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Abstract: With the rapid surge of M-Health and smart city systems, the need to accommodate sensors and actuators to achieve effective automation turns out to be imposed, for an efficient machine-to-machine communication to be maintained. In this regard, the key elements necessary for a successful M-Health system to take place are discovered to be the power consumption and interoperability maintaining factors. In this context, the present study is conducted to devise a special elderly tracking and monitoring system, closely connected to a walking stick device. The proposed design involves a cane cased transmitter node, enabling to send data related to the position and the state of the elderly to a base station, through implementation of the LoRa technology. The latter would then apply the message queuing telemetry transport (MQTT) protocol to interact with the environment once a fall proves to take place. For the purpose of evaluating the advanced design associated coverage range and power consumption rate, as enhanced via LoRa network, several experimental tests have been administered. The achieved results appear to reveal that the suggested architecture recorded average covered area turns out to be of the rate of 6 km^2.

1 Introduction

Demographic growth and urbanisation are creating a desire to integrate technology into the design of urban services, culminating in the idea of 'smart cities'. This new tendency has resulted in the application of information and communication technologies for the purpose of maintaining urban support, versatile for the persistence of large communities, involving transportation [1], energy systems [2], criminality sources [3] and smart health [4].

In effect, smart cities rely heavily on sensors to perceive such parameters as temperature, humidity, pollution, traffic conditions and the state of the power grid. Actually, these parameters associated values help provide a special context enabling to recognise the specific state of a particular citizen at a given moment [5]. Thus, responding strategically to the detected data should contribute in rendering the health care services rather smart. Hence, by gaining real-time access to such information, city departments can respond quickly to urgent health needs and make the appropriate decisions whereby serious situations could be avoided.

According to the World Health Organization [6], between 28 and 35% of people aged 65 and over fall each year. These rates increase even further to range between 32 and 42% concerning people aged over 70 years. In fact, fall occurrences prove to increase exponentially with age-related biological changes, resulting in a high incidence of fall-related injuries, mainly in ageing societies. If no preventive measures are promptly taken as, the number of fall related injuries would be 100% higher by 2030. Therefore, special mobility and personal assistance related devices turn out to be urgently required to ensure a certain degree of independence for the concerned people. Among the efficient assistance devices are canes, frequently used by a large number of older people, owing mainly to the simplicity, ease of use and the effective walking assistance they provide.

In this respect, the Internet of Things (IoT) [7], with the related technological progress it provides, could stand as an effective means whereby more comfortable living conditions could be provided to the elderly, mainly through effectively monitoring their health statuses, thanks to the development of innovative smart environments [8]. Such technologies can also provide older people with greater security through the provision of highly performing emergency response mechanisms [9], fall detection solutions [10] and video surveillance systems [11]. In addition, they provide daily life related support and activities' monitoring devices, e.g. reminders [12], enabling old people to communicate with their families and medical staff. In this regard, the major active surveillance-system critically associated elements turn out to be the energy consumption and interoperability factors.

It is worth highlighting that the major difference distinguishing the 'Internet' from 'IoT' [13] lies in the fact that in IoT, there is just 'less of everything' available on a device or network device: less memory, less processing power, less bandwidth, and so on, and of course, less energy available. This is due to the fact that things (objects) are either predominantly battery-powered, which makes their life maximisation issue a major priority, or marked with a remarkably huge number (it is estimated that no less than 50 billion devices would be connected by 2020 [14]). Actually, this desire to 'do more with less' has brought about certain constraints leading to noticeable limitations in the applicability of traditional cellular networks, as well as technologies, such as WiFi, due to the serious energy and scalability requirements. In this regard, the LoRa technology turns out to be essentially useful for targeting and monitoring deployments where end devices have limited power (e.g. battery-powered), or do not need to transmit more than a few bytes at a time [15] and where the terminal can initiate data traffic (for instance, when the terminal is a sensor) or in case where an external entity wishes to communicate with the terminal (i.e. when the terminal is an actuator). It is actually the LoRa associated long-range, low-power character which makes it an attractive candidate for maintaining intelligent sensing technology in civilian infrastructures (such as health monitoring, intelligent measurement, environmental monitoring etc.) as well as in industrial applications.

