USING LPWAN CONNECTIVITY FOR ELDERLY ACTIVITY MONITORING IN SMARTCYTIES SCENARIOS

D. Fernandes Carvalho, P. Ferrari, E. Sisinni, P. Bellitti, N. F. Lopomo and M. Serpelloni

Abstract Home care is an increasing research area; an example is the interest in daily activity and mobility tracking, known to be a strong indicator for people's health. In particular, the digital mobility assessment of elderly can anticipate and prevent hard clinical events such as falls, that could result in hospitalizations and deaths. In this work, the use of LoRaWAN is verified in a real-world scenario as an effective communication infrastructure for transmitting activity level information to a supervisor structure like a clinic or a hospital. An experimental setup has been purposely implemented to evaluate the feasibility; in particular, the activity level inferred analyzing accelerometers data can be notified with an average delay in the order of 500 ms.

10.1 Introduction and Motivation

The Internet of Things paradigm has already affected the way healthcare services are provided [1]. In non-urban areas, in mountain areas, in smaller islands, or in any case characterized by a sparse population, in which the use of single clinical sites is not conceivable, it is necessary to promote the use of telemonitoring, teleassistance and, more in general, telehealth solutions. In this perspective, the use of ICT applications in home care results to be an increasing research area, with a huge set of ICT solutions that can be used to enhance accessibility to home care [2]. For instance, daily activity and mobility result to be a strong indicator for people's health [3]. Additionally, permanent digital monitoring would allow earlier diagnosis and faster response times, providing new digital biomarkers able to anticipate and prevent hard clinical endpoint such as falls. Here relies the importance of monitoring the activities of elderly people and chronic patients in the home ecology.

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In light of these considerations, this work suggests using LoRaWAN, a wireless communication solution belonging to the LPWAN category, for telehealth. Purposely designed for addressing many IoT-related applications requiring wide coverage and sporadic transmissions, LoRaWAN allows to implement cellular networks without the support of a third-party provider. Thus, limitations of mobile-based solutions are avoided. Additionally, the high sensitivity offered by the LoRa radios ensure good coverage, overcoming WiFi-based solutions when hybrid indoor/outdoor scenarios are taken into account. Security aspects are considered as well; encryption on both the network and application level is implemented. Consequently, LoRaWAN has been already proposed as a viable solution for e-health monitoring by many researchers, as demonstrated by the available literature [4–9]. In this paper, differently from other works, several innovative wearable devices, including a LoRaWAN modem complemented by an accelerometer-based monitoring system, are deployed and tested in a real-world public infrastructure. Each device allows to track body movements, offering minimum invasiveness. A parameter is locally evaluated, assessing the physical activity, and periodically sent to a supervisory center. Results about the communication delays confirmed the suitability of the proposed solution not only in monitoring the activity in elderly in a daily-life scenario, but for fall detection as well.

10.2 The Proposed Wearable System for Tracking Elderly Activity

As stated in the introduction, falls are ones of the leading cause of injuries [10] in geriatric population, and a sedentary lifestyle leads to a lower quality life [11]. Figure 10.1 shows the proposed tracking system application scenario, where a self-sufficient elderly person can carry out normal daily activities wearing the device. The data, collected by local LoRaWAN gateway(s), are tunneled through an Internet

