Figure 6 and Figure 7 show the Advertising Packet format.

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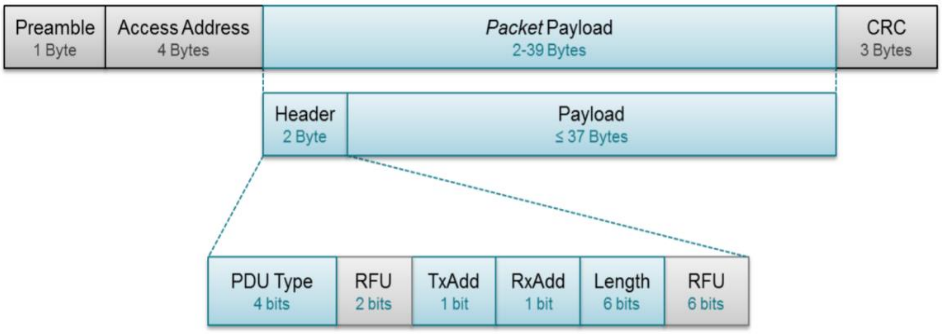

Figure 6 Advertising Packet format: Header of the Packet Payload

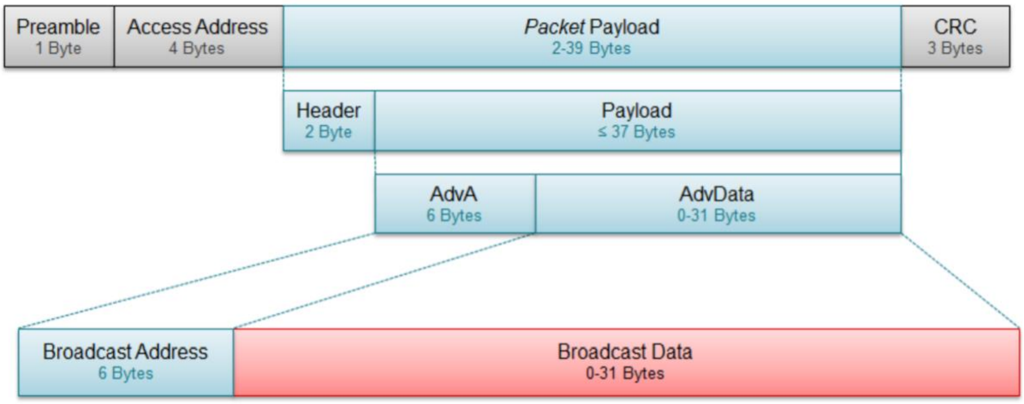

Figure 7 Advertising Packet format: Payload of the Packet Payload

The payload broadcast data consists of the following values:

Battery level	uint8	1 byte
Movement detection	bool	encapsulated in 1 byte
Temperature*10	int16	2 bytes
Humidity	uint8	1 byte

The temperature value has not been reported in float format but multiplied by 10 with a casting to int16 to reduce the data amount to send. In the following, the parameters chosen:

Variable	Value	Unit of measure
ADVERTISING_PERIOD	250	milliseconds
TEMPERATURE_HUMIDITY_SAMPLING_PERIOD	3	seconds
BATTERY_SAMPLING_PERIOD	24	hours

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2.2 Ballistocardiography

Despite being used commonly in sleep medicine, the term "sleep quality" has not been rigorously defined. Usually it refers to well defined questions in dedicated questionnaires. One of the goals of NESTORE is to find a measurable sleep quality index starting from sleep related physiological characteristics. The main variables influencing sleep quality are Heart Rate (HR), Heart Rate Variability (HRV), Resipratory Rate (RR), and Respiratory Rate Variability (RRV). Please see deliverable D2.1 for more insights on the physiological aspects.

From a technological point of view, there are very few ways to monitor sleep quality, among them we find polysomnography (PSG), actigraphy [9], and ballistocardiography (BCG). Being one of the main requirements of the NESTORE system its unobtrusiveness, we easily chose BCG as best candidate.

Ballistocardiography (BCG) is a method for the measurement of the mechanical forces originated from the body [10]. This phenomenon was first studied in 1877 by Gordon and further investigated through the 1900s century. However, BCG was not accurate enough for medical use until recent improvements in the signal processing methods. The new ways to assess BCG signal have produced reliable results when compared with the traditional ECG measurements [11].