In this respect, machine-to-machine (M2M) communication represents a promising IoT potential, where billions of everyday objects and surrounding environments turn out to be interconnected and managed using a wide range of devices, communication networks and cloud-based servers [16]. In this context, M2M communication, also known as machine type communication, appears to be able to maintain information exchange between machines and machines without any human interactions or
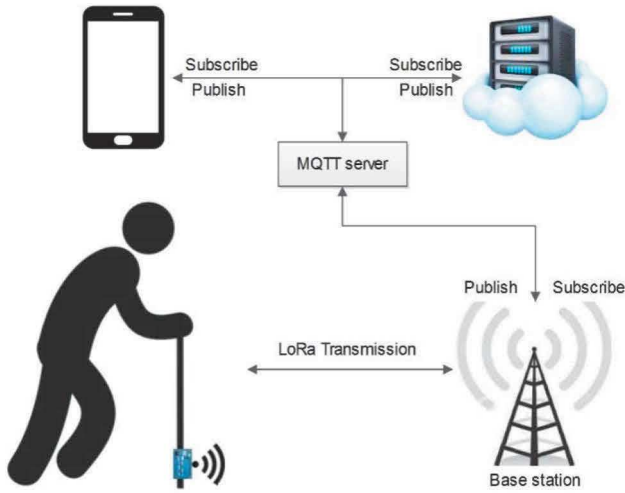
Fig. 1 *Designed system relevant architecture*

interference. It proves to be applicable in many fields of IoT applications [17], including health care, industrial and agricultural automation, transport systems and electricity grids. Hence, message queuing telemetry transport (MQTT) is an IoT-related M2M connectivity protocol, designed as a publish-subscribe messaging protocol based on the extremely lightweight TCP/IP protocol. Pub-sub messaging is a form of data-centric communication, widely used in enterprise networks, owing mainly to the scalability and support features it provides for maintaining dynamic application topologies. The adoption of the pub/sub paradigm in sensor networks makes it possible to simplify their integration with other distributed applications. The data-centric communication approach is based on data content rather than receiver addresses, and exhibits remarkable efficiency and appropriacy in supporting wireless sensor networks [18]. Similarly, MQTT has been designed as a suitable communication middleware, enabling to hide and attenuate the low-level network protocols associated complexity, while enhancing application development and interoperability [19].

As part of the present work context, our focus of interest is laid on the LoRa network as constructed and targeted to maintain low-cost, low power and secure communication links between a connected walking stick and the supervisor, with the aim of ensuring the data transmission to the different related services via MQTT. The contributions intended to be provided through conducting the present research lie in the implementation of a new health monitoring system using a connected walking stick, while maintaining effective interoperability between the cane and other connected objects, within a smart city environment, via MQTT.

The remainder of this paper is organised as follows. Section 2 is devoted to provide a brief review of the related works. Section 3 serves to detail our M-Health system related architecture. Concerning Section 4, it involves a presentation of the communication protocol, as applied to maintain M2M communication. Section 5 involves an evaluative assessment of the suggested design associated performance, while the ultimate section involves a discussion of the major achieved results, along with highlights of the main concluding remarks and perspectives for a prospective research line.

2 Related works

In this section, we present recent related works on IoT-based health monitoring system.

In [20], the authors provided a novel architecture for health monitoring using wearable devices that transmit data to a LoRaWAN gateway via different wireless transmission protocols like Bluetooth, Zigbee, 2G, 3G, then the gateway transmit those data to different health centre via LoRa. The main advantages of this work are the multiples connection protocol, but the problem consists of the high cost of the system implementation and the power consumption due to Bluetooth, 2G, 3G connectivity. In

addition, the system is not autonomous and the interactivity with a connected object in a smart city environment is challenging.

In addition, a special presentation of a novel IoT-based health monitoring approach is provided in [21], whereby, the sensor collected medical data are sent to an analysis module via low-cost, low power and secure communication links provided by LoRaWAN network infrastructure. The project related limitation lies mainly in the high cost associated with the medical-data collection material. Besides, interoperability is not effectively maintained, given the fact that the various interconnected objects appear to apply different transmission protocols.

As for the authors in [22] they put forward a special system implementation, useful for tracking and monitoring the mental disorder affected patients' activities. The system consists of a special patient-installed tracking devices, by applying the LoRa client, along with other LoRa gateways installed hospital and public-location instruments. The LoRa gateways are connected to local as well as cloud servers by means of mobile cellular and Wi-Fi networks, as appropriate communication media. The main limitation, noticeable in this respect, consists mainly in the lack of interoperability between the patient and the surrounding environmental contexts.

3 Proposed system relevant design

The advanced M-health system, as can be depicted through Fig. 1, involves a specially conceived walking stick, whereby, the elderly state related data (GPS tracking, fall detection, steps number) can be transmitted to the base station (BS) via the LoRa (long distance, low power) technology. Accordingly, the BS stands as an M2M gateway, enabling communication to be maintained with another connected object, via MQTT, within a smart city environment. The devised scheme is conceived in such a way as to enable users to visualise the state of the cane via a mobile phone, to help monitor the elderly associated movements across a smart city environment, while localising them. It is operable by allowing the cane to communicate with several other connected objects, whenever a fall seems imminent to take place.

