IoT Generic Architecture Proposal Applied to Emergency Cases for Implanted Wireless Medical Devices

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Abstract—**This paper explains the generic function of implanted devices in humans to guarantee communication between patients and medical monitoring centers for emergency cases, analyzing transmission parameters, such as transfer rate, bandwidth used, data addressing, and technology comparison. The proposed architecture consists in bidirectional conveying between a web-based platform and medical external device through an Ultra-Wide Band local network. It presents an IoT architecture with its logical layers, building an infrastructure for different scenarios for patient mobility.**

Index Terms—**CoAP, IoT Architecture, MQTT, Ultra-Wide Band.**

I. Introduction

INTERNET of Things (IoT) has a versatile concept, but in general terms refers to any object connected to other devices for communication between them to make decisions, i.e., billions of objects interconnected between them to form a huge network for communications and perform smart actions.

In the American continent, the Pan American Health Organization (PAHO) establishes partnerships with telecommunications companies dedicated to TIC development in social networks and e-Health to involve different industry sectors that several years ago were unthinkable to access [1]. The eHealth set of services is formed by telemedicine, m-Health, digital clinical report, wearable devices (devices and accessories used for human parameters monitoring), among others, helping to reach areas of difficult access to monitor and treat patients remotely [2]. Different applications represent a challenge to engineers to improve the quality life through this concept. Nowadays, electronics components, like sensors, connect to a network that allows monitoring, control systems and data acquisition. The social significance of this type of design is that it will be implemented computational scientific knowledge to improve patients health, because there will be uninterrupted monitoring between them with the medical staff, as tend to be ubiquitous and mobile. Designing an architecture indicates how these components interconnects to each other.

The main reason to use an IoT architecture in wireless medical devices is that it provides patients an environment where they can move around any scenario, even offering therapies for different discomforts, e.g., cardiac, gastric, neuronal, cochlear implant, bone fractures, and insulin treatment, among others.

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II. State of the Art

The use of wireless sensor networks in the field of medicine have as objective that people are monitored in real time without the necessity of deprive about their daily activities to go to a hospital or medical center.

A. Concepts Applied

Different concepts applied for IoT in implanted devices in human beings are (Figure 1):

- Wireless sensor networks (WSN): Constitute as a network of several devices distributed in a geographical area to sense several environmental conditions.
- Sensors: Devices capable to detect physical or chemical magnitudes to convert it in electrical variables, e.g. luminance intensity, temperature, distance, acceleration, inclination, pressure, torsion, humidity, movements, among others [3].
- Wireless communication technologies: Helps to communicate locally with the implanted devices. Diverse technologies are available, such as Zigbee, Bluetooth, and Ultra-Wide Band (UWB).

B. Protocols

In IoT architecture exists some protocols used in different fields. This paper mentions MQTT and CoAP (See Table 1):

- MQTT: Refers to *Message Queue Telemetry Transport*, lightweight messaging protocol that provides limited resources to the client network regarding to telemetric information distribution. This protocol uses a communication pattern of publication/subscription, helpful for machine-to-machine communication [4].

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- CoAP: Refers to *Constrained Application Protocol*, defined as a transfer protocol to use with restricted nodes and restricted networks in IoT, following a client/server model [5].

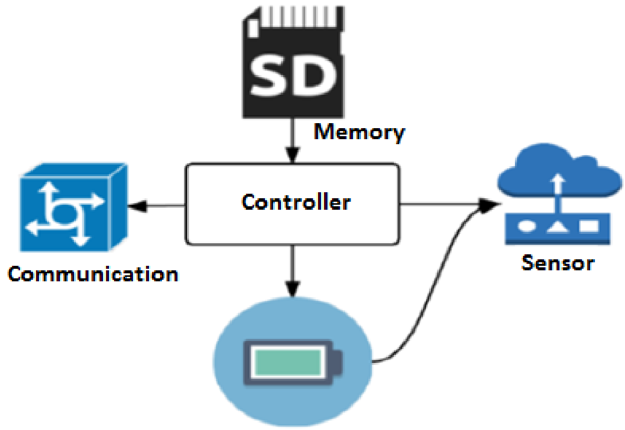

Fig. 1. Generic components in a WSN that allows the use of sensors for the signal handling of analog signals in a controlled environment.

TABLE I
COMPARISON BETWEEN COAP AND MQTT

Protocol	CoAP	MQTT
Transport	UDP	TCP
Messaging	Publish/Suscribe	Publish/Suscribe
2G, 3G, 4G	Excellent	Excellent
Low power for a network of 1000 nodes	Excellent	Low
Computational resources	10 Ks RAM/Flash	10 Ks RAM/Flash
Areas to employ	Network fields	Corporative networks

C. *Wireless Medical Devices*

Wireless medical devices deployed in patients help to provide treatments, which generates electrical pulses to the respective organ. The elements of the device are:

- Microprocessor.
- Read Only Memory (ROM).
- Random Access Memory (RAM).