In a stationary state, primary mechanical forces acting on the body originate from the heart and circulation of blood, with beating of the heart as a detectable cyclic event. The BCG measurement is physiologically based on the Newton's laws of motion. This force causes a recoil effect on the body that can be visualized in a ballistocardiogram (Figure 8, picture taken from [12]).

The BCG pulse starts when the atria contract, right before the ventricular contraction. The pulse wave maxima and minima are denoted with letters from H to N. The H-K waves form the ventricular systole and L-N waves occur during the diastole which corresponds to the relaxation of the heart. The waves of the BCG pulse are a combination of the forces created by the heart and blood flow. Due to respiratory effect, the I and J waves normally have increased amplitude during inspiration and decreased amplitude during expiration. The sum of all waves roughly represents the relative stroke volume of the heart.

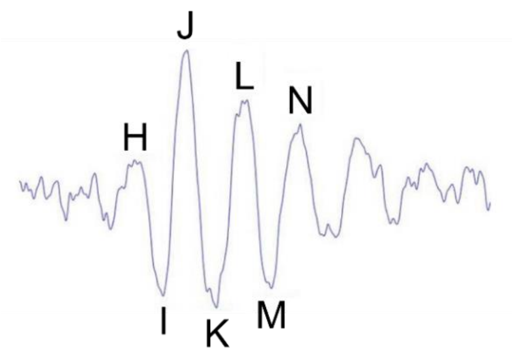

Figure 8 Ballistocardiogram. The BCG pulse is noted with letters from H to N [12].

The magnitude of the forces can be measured as vectors in one direction at a time. Ballistocardiographic forces acting into the longitudinal direction of the body are the strongest and thus easiest to detect. The noise from the environment is small in a stationary state compared to the amplitude of the BCG pulse. BCG devices usually measure only the longitudinal component. Three dimensional BCG is still an evolving research area. Bed or chair systems produce better results compared to ambulatory systems as the subject is generally in still position. In bed, the whole body is longitudinally positioned, further improving the accuracy of single-axis measurements.

In addition to the cardiac events, BCG can be used to detect respiration. Breathing modulates the stroke volume of the heart which is related to the BCG pulse amplitude, as previously explained. The amplitude sum of pulse waves is higher during inspiration and lower during expiration. Respiratory rate can be extracted from the pulse modulation. Respiratory depth is related to the amplitude of the BCG pulse.

BCG enables accurate and non-invasive measurement of the cardiac and respiratory events in a stationary state, i.e. during sleep or rest. Unobtrusive BCG techniques for automatic sleep stage classification have provided good results in continuous home sleep monitoring [13]. The detected cardiac and respiratory events give information about the sleep quality.

A wide variety of different sensors have been recently used in bed-based BCG systems, from static charge sensistive bed and pressure to pneumatic and hysdraulic sensors, but due to its accuracy and low cost, the more commonly used in commercially available products are accelerometers.

For example, resolution of less than 100 µm can be achieved with the Murata SCA11H accelerometer that was utilized in the BCG device for NESTORE studies. High signal resolution and low noise level of the sensor provides advantages in use for sleep analysis. Other commercial BCG based sleep analysis products include Beddit Sleep Tracker [14] and Emfit QS Sleep Monitor [15]. PSG is still used in clinical testing but the BCG products provide an easy way to track sleep over a longer period of time.

Table 4 Manufacturers selection indices

Manufacturer	Connectivity Protocol	API	Price
Emfit QS	WiFi/3G	3rd party cloud with token	$$$
Beddit 3 Sleep Monitor	BT Smart	N/A	$
Murata SCA11H	WiFi	Open both local and remote access	$

2.2.1 MURATA SCA11H

As previously said, the rationale behind the performed sensor selection is the possibility to collect data without an explicit interaction of the user with 3rd party applications or the device itself. For this reasons, among the possible BCG solutions available on the market, we have chosen a device able to transmit data over WiFI (in order to not have a dedicate application on the user's smartphone) and that allows us to gather data with available open API. The cost has also been kept in mind. Table 4 shows the considered devices with their characteristics. We also performed a preliminary study about their usability and performance, as shown in Table 5. From the usability point of view we considered how the device is installed, if the user has to manually start and stop the data collection and how he can view his own data. These considerations confirmed our choice of the Murata SCA11H sensor, also because it allows to design our own user interface to be integrated in the NESTORE dashboard. Also the performance analysis confirmed the Murata SCA11H as the best candidate, being the sensor that instead of providing an already aggregated and usually unreliable information about user's sleep quality it collect a more rich set of raw data, like HR, HRV, RR, RRV, and Rdepth.