LoRa stands for Long Range Radio, which helps in supporting the IoT networks operated at the ISM frequency band of 433, 868 and 915 MHz. It applies the frequency shifting keying method, which enables to establish communication with low power and a small error rate [23, 24]. In its full form, the LoRa framework displays two distinct layers: (i) a physical layer that applies the chirp spread spectrum [25] radio modulation technique, along with a (ii) MAC layer protocol (LoRaWAN) [26]. Still, the LoRa communication system also involves a specific access network architecture.

Initially developed by Semtech, the LoRa associated physical layer allows for long-range, low-power and low-throughput communications to be effectively maintained. It is operable on one of the following bands 433, 868 or 915 MHz ISM, depending on the observed application area. Each transmission related payload range can be comprised between 2 and 255 octets, while the data rate can reach up to 50 kbps when channel aggregation is deployed. The modulation technique remains a proprietary technology, exclusively provided by Semtech.

As regards the LoRaWAN, it provides a medium access control mechanism, enabling several end-devices to communicate simultaneously with a gateway via the LoRa modulation. While the LoRa modulation is maintained on a proprietary basis, the LoRaWAN remains an open standard, predominantly developed by the LoRa Alliance.

Our choice for implementing the LoRa methodology has its justification in its ability to maintain a long-range network platform in a long-distance communications environment with long-term battery performance.

As an (M2M)/IoT connectivity protocol, the MQTT is designed to be applicable on top of the TCP/IP protocol stack, conceived to stand as an extremely lightweight broker-based publish/subscribe messaging protocol. It is willingly selected to serve in our study context for a number of characteristics it displays, particularly, its associated small code footprints (e.g. 8-bit, 256 KB ram
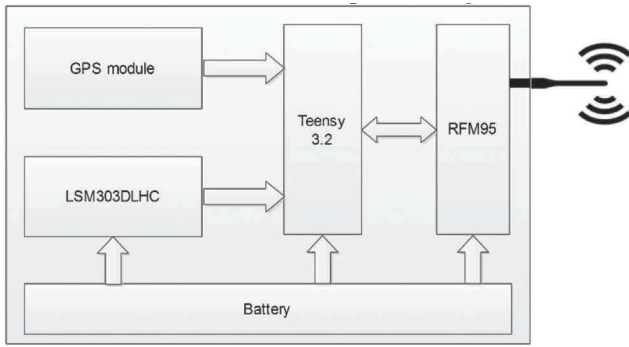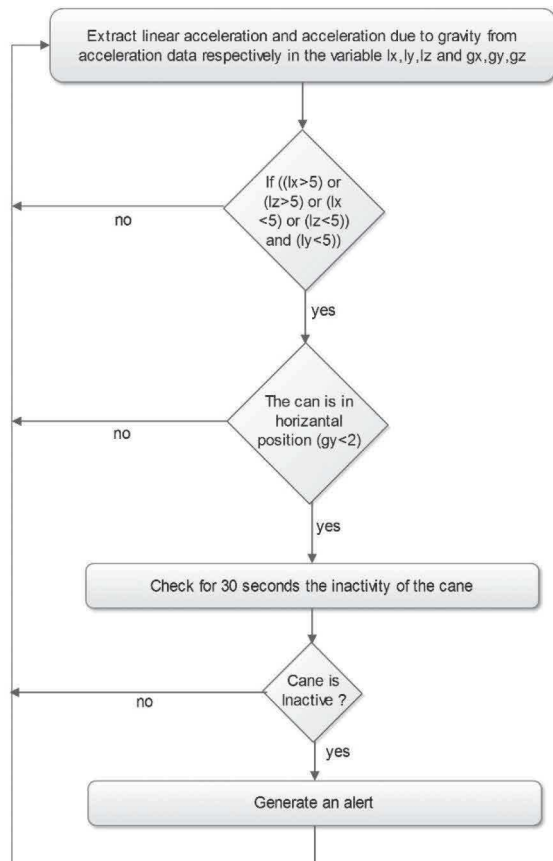
Fig. 2 *Node architecture*

Fig. 3 *Fall detection algorithm*

controllers), low bandwidth and power, high-cost connectivity and latency, variable availability, as well as the negotiated delivery guarantees [27].

The transmitter node is responsible for collecting the cane relating data (fall detection, steps' counting, walked distance, the cane's position and state), along with transmitting these data. For this purpose, an appeal is made to the lsm303dlhc [28], as a system-in-package featuring a 3D digital linear acceleration sensor and a 3D digital magnetic sensor, to an Adafruit Ultimate GPS module, to the Teensy 3.2 [29] card, as well as to an RFM95 (RFM95 ISM transceiver module V1.2) radio module for effective data transmission to be ensured. These devices are entirety powered with a small LiPo battery. The detailed node associated architecture is depicted in Fig. 2.

The LSM303DLHC has linear acceleration full-scales of $\pm 2g/\pm 4g/\pm 8g/\pm 16g$ and a magnetic field full-scales of $\pm 1.3/\pm 1.9/\pm 2.5/\pm 4.0/\pm 4.7/\pm 5.6/\pm 8.1$ gauss. The entirety of full-scales available is completely subject to the user selection.