Additionally, there have to be considered components as digital controllers, circuit amplifier, output circuits, and a unit of telemetry/programming (Figure 2).

III. ANALYSIS

Wireless devices implants have as general feature a system that allows data storage to read it from a remote desk by a medical doctor or a nurse practitioner, establishing alarm levels configured by the end user support.

In general terms, medical devices (e.g., defibrillators) send an electrical burst with different intensity depending on the treatment, reason why a generic communication module diagram can be specify.

The programmer is located in the exterior of the body and the implanted telemetric system inside the human body. The modules must have a mix of physical layer and MAC technology. It is important to avoid ionizing radiation to prevent other diseases provoked by the constant electromagnetic field invasion.

It is important to know the maximum power measured in which radiofrequency influences in the living tissue, known as Specific Absorption Rate (SAR), denoted in units of W/Kg, describing the electrical power per kilogram that humans absorbs.

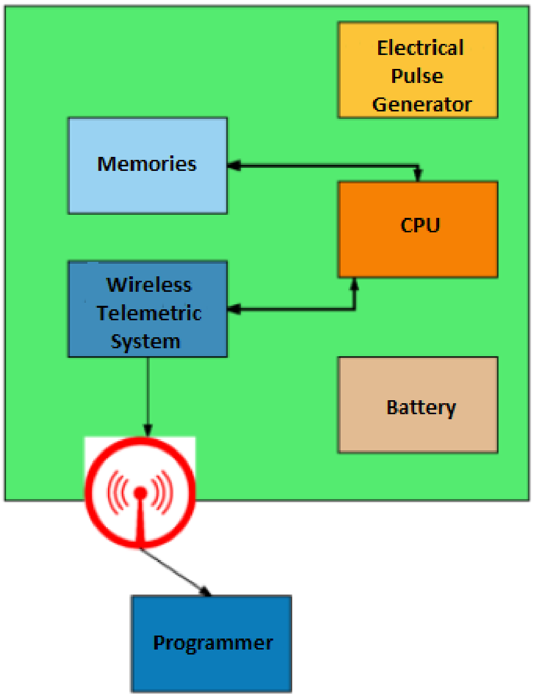

Fig. 2. Diagram of the generic module for wireless devices implanted.

Frequencies used for human body monitoring are located between 100 kHz and 100 GHz, range known as non-ionizing radiation. SAR magnitudes, according to occupational exposure, classify in three ranges [6]:

- Average in the whole body, 0.4 W/Kg.
- Head and trunk, 10 W/Kg.
- Extremities, 20 W/Kg.

Wireless devices' materials must have characteristics accepted by the human body. Inside the body exists fluids highly corrosive, reason to build devices with resistant materials, to eliminate corrosive side effects after many years of implantation. Materials also have to be stable through the time. Body movements considers mechanical effects, doing the material chosen be more resistant to accomplish electric pulses generation objective. Biocompatible elements are possible by the combination of Titanium, Zirconium, Tantalum, or Molybdenum. These chemical components help to protect the electronic components of the devices from external radiations. Primary components of electrode cables in wireless devices implanted inside the body generally use biocompatible plastic materials (e.g., thermoplastic urethane) [7].

IV. Architecture Model

The architecture model depicted in Figure 3 suggests layers related to each other to form a WSN with energy saving feature of the battery. Devices must be small and have to gather information about what is happening with services concerning to human health.

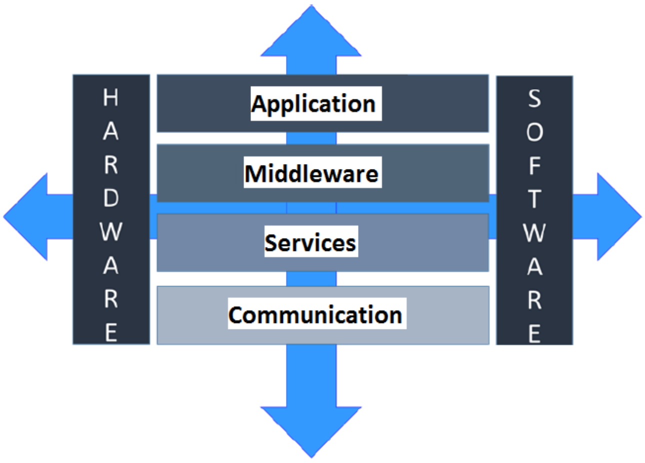

Fig. 3. IoT Generic Architecture applied to emergency cases for implanted wireless medical devices.