The information shown in Table 5 are the results of the comparison of products available on the market being performed in a real home environment. The obtained performances are presented in [12]. It is important to notice that Murata SCA11H presents features that are available as "is development", but the data gathering capabilities offered by its APIs allowed the Work Package 4 developers to implement a refined version of the sleep time and stages detection. Further details are available in document D4.1. Furthermore, NESTORE will implement its own user interface in the dedicate user application.

Table 5 Usability and performance analysis of the candidate sensors (from [12]).

	Emfit QS	**Beddit 3**	**Murata SCA11H**
Usability			
Installation	Tape	Tape	Attachment plate
Start/close	Automatic	Manual	Automatic
User interface	Complicated	Simple	In development
Performance			
Sleep time	Unreliable	Unreliable	In development
Sleep stages	Yes	No	In development
Cardiac	HR, HRV	-	HR, HRV
Respiratory	RR	Avg RR	RR, RRV, Rdepth

2.3 Smart scale

In order to collect information about the user's body composition, we plan to integrate in the NESTORE system a smart scale able to detect the variables indicated in the D2.1 document (e.g., weight, percentage of fat mass, percentage of muscle mass, percentage of water, percentage of bone mass). All of the considered devices uses Bioelectrical Impedance Analysis (BIA) to calculate the body composition [16]. BIA actually determines the electrical impedance, or opposition to the flow of an electric current through body tissues which can then be used to estimate total body water (TBW), which can be used to estimate fat-free body mass and, by difference with body weight, body fat.

Table 6 Manufacturers selection indices

Manufacturer	Connectivity Protocol	API	Price
Generic BT solutions	BT	Ony via mobile app, then cloud with token	$
Open scale solutions	BT	Openscale	$
NOKIA Body+, Fitbit Aria 2	WiFi	Cloud with token	$

Also for the selection of the best candidate smart scale solution we considered the easiness of installation and use (no need to manually synchronize a mobile app and the device after a weighing), but also the availablity of APIs to gather the collected data. There is a plethora of smart scale solutions on the market but most of them use dedicated applications on the user's smartphone collecting data via BT and then available on a 3rd party cloud server. An interesting solution for BT smart scales is offered by the openScale project [17]; it is an open

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source mobile application which supports various Bluetooth scales to keep easy log of the users's body metrics. Also in this case, we need a dedicated mobile application to gather data but this solution can be considered as a valid alternative in case of the integration of a BT scale, thanks to its open source nature. As shown in Table 6, the only available WiFi scales on the market (with a certified level of accuracy) are the NOKIA Body+ and Fitbit Aria 2. These two models are the ones currently being tested In the NESTORE WP3 activities.

2.3.1 Withings Body+

Withings is a French consumer electronics company. Withings was known for design and innovation in connected devices, such as the first Wi-Fi scale on the market (introduced in 2009), an FDA-cleared blood pressure monitor, a high-definition wireless security camera, a smart sleep system, and a line of automatic activity tracking watches.

The Body+ device has been chosen on the basis of the availability of open APIs provided by the withings development community. It comes with a full specification and documentation available on a dedicated website: http://developer.withings.com/oauth2/.

Withings has been purchased by Finnish company Nokia on 26 April 2016. The deal closed on 31 May, with Withings having been absorbed into Nokia's new Digital Health unit led by the former Withings CEO; the division became known as Nokia Health. The Withings brand continued to be used until June 2017, when it was replaced by the Nokia brand. In May 2018, Éric Carreel, Withings' founder, finalized a deal to regain control and the company became independent again, under the Withings name.

This has also been reflected on the naming conventions used in the APIs that had an impact on the integration and development effort in NESTORE. This risk has however been mitigated both thanks to the prompt modifications applied by the Withings developer community and the effort made by the Work Package 6 partners.