Noteworthy, in this respect, is that the applied Teensy 3.2 displays the following features: MK20DX256 Processor, 32-bit ARM, Cortex-M4, 72 MHz, as well as a Flash Memory of: 262144, and a RAM Memory of: 65536. EEPROM: 2048.

Concerning the RFM95/96/97/98(W) transceivers, they feature the LoRaTM long-range modem that provides an ultra-long-range spread spectrum communication and a high interference immunity, while minimising energy consumption. On applying the Hope RF's patented LoRaTM modulation technique, the RFM95/96/97/98(W) can achieve a sensitivity range that exceeds −148 dBm, using a low-cost crystal and bill of materials. The high sensitivity combined with the integrated +20 dBm power amplifier yields industry leading link budget making it optimally fit for implementation with any range or robustness requiring application. Additionally, the LoRaTM technique helps also in providing significant blocking and selectivity advantages, relative to the conventional modulation techniques, thus, enabling to simultaneously solve the traditionally often encountered issue of design compromise between range, interference immunity and energy consumption factors.

Regarding the Adafruit Ultimate GPS module, it is constructed around the MTK3339 chipset, a no-non-sense, high-quality GPS module that can track up to 22 satellites on 66 channels. It is equipped with an excellent high-sensitivity receiver (−165 dBm tracking), and a built-in antenna. It can perform up to ten location updates per second for high speed, high sensitivity logging or tracking ends. As for the power consumption range, it is incredibly low, reaching just 20 mA during navigation.

Concerning the BS, it consists of a Raspberry Pi 2 [30] card equipped with a Chistera Pi [31] radio module that bears a dual radio interface (866 and 433 MHz).

4 Applied methods

This section presents a thorough depiction of the deployed methods and protocols, as developed to maintain communication between the cane and the BS, via LoRa, on the one hand, and between the cane and the environment, via MQTT, on the other.

4.1 Cane-based data acquisition process

The Smart Cane applies a multi-stage thresholding method based on acceleration data, associated with the fall-detection and step-counting algorithm. For the threshold values to be reached, we consider to analyse both of the linear acceleration and gravity acceleration related data once the person falls or makes a step.

Following analysis of the sensor-related data, one can identify the fall-related three-step process: (i) the fall itself, (ii) the cane associated horizontal position and (iii) the person relating inactivity. The implemented fall detection algorithm is explained in Fig. 3.

As for the step counting process, the cane generates an acceleration procedure on the *z*-axis and the *y*-axis, of a minimum threshold of 0.5 ms^2.

As for the GPS relevant data, the system keeps perpetually asking for the newly occupied position. Once unavailable (e.g. an indoor location), the cane would send the most recently recorded GPS position, along with the associated date and time data. We also envisage to set up a special indoor localisation system using UWB, on a complementary basis to the GPS [32].

4.2 Data transmission via LoRa

The cane positioned transmitter undertakes to send data to the BS by means of LoRa, liable to send a message to the cane bearing a request for data.

The radio transmission, as implied in our case study context, applies a frequency band of a type ISM (Industrial, Scientific and Medical) 866 MHz. Actually, the ISM bands [33] are frequency bands liable to the application in a small space for industrial, scientific, medical, domestic or similar purposes.

In effect, for anyone using a radio to communicate across a specific range distance, whatever the type of communication might be, the range capability usually stands as an inevitably primary concern, which entices us to make a further attempt in a bid to find out a reliable factor or source likely to help us improve the capability range.

The equation applied to describe this wave's behaviour within a 'free space' environment is that devised by H.T. Friis [34], also known as the Friis transmission equation, defined as follows:

$$P_R = P_T G_T G_R \left(\frac{1}{d}\right)^2 \times \left(\frac{\lambda}{4\pi}\right)^2 \qquad (1)$$

where

- P_R is the power received (watts)
- P_T is the power transmitted (watts)
- G_T is the gain of transmit antenna (scalar)
- G_R is the gain of receive antenna (scalar)
- λ is the wavelength
- d is the distance separating the transmitter and receiver
- n is the exponent for environmental conditions as represented in Table 1 ($n = 2$ defines 'free space').

In its basic form, the equation states that the strength of the electromagnetic radio wave received at some location is a function of: (a) the strength of the original transmitted signal, (b) the antennas' performance at both of the transmitter and receiver levels, (c) the wavelength corresponding to the operation frequency and (d) the distance separating the transmitter and receiver.