IoT architecture of implanted wireless medical devices interacts with several elements and users. Each scenario predicts a warning to medical staff in case patients suffer emergency event. Although implanted medical devices are useful to assist any situation as a heart attack, medics can supervise events with an idea of its origin. For example, in the case of cochlear implant, the use of this architecture let to know progress achieved regarding to hearing problems, in order to configure parameters to minimize deaf. Another example could be a neurostimulator that sends electrical pulses to the brain by blocking abnormal signs. It has a telemetric UWB system, which sends information to an external device to know treatment performed into the brain; the external device programs treatment and simultaneously sends information to medical staff [8]. To know if patients are improving with treatments, radio coverage is necessary to have signal strength that guarantees the reception of patients' information with programmed device 10 meters around the person, no matter where the patient is located as long as the device has Internet connection through IoT protocols.

V. Components

Variety services with IoT are available. The proposed architecture can specify several requirements imperative for patients' health. A server farm is setup in the hospital. Medical staff receives programmed alarms in the WSN, consisting in the implanted device and the exterior sensor.

Alarms could be set as emails or application web tools. Medical staff supervises and receives alarms about what is happening to patients, using mobile devices, e.g. tablets, PDAs, cell phones, receiving alerts at their address or at any other location, as long as the device has an adequate signal strength. A proxy server enlists supervisors (as clients) to access patient information to take decisions about treatments.

To keep supervisors informed without intermissions, 3GMS or 4G connectivity is required, complemented with a node discovery protocol with cache storage, due to time efficiency to reach specific nodes.

Hardware used is a microprocessor Texas Instruments MSP430, commonly used for wireless sensors of reduced size with memory addressing from 8 to 16 bits. A feature in which sensors indicate "Stand By" times to devices to save energy is useful. A "Stand By" state would help wireless devices to consume a minimum percentage of energy in mode ON. An annex in the CoAP of the middleware has to be set to send data between the programmer device and the implant. To limit memory addressing for a proper replication and data analysis, the use of development cards are necessary.

The external device or programmer does not need to be subject to limited resources, but wireless devices should consider rechargeable energy. Middleware uses CoAP server as a node. These devices mentioned form the WSN. However, monitoring devices are located at remote distances. To access them is necessary to deploy a proxy server to facilitate communication about the wireless device implanted on the patient. Table 2 lists some requirements of the implanted sensors.

TABLE II
Requirements of Implanted Sensors for a WSN

Commercial devices	Transmission rate	Bandwidth	Memory Addressing
ECG	71 kbps	100 - 150 Hz	12 bits
EMG	320 kbps	0 - 10000 Hz	12 bits
EEG	43 kbps	0 - 150 Hz	16 bits
Glucose monitor	1,6 kbps	0 - 50 Hz	16 bits
Movement sensor	35 kbps	0 - 500 Hz	12 bits
Cochlear implant	100 kbps	N.A.	N.A.

Software options available for programming over Android platform are C, Python, Visual.Net or Java. The processor in the implantable device could be developed in Assembler language or C, to optimize resources concerning to data capacity and power energy. However, other programmable interface tools are alternatives (e.g., LabView). Other resources that use updated information during the monitoring, known as observers, are useful as complement the CoAP. Exterior devices keep this software as a small programming module.

Advantages of using CoAP is the connectivity with HTTP or RESTFUL, due to the client/server model using UDP. This protocol provides adaptability to the design with small addressing microcontrollers, based on 8 to 16 bits, because it would become possible to send small packets through the Internet, avoiding overload from other devices and packet losses. CoAP manages four types of messages, listed hereafter:

- CON: For monitoring request. External receivers (located in patients) receives this type of message to accomplish confirmation packets requirements (e.g. confirmation asked by the medics).
- NON: Non-Confirmable message. Required when messages consist in lectures from implanted sensors.
- ACK: Confirmation reply to a CON message.

- RST: A message delivered when a device restarts. It does not send replies to CON or NON-messages.

Implanted wireless devices are better portable in the body with wearable technology, to maximize covering range in meters regarding to the physical layer. Energy consumption comparison is another aspect to consider. Wi-Fi is the technology that most energy consumes, with 722 mW in transmission and 709 mW in reception. Far below is Zigbee, Blueetooth and UWB, with 2,2 mW in transmission and 13,2 mW in reception. A difference is energy consumption comparison in relation to data submitted, showing that UWB requires less energy consumption comparing to other technologies. Maximum data transfer is also a relation to consider due to the pulsations transmitted must be measure in real time without margin of error. UWB reaches a maximum data transfer with 110 Mbps (See Figures 4 to 7).