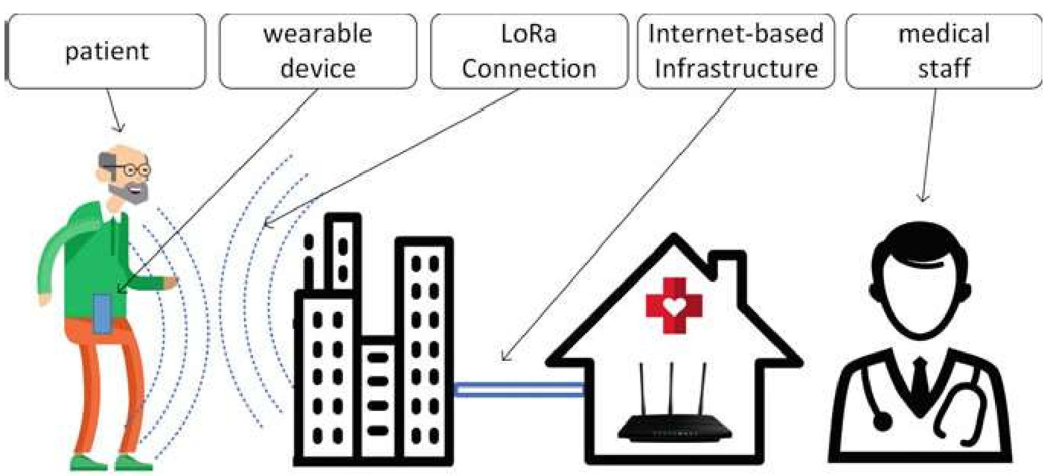

Fig. 10.1 Typical scenario application of the proposed wearable device

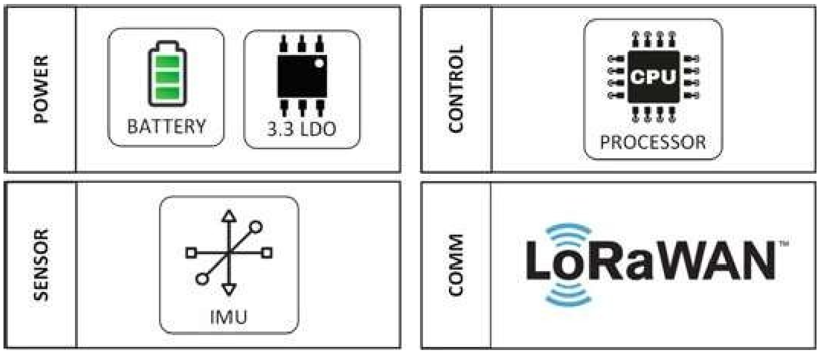

Fig. 10.2 Wearable device block diagram

connection to a supervisory structure, like a clinic or a hospital, where medical staff can infer the patient's health status by analyzing the data. Additionally, in case of a detected fall, emergency services can be provided promptly.

The proposed system is composed by a small and lightweight wireless wearable module that can track the motion thanks to its sensors. The main components are represented in Fig. 10.2.

All the measuring and transmitting operation are coordinated by an ATmega328P microcontroller unit. The motion data are retrieved from the accelerometer section of an inertial motion unit (IMU), LSM9DS1 from STMicroelectronics. The wireless low-power data transmission is provided by a LoRaWAN modem (an RN2483 from Microchip). The overall board is supplied by a small-size LiPo battery (20 mm × 11 mm × 3 mm) which guarantees proper functioning for about two days when the accelerometer data are sampled at 20 Hz and the activity level parameter is transmitted once per hour (and excluding event-based transmissions due to fall events recognition). If needed, the processor can reduce the measuring and transmitting frequency to save energy. Both electronic board and battery are closed inside a box fabricated with addictive manufacturing technique (3D printing), box size: 36 mm × 26 mm × 10 mm. The overall device weight is about 15 g to increase its wearable characteristic.

10.3 LPWAN for Smartcities: The LoRaWAN Solution

The LoRaWAN is a network with star-of-stars topology. The vast majority of information is transferred with "uplink" transactions: they are started by the end nodes and directed to the backend servers. Wireless messages are collected by gateways, which run the "packet forwarder" software, that tunnels messages over the air into the wired backhaul network (and vice versa, when reversed transactions—"downlink"—are needed). Regarding security aspects, messages are encrypted on a session base by means of application keys, while authentication at the network level is provided by network keys; another backend server is generally in charge of managing the