The Friis equation, as formulated in decibel form, turns out to be

$$P_R(\text{dB}) = -20\log\left(\frac{\lambda}{4\pi}\right) - 10n\log(d) + P_T + G_T + G_R \qquad (2)$$

The path loss, as rendered in scalar form (where $G_T = G_R = 1$), looks like [36]

$$L_{\text{PATH}} = \frac{P_R}{P_T} = \left[\frac{\lambda}{4\pi}\right]^{2[1/d]^n} \qquad (3)$$

While in decibel form (where $G_T = G_R = 1$), it (the path loss) is described as

$$L_{\text{PATH}}(\text{dB}) = P_R - P_T$$
$$= 20\log\left(\frac{\lambda}{4\pi}\right) - 10n\log\left(\frac{1}{d}\right) \qquad (4)$$

As for the generic range calculator spreadsheet equation, as solved for distance d, it takes the form of

$$d = \frac{\lambda}{4\pi 10^{a_r/20}} \qquad (5)$$

With a_r = Path loss + Fade margin.

Based on (5), one may well conclude that the major significant factor affecting the transmission range turns out to be the wavelength.

LoRa defines the spectrum spreading factor (SF) [37] by means of the formula: SF = log2(Rc/Rs), with Rc denoting the transmitted message rate (Chirp), while Rs denotes the rate of the symbol to be transmitted. In effect, an increase in the SF makes it possible to cover a greater distance between the equipment and the gateway, at the expense of the available bandwidth.

The possible bandwidths, likely to be configured for a particular channel, are 125, 250 and 500 kHz with regard to the 868 MHz band, enabling to achieve a maximum rate of 27 kbit/s through a bandwidth of 500 kHz, and a SF of 7.

Noteworthy, also, is that the RF95 module features four configurations, specifically:

- Bandwidth = 125 kHz, Cr (Error correction rate) = 4/5, Sf (Spreading factor) = 128 chips/symbol
- Bw = 500 kHz, Cr = 4/5, Sf = 128 chips/symbol
- Bw = 31.25 kHz, Cr = 4/8, Sf = 512 chips/symbol

Table 1 Values for 'n' [35]

Environment	'n' value
free space	2
grocery store	1.8
retail store	2.2
office (hard walls)	3
office (soft walls)	2.6
remote keyless entry	4

Table 2 Normal and sleep modes related frame formats

Name	Description	Size (byte)
cane Id.	unique identifier of the cane	16
status	moving or standing	1
longitude	the cane's position longitude	16
latitude	the cane's position latitude	16
distance	distance travelled	16
steps	steps' number	16
fall	fall detection	1

Table 3 Request mode relevant frame format

Name	Description	Size (byte)
cane Id.	unique identifier of the cane	16
request	request code	32

Table 4 Falling mode associated frame format

Name	Description	Size (byte)
cane Id.	unique identifier of the cane	16
longitude	the cane's position longitude	16
latitude	the cane's position latitude	16
roll	rotation angle on the X-axis	16
pitch	rotation angle on the Y-axis	16
yaw	rotation angle on the Y-axis	16

- Bw = 125 kHz, Cr = 4/8, Sf = 4096 chips/symbol.

With respect to our study case, we consider it rather convenient to apply the fourth configuration, as it displays the highest SF and smallest BW range.

After adjusting the configuration value, we proceed with determining the four transmission protocol associated modes, namely, the normal mode, sleep mode, falling mode and request mode, as detailed below.

The normal mode: it is activated throughout the cane's motion process, i.e. when it is moving. In this case, the transmitter node undertakes to send a frame to the BS on a regular basis, specifically, every 10 min. The frame-encapsulated data are detailed in Table 2.

The sleep-state mode: this mode is applied whenever the cane is not moving (e.g. at night). In this case, the transmitter node sends a frame to the BS on an hourly basis interval. Should the cane resume its motion state anew, the normal mode is then activated.

The request mode: it is a state during which the BS proposes to send a request frame to the cane positioned node. The frame-encapsulated data are detailed in Table 3.

The falling mode: this state is activated whenever a fall is detected. In this case, the transmitter node undertakes to send a regular frame to the BS (every 100 ms) to visualise the state of the cane in 3D, for a more clearly explicit recognition of the cane's state to be maintained. The frame encapsulated data are depicted in Table 4.

4.3 BS relating mathematical model

A mathematical model consists of the system's description using mathematical and linguistic concepts. In this regard, a model

decision would seem somewhat helpful for a thorough explanation of the overall system and a clear examination of the different components' associated effects. This modelling procedure is also helpful for certain predictions to be made as to the appropriate behaviour. Regarding our particular context, a description will be made concerning the BS relevant behaviour while receiving messages via MQTT or data through the RFM95.
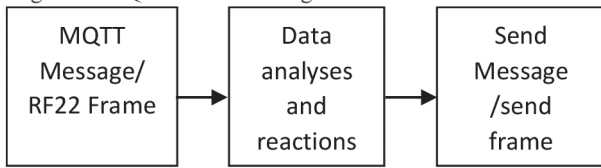
In its complete form, the system proves to englobe the sets of I, O, F, Fc, Sc, detailed as follows:

S = {I, O, F, Fc, Sc}

- I: set of inputs.
- O: set of outputs.
- F: set of functions.
- Fc: set of failure cases.
- Sc: set of success cases.