3 Integrated system tests

This section reports the tests we conducted with the hardware for detecting the social interactions and for the indoor mobility analysis. Tests have a twofold goal: get familiar with the hardware and test the basic features at real conditions.

3.1 Hardware setup and tests

The hardware kit is composed by:

- The NESTORE wristband and the charging station;
- The social and environmental beacons.

Figure 9 shows the hardware kit we tested while Table 7 reports the tests we conducted, they are split in two macro-categories:

1. Usability tests;
2. Functional test.

It is worth to notice that the following tests do not aim at replace test conducted by Flex for assessing the quality of the wristband and beacons, rather they aim at assess qualitatively their effectives during the NESTORE pilot sites.

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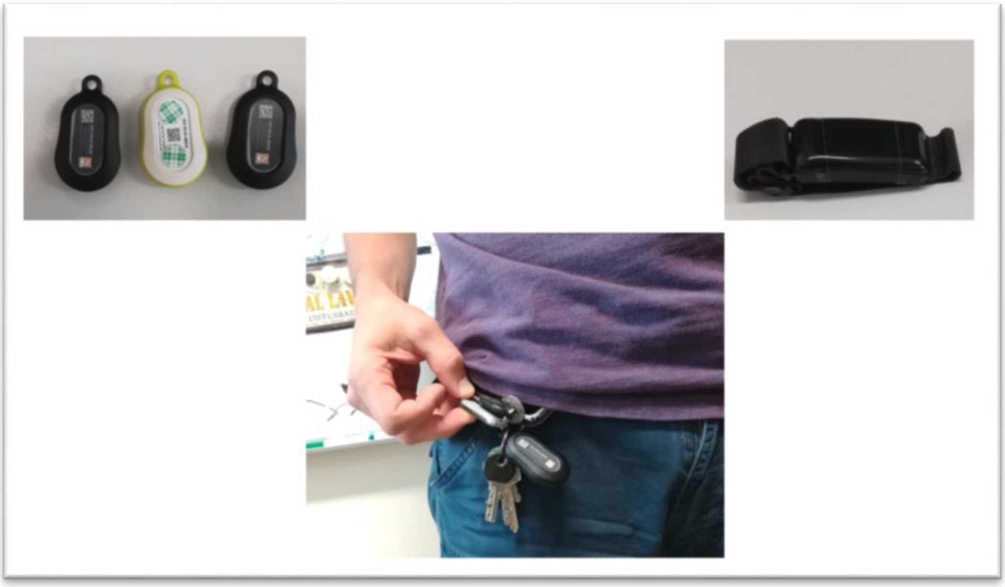

Figure 9 Hardware kit.

Table 7 The tests conducted.

Category	Description
Usability test	• Wearing the wristband • Open and lock the wristband
Functional test	• Switching on /off • Pairing with the WoT Agent • Setting the wristband from the Wot Agent • Force synch with the WoT agent • Access data uploaded via Web • Lock to the dock station • Check charging status • **Measure RSSI of messages collected** • Measure beacon loss rate • Mimic interaction between NESTORE user and friend

We further analyse the RSSI of the messages collected both from the social and environmental beacons with the goal of defining a suitable setting for the power of emission for all the NESTORE pilot sites.

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3.2 Setting social beacons

Concerning the social beacons, the requirement is being able to identify a social interaction between a NESTORE user and a friend at very different conditions and distances. We figure out 2 possible scenarios:

- Social beacon close to the place of the interaction (e.g. 0 to 2 meters);
- Social beacon far from the place of the interaction (e.g. 6+ meters).

More precisely, the goal in this case is to record the higher number of messages, therefore the higher the power of emission the more messages can be collected and, in turn, more messages can be analysed. It is worth to notice that a further refinement to the messages is performed by the algorithm for detecting the social interactions. In particular, it filters out those messages considered of low quality and hence not useful for assessing interaction or non-interaction.

We tested beacons with different power of emission: -8dbm, -4 dbm and 0dbm. After some preliminary tests, we observed that social beacons set with power of emission to -8dbm do not allow to identify interactions between users in all the situations (see D4.3). We agreed to set social beacon at least at -4dbm or 0 dbm. In Figure 10, we report the RSSI distribution for both performed tests during the interaction phase.