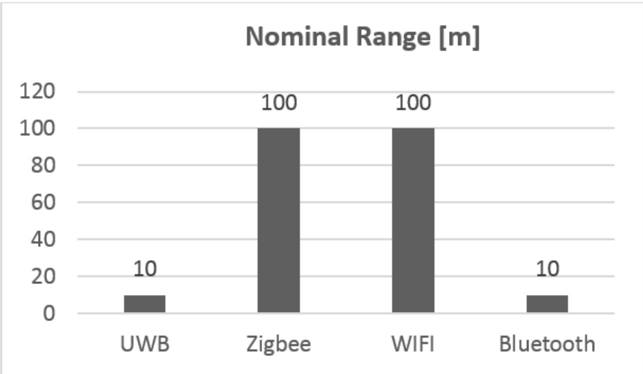

Fig. 4. Distance comparison between different wireless technologies.

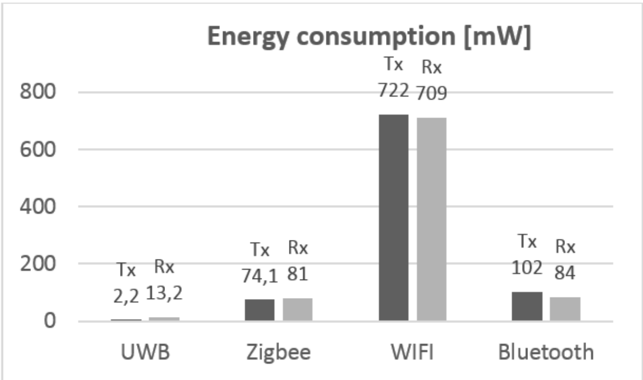

Fig. 5. Energy consumption comparison between different wireless technologies.

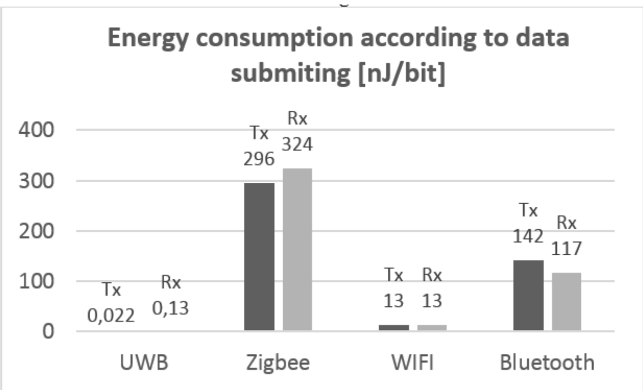

Fig. 6. Energy consumption comparison between different wireless technologies according to data submitted at the physical layer.

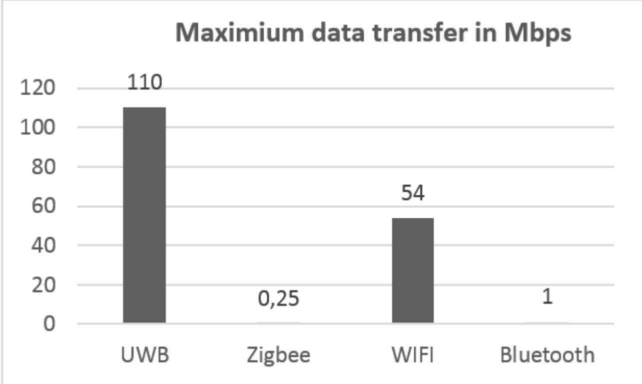

Fig. 7. Maximum data transfer comparison between different wireless technologies.

VI. Conclusions

Internet of Things oriented to eHealth is an emerging application that includes people from both urban and rural regions aiding the economy of the sanitary sector, in order to either diagnose or treat a patient, doing it ubiquitously and in mobile way. A proposed architecture provides high-speed wireless communication to exchange information between hospital system infrastructure and implanted medical devices, through an external device located inside a local network to cover a telemetric communication range. Besides, medical staff monitors patients in continuously real time to identify critical events. This would turn in a potential benefit for several parties involved in health provision, including public (or private) sector. In some countries, Constitution guarantee the right to access medical benefits without regulating or constraining technology to achieve it.

The proposed design is subject to changes depending on the devices requirements. Reuse of existing resources, as software and hardware, is necessary to maximize program languages and technologies availability.

It is important to have an integral application, but also to take cautions of not saturate the network. It is necessary to choose a technology that accomplish the capability to read thousands of pulsations per seconds and save energy at the same time. Technology comparison depicts UWB is the most appropriated one for wireless medical devices, because it allows maximum data transmission rate and minimal energy consumption, as well as incident power is low and non-ionizing.

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