Input:

- Message received using MQTT
- Received frame using RFM95

Output:

- RFM95 frame
- MQTT message

Functions:

- Subscribe to a topic
- Verify the existence of an RF95 frame
- Decision making
- Sending frame using RFM95 module
- Sending MQTT message using MQTT broker

Failure cases:

- Could not connect to the MQTT broker
- Could not get the RFM95 frame
- Could not send the RFM95 frame

Success cases:

- RFM95 sent successfully
- MQTT message is sent successfully

Based on the above-described schema, one could well deduce that the BS is responsible for simultaneously ensuring interoperability and monitoring the system's automation.

4.4 Communication via MQTT

In this section, description of the IoT message design is provided based on the MQTT protocol, as fit for implementation to our M-Health scenario.

Table 5 highlights the IoT message as applicable with the MQTT protocol functioning. The IoT messages relate to the cane associated information, information request as well as fall detection alert. For each message type, the MQTT associated topic heading is provided, along with the identification of the relevant publishing and subscription themes, as well as the definition of the subscriber on taking action following reception of the message.

As depicted in Table 5, a determination of the topic management system, as relating to MQTT communication, is defined for the most optimum security and reliability level to be attained. To note, the symbol '#' denotes any string character, and the topic is conceived to involve three major parts, namely:

- The nomenclature CANET designates our proper monitoring system.
- The Appcode stands for the code attributed to each different application.
- The CaneID denotes the walking cane attributed id, derived from the RF95 frame, for more robust data reliability purposes.

The communication process, as undertaken via the MQTT, is explained in details through Fig. 4. Accordingly, the cane keeps computing the parameter every 100 m of walk to determine the exact functioning mode (normal, falling or sleep). Throughout each of the modes' lapse period, the cane undertakes to send a frame to the BS and, according to the cane provided data (fall, moving etc.), the BS decides to identify the specific topic heading, under which it should publish the data to transfer, as indicated in the preceding table. Thus, the MQTT client should be subscribed to the corresponding topic to be able to receive the message and make the relevant interactions necessary.

For the data transmission frequency to be minimised and the request notification system to be enabled, the request notification mode has been implemented. Once the smartphone is connected, the user can send an information request to the cane, which would in turn respond immediately, as illustrated trough Fig. 5.

Table 5 Topic management

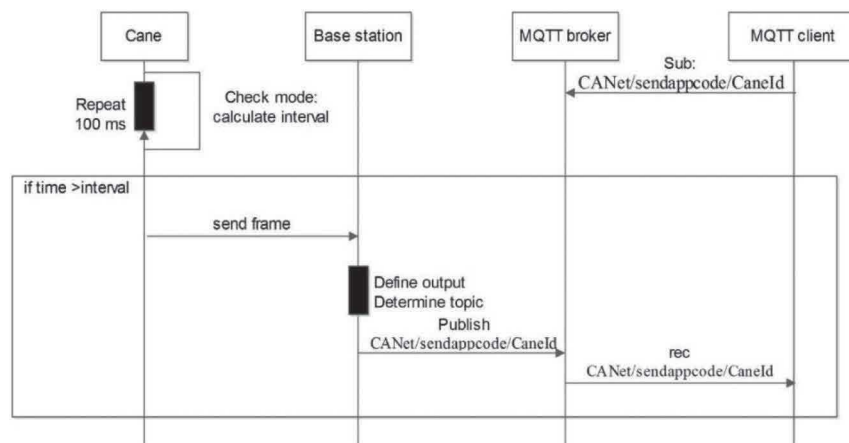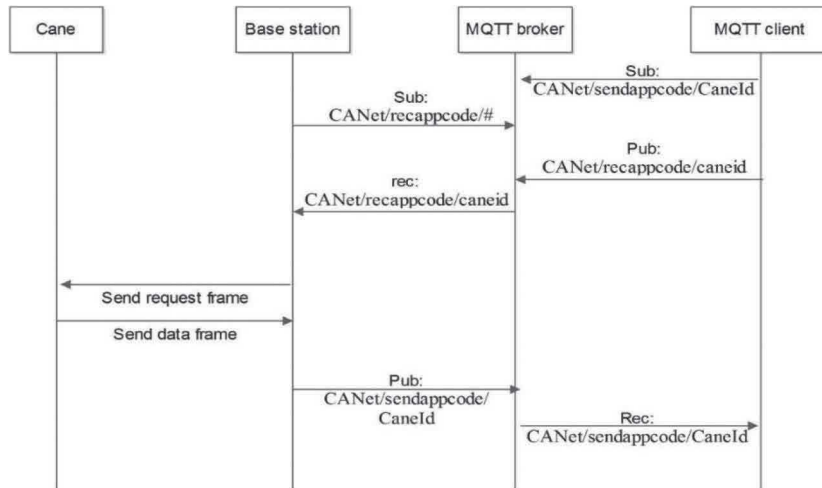| IOT message	MQTT topic	Publisher	Subscriber
info of the cane	CANet/sendappcode/CaneId	base station	MQTT client
request for info	CANet/recappcode/#	MQTT client	base station
fall detection	CANet/fallappcode/#	base station	MQTT client