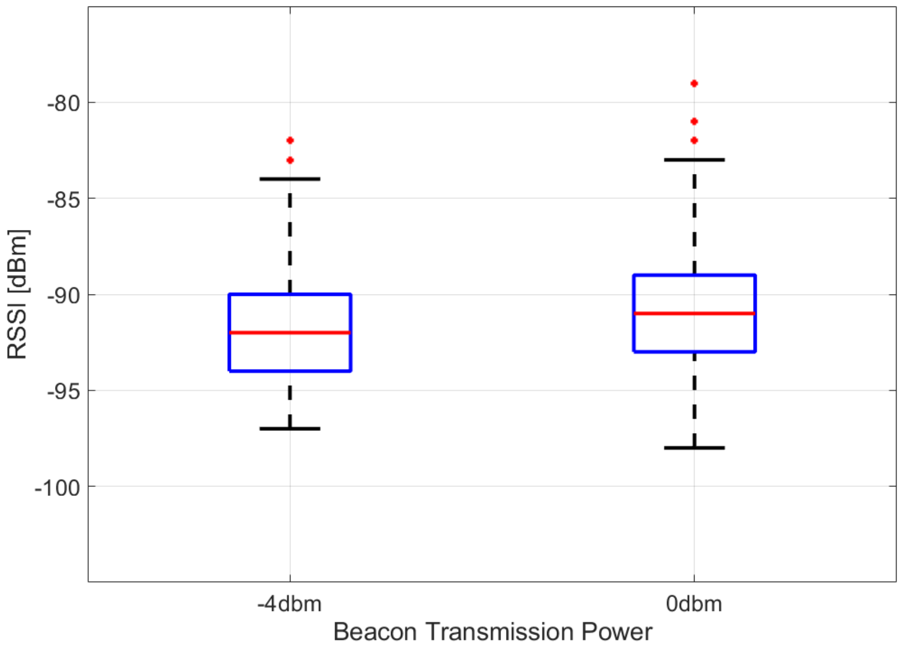

Figure 10 RSSI distribution with transmission power of the social beacons set to -4dbm and 0dbm.

3.3 Setting environmental beacons

Differently from the social beacon, in this case the requirement is being able to detect proximity between the wristband and the environmental beacon deployed in a room in a range of 0 to 2 meters. To this purpose, we set up some tests whose goal is measuring how the RSSI varies when the distance between wristband and beacon increases.

This scenario tests how the RSSI varies when increasing the distance between the wristband and the environmental beacon:

- The NESTORE user wears the wristband;
- The environmental beacon is set to -16dbm and -20dbm

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The protocol we followed is the following:

1. Environmental beacons placed in a fixed position;
2. The NESOTE user steps away from the environmental beacons at steps of 60 cm: from 120 cm to 420 cm away.

We collected all the messages from the 2 environmental beacons (-16 dbm and -20 dbm) for the whole test duration and we analysed how the RSSI varies. Figure 11 and Figure 12 show a sequence of box plots, one for each step. The box plot shows maximum and minimum (low and high whiskers). Box plots also report median, 25th and 75th percentile of the RSSI. As expected, the higher the distance, the lower the statistics of the RSSI.