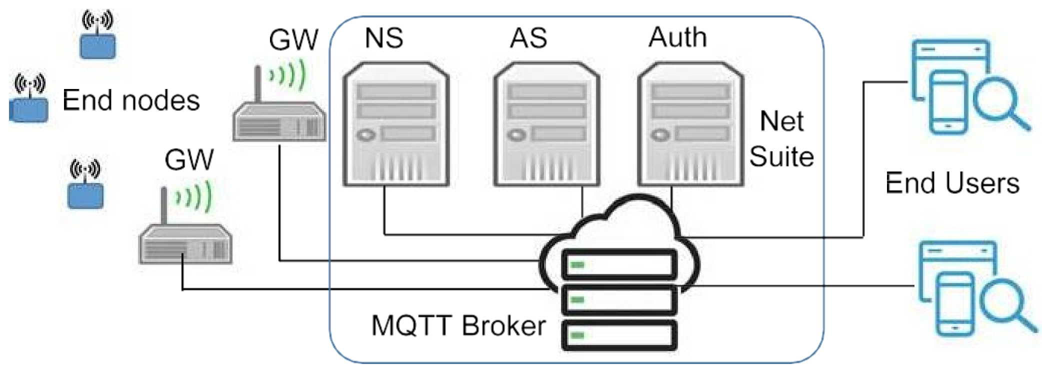

Fig. 10.3 Architecture of the LoRaWAN solution used in the BSL project

keys depending on the activation procedure. An example of possibilities offered by LoRaWAN for smartcity applications is given by the "Brescia Smart Living" (BSL) project. The Patavina NetSuite solution, provided by A2A Smart City, is used as the LoRaWAN backend (see the block diagram of the implemented architecture shown in Fig. 10.3).

It implements the Network, the Application and the Authentication Servers (NS, AS and Auth in Fig. 10.3), for managing the network, allowing end user application integration through a MQTT Broker and handling keys. Each end node uplink is published by the Broker as an MQTT topic, which can be subscribed by the end users interested in the information. It has to be pointed out that more than 100 LoRaWAN gateways are currently used to cover all urban areas of the city of Brescia, making BSL one of the wider LoRaWAN project across the world.

10.4 Experimental Validation

In this section the capabilities of the proposed wearable device are detailed. In particular, first it is shown how the system can collect information about physical activity and then the delays in transmitting such information are evaluated.

10.4.1 Activity Monitoring

In Fig. 10.4 an example is reported, regarding the data obtained from the analysis of two movements. In the left part (Fig. 10.4a) there are the acceleration components measured during a walk at a normal rate. The system is able to compute an activity level related parameter which is periodically sent to the healthcare physician for helping him in deciding if the patient has a sufficiently active lifestyle. In Fig. 10.4b

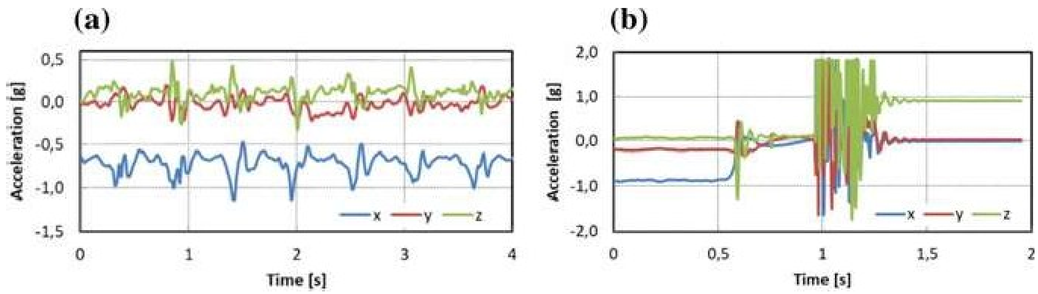

Fig. 10.4 Acceleration component retrieved by the system: **a** normal walking, **b** ahead fall ending face downward

we can observe an ahead fall ending with face downward. In this case, the device can send an automatic help request.

10.4.2 Application Delay of the LoRaWAN Network in BSL

In order to measure the application delay [12] inside the Patavina NetSuite infrastructure, the experimental setup of Fig. 10.5 has been built; it consists of one single node (located in the University laboratory and based on a PC connected to the LoRaWAN modem RN2483) sending information via uplink to several user end points (implemented by IOT2040 platforms; EP1 is connected to the Internet via the University reliable and fast access; EP2, located in Brescia and EP3, located in Milan, leverage on ADSL links).

In this way, timestamp T1 is registered when a LoRaWAN uplink transmission initiates. Each EP_n is a MQTT subscriber of the topic "event of interest" in the MQTT