Fig. 4 *Communication sequence diagram using the MQTT*

Fig. 5 *Sequence of communication diagram between the cane and a smartphone*

Fig. 6 *Transmitter node relevant design*

Fig. 7 *Cane fit battery*

Fig. 8 *BS layout*

In this scenario, the MQTT client proceeds with publishing a message to the topic 'CANet/recappcode/caneid' requesting to update the cane associated information for the normal, sleep or falling modes to be activated. Then the BS, subscribing to the topic 'CANet/recappcode/#', will receive the message and perform an information request process directed to the cane, using caneid, as derived from the topic. It consists in sending a request frame, as drawn from the receiver, and, then obtaining another frame to be resent to the specified topic heading.

5 Experiments and results

In the first place, a unique electronic card has been designed and constructed to fit for implementation in the transmitter node (Fig. 6), equipped with an appropriate battery (Fig. 7).

Actually, a Raspberry PI board has been equipped with a Chistera Pi radio interface board. At this level, a Python programming language is applied to develop a particular script, whereby, the BS relevant functionalities could be maintained. Regarding the Server, the AWS (Amazon Web Services) have been applied to englobe the MQTT Mosquitto [38] broker, and the Java application to ensure data backup (Fig. 8).

The conceived design has been tested in the French city of Blagnac. For a reliable testing of the designed framework's efficiency, we have placed the BS on top of a high building, at an altitude of 12 m altitude, sited at the IUT Blagnac. Two equipped canes were used by two elderly people throughout a 24 h time interval, and certain values, including battery consumption, transmission efficiency and maximum distance were being tested in the meanwhile.

Table 6 Fall detection rates (30 trials) regarding different types of falls

Project	Cane3D, %	Smart fall [34], %
forward	97.9	100
backward	96.7	93.3
side	97.1	100

To this end, a special MQTT broker was constructed on a private server to serve as a platform whereby the IoT services, applied to monitor the cane, could be maintained via a smartphone.

In a second place, a secure fall reserved platform has been constructed for experimental purposes. It consists in a soft cushion for the person to fall over without damage, and a harder surface to monitor the cane fall. The cushion positions and orientations are adjusted in accordance to different fall modes. An elderly person was selected to perform all types of fall. The attained results were then compared to the Smart fall [39] attempts, as figuring on Table 6.

Table 6 figuring results prove to exhibit a detection rate of almost 100% with regard to the three fall types, as performed by the elderly.

Table 7 false-positive rate (30 trials).

Project	Smart cane, %	Smart fall, %
slow walk	0	3.3
fast walk	0	0
swing	0	0
sit and stand	3.3	16.7
lay on lap	3.3	10
free fall	0	0

Table 8 Delay in communication relevant to the three QoS

QOS	Message loss (100 messages), %	Delay, ms
QOS 0	3	0.4
QOS 1	0	0.5
QOS 3	0	0.8

The results achieved, as depicted in Table 7, appear to indicate well that the algorithm turns out to be remarkably robust in terms of false-positive rate, while perfectly solving the sitting, standing as well as lap laying associated problems or inconveniences.

Indeed, the applied design proves to be rather remarkably accurate in relation to the Smart-fall system.

- Forward: simulates a trip-over engendered face down fall.
- Backward: simulates a fall on the back or bottom due to a slip.
- Side: simulates a sideward fall due to balance loss.
- Slow walk: walking with the cane at a pace of less than one step per second.
- Fast walk: walking with the cane at a pace of around two steps per second.
- Sit and stand: standing up, with the cane's help, following a sitting position.
- Swing: swinging the cane back-and-forth at around 1 Hz at an angle of less than 30± from the vertical axis.
- Cane on lap: picking up the vertically oriented cane and placing it horizontally on the lap.
- Free fall: simulates an unobstructed topple of the cane due to loss of control. The subject does not fall with the cane in this case.

For a high messaging reliability aspect to be maintained, three quality of services (QoS) levels turn out to be supported through the MQTT. With respect to the highest QoS level, more packet exchange proves to prevail. Indeed, the higher the QoS service level is, the more effective it turns out to be, if no message loss stands as the major aim or requirement.

The wireless network related message loss and end-to-end delay have been investigated, along with the relevant correlation displays, in terms of payload and QoS levels. The end-to-end delay, as recorded to persist between the BS and an MQTT client, as associated with the three QoS' levels' transmission loads, are tested in conformity to a message size case that is inferior to 20 kbytes.