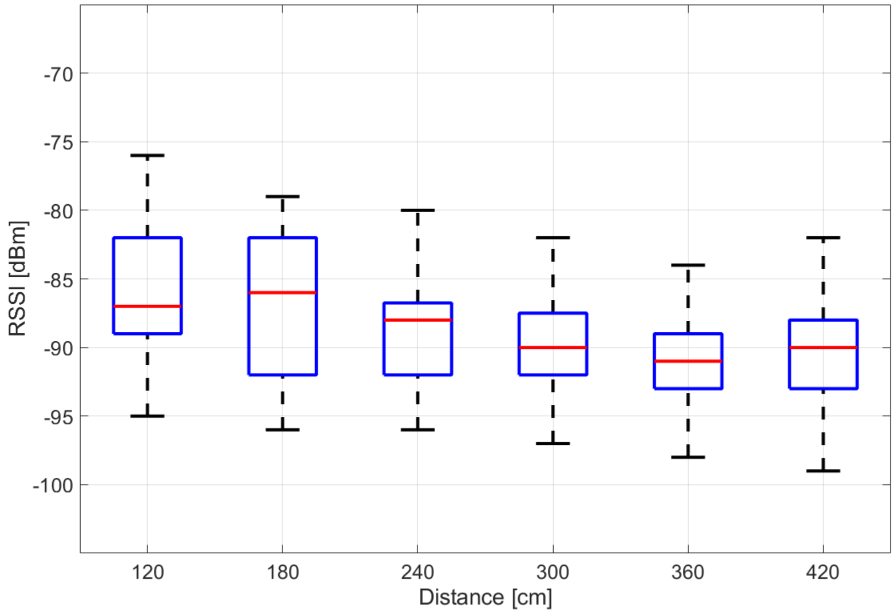

Figure 11 RSSI variation for environmental beacon set to -16dbm.

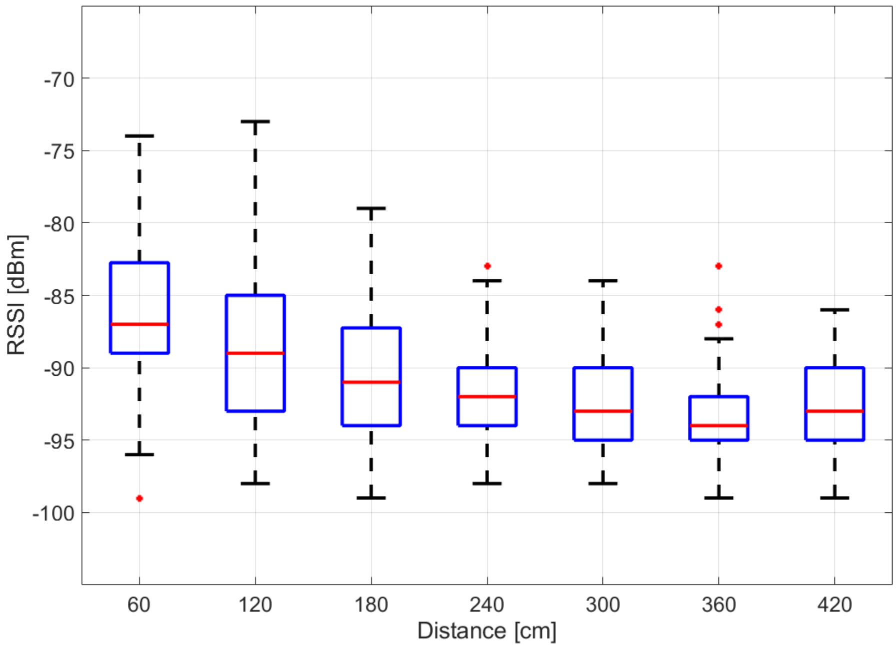

Figure 12 RSSI variation for environmental beacon set to -20dbm.

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4 Conclusions

This document describes the outcomes of the activities performed in the Work Package 3 and extends the results of the first iteration in the sensors selection for the environmental devices described at M12 in the deliverable D3.2.1. As we have seen, with the current set of devices we cover a subset of all the possbile variables in the defined domains. This was expected because the work performed in WP2 activities tried to fully cover the variables affecting the user's life in all of his dimensions. Most of the indicated variables are difficult to be monitored with off-the-shelf devices, but fortunately the frequency of collection is low, therefore it can be done in dedicated shared environment when needed.

The second iteration in sensor selection had the aim of enriching the set of monitored variables, in terms of integrated technologies and devices. The additional BLE devices are ready to be used in a typical NESTORE and the availability of additional interated devices also allows a modular approach in the exploitation strategy: if a NETORE user needs a particular device for a specific aspect of one of his domains, the device will be ready to be added to the NESTORE ecosystem at a later time.

The final set of devices has been througly tested following the NESTORE use cases, especially for non off-the-shelf devices like the custom NESTORE beacons. The integrated devices can be extended in their use in collaboration with WP4 and WP5 work group. In particular, the presence of BLE beacons in the house will be exploited for monitoring sedentariness of the user, fusing the information coming from the smart wristband, and to augment the results of the social detection algorithm providing information about the location in which the interaction happens, in terms of closest beacon location seen by the wristband.

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