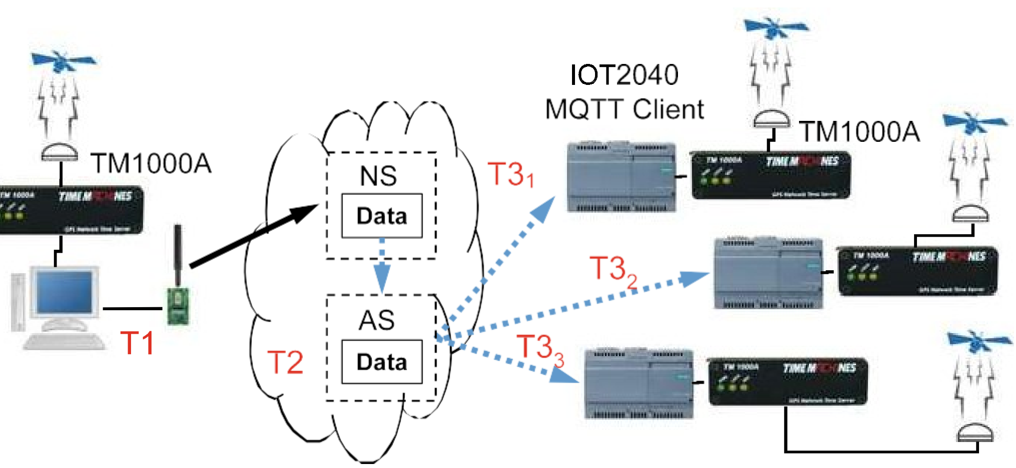

Fig. 10.5 Experimental setup with different end points (EP1 is connected to the Internet via the University reliable and fast access; EP2, located in Brescia and EP3, located in Milan, leverage on ADSL links)

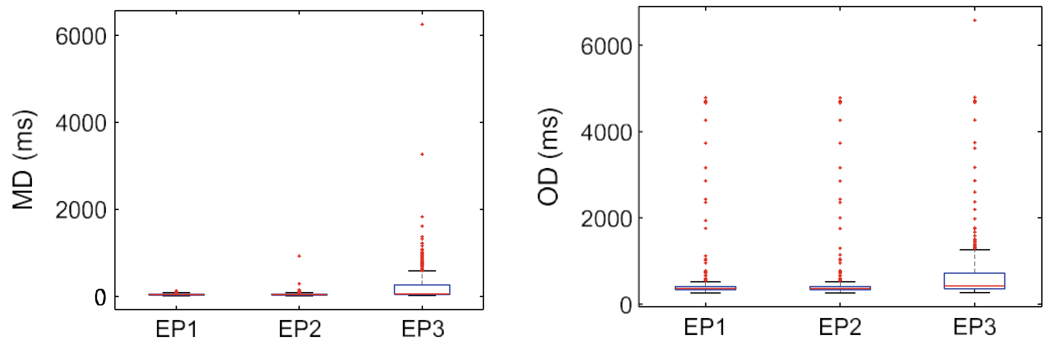

Fig. 10.6 Boxplot of the overall end-to-end delay OD for the three considered endpoints

Broker; when a new message is received, the message is timestamp tagged as $T3_n$. Moreover, the AS is in charge of registering the timestamp T2 when the "event of interest" arrives. The following metrics are calculated based on these timestamps: the LoraWAN backbone delay is $ND = T2 - T1$; the MQTT broker delay is $MD_n = T3_n - T2$; and the overall end-to-end application delay is $OD_n = T3_n - T1$. Time dissemination is performed by means of TM1000A NTP time servers, each one UTC-synchronized via a GPS receiver. The NetSuite is natively UTC-synchronized.

The experiments last for one day, summing a total number of 1440 messages transmitted every 60 s. Without losing generality, the user message length is 30 B and includes the transmission timestamp and a sequence number for sorting, totalizing the time on air of about 226 ms (Spreading Factor = 7 and Coding Rate = 4/5). Regarding the network delay, the average delay is $ND_{AVE} = 438$ ms and the standard deviation is $ND_{STD} = 592$ ms; however, it is interesting to highlight that some outliers exist, leading to a maximum value $ND_{MAX} = 4738$ ms. The distribution of the MD and OD metrics are reported in Fig. 10.6a and b, respectively. The three endpoints (EP1, EP2 and EP3) have an average OD delay of about 500 ms, enough for long-term monitoring and possible fall detection and notification. As expected, the EP3 has the worst performance, due to the poor performance of the available internet connection.

10.5 Conclusions

In this work a wearable system for continuously tracking the physical activity of elderly has been proposed and described. Patient movements are collected by means of a MEMS accelerometer and used to compute resuming activity-related parameters by the local microcontroller. The device is complemented by a LoRaWAN modem, which exploits the LoRaWAN infrastructure to update periodically several supervisory center (e.g. hospital) or patient relatives. Doctors can then estimate if the patient is doing enough activity or not. Accelerometer data are used to detect falls as well; in such a case, a notification is promptly sent.

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