As depicted in Table 8, the attained results prove to indicate well that the delay gap persistent between the QOS 0 and QOS 1 is of a rate of just 0.1 s, while the transmission efficiency turns out to be noticeably higher concerning QOS 1 (with no message loss being recorded). Hence, we consider it more appropriate to apply the QoS level 1.

As regards the cane battery associated electricity consumption level, it is measured on a 12 h basis, highlighting that both of the power consumption and time rates prove to increase linearly. Indeed, for $T = 5$ min, it appears clear that the amount of electricity consumed turns out to be higher than that consumed at $T = 10$ min. In addition, and as time continues to go on, it has been discovered that the connection proves to witness certain disruptions. Hence, from the recorded power rates and system stability perspectives, one is enticed to consider that the general selection of $T = 10$ min turns out to be a rather fit choice. Computed in terms of $T = 10$

min, the hourly rate of electricity consumption appears to be 0.76 J, 24 h, that is, 18.24 versus 179 J for a GPRS-based transmission system.

Hence, for transmission range evaluation purposes, we consider to calculate the percentage of packet loss corresponding to the four configurations, as already outlined:

- Config1: Bw = 500 kHz, Cr = 4/5, Sf = 128 chips/symbol
- Config2: Bw = 125 kHz, Cr = 4/5, Sf = 128 chips/symbol
- Config3: Bw = 31.25 kHz, Cr = 4/8, Sf = 512 chips/symbol
- Config4: Bw = 125 kHz, Cr = 4/8, Sf = 4096 chips/symbol

Fig. 9 indicates well that the best configuration for a long-range communication to be effectively maintained turns out to be config.1, which proves to exhibit the maximum SF value and a low bandwidth. Indeed, through this configuration, we are able to reach a distance range of 1 km. With respect to our study case, the data rate factor does not seem to be highly essential, since the packet size proves to be lower than 1 ko.

6 Conclusion

In the present work, a novel elderly walking monitoring architecture is put forward, which uses the LoRa model for a long-range and low-power communication to take place, and the MQTT protocol for interoperability to be maintained. In a first place, the cane undertakes to transmit the cane state associated data (GPS position, fall detection and steps counting) to the BS via LoRa. In a second place, the BS undertakes to transmit these data, via MQTT, in accordance with a specifically associated topic. To this end, we have equipped the walking stick with a transmitter node involving a teensy 3.2 card and an LSM303DLHC mag sensor with a GPS module, along with a LoRa transceiver connected to a BS (Raspberry Pi with Shiestera Pi), which serves to send messages to different objects via the MQTT protocols. The achieved findings prove to indicate well that our suggested design turns out to be so effectively robust and efficient that it can be used within a smart city environment.

As a future work proposal, we envisage to establish a rather complex interaction between a wide range of connected objects, through enabling the message transmissions to be maintained via a variety of protocols, other than the MQTT, such as the HTTP and XMPP, to achieve an even higher interoperability level. Even though the monitoring system, as perceived in the present work, is limited to a single cane case with a single BS, we still intend to further extend the data transmission range to involve a multiplicity of canes and BSs. The purpose is to limitlessly broaden the extent reach of the elderly monitoring process to reach as much scope as possible (Smart City).
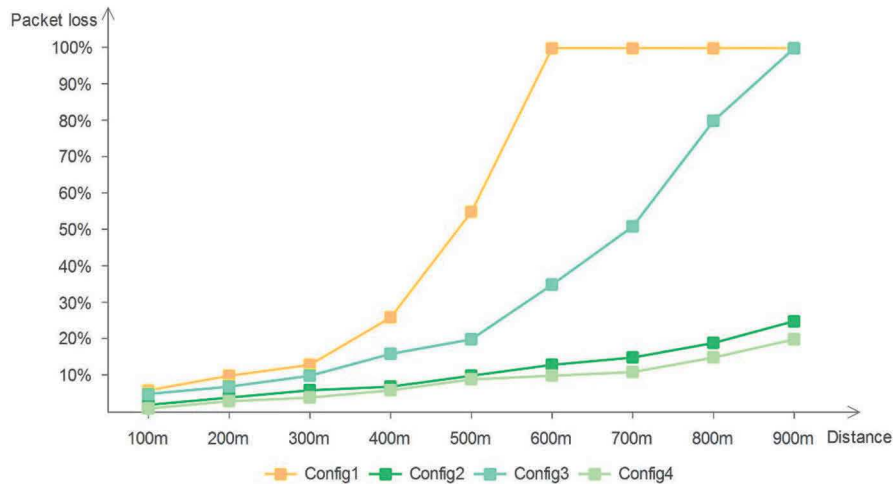
Fig. 9 *Packet loss relevant to distance regarding each configuration requirement*

7 References

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