"Internet of Things for Healthcare" Networking protocols and architectures

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Abstract—**Nowadays hospitals are the main delivery center of healthcare, which came with their costs and resources. New strategies have been required to adopt a more user-centric approach, moving from hospitals to home health monitoring scenario. In order to meet these new needs, suitable technological solutions, generally referred to as e-health, have been studied, [1] and a growing interest has been put in the so-called Internet of Things (IoT). Wireless Body Area Network (WBAN) has been a key element in e-health to monitor bodies. This technology enables new applications under the umbrella of different domains, including the medical field, the entertainment and ambient intelligence areas. Given its relevance in this report it will be resumed the state of art of the networking protocols and architectures for healthcare application.**

Index Terms—**Internet of Things, Network protocols, WBAN, E-health.**

I. Introduction

About 30 years ago it was introduced the first smart device: a electronic device that was connected to the network. Today smart technologies can enable one or more communications protocols (Wi-Fi, ZigBee, Bluetooth, LoRaWAN, ..) and can operate to some extent interactively and autonomously. However it must be said that the connection of devices is not enough for future perspective. What is really interesting is the actual ability of controlling objects through the internet. Therefore it is needed a way to manage remotely the devices. Indeed the original concept of the well-known Internet of Things (IoT) was to implement an ubiquitous distributed network of wireless dynamic low-energy-consumption devices: everything connects. This idea was also supported by the development of wireless sensor nodes, that are tiny enough to be considered as dust [2]. Even if the size of the devices can be reduced by increasing the operating frequency (today up to several dozens of GHz), the main issue with this concept remains the minimization of the size of the power supply and it is only in the last few years that wireless power transfer was seen as a valuable alternative to battery-supplied devices, exploiting back scattering of electromagnetic waves. The IoT concept evolved through years from a distributed network to a virtualized global infrastructure, enabling advanced services by interconnecting virtual and physical things, including new services that couldn't be forecasted [3]. Following this abstraction the space can be divided in two as can be seen in Fig. 1: the Physical space in which all the real devices are communicating and the Cyber space consituted by virtual entities that can be runned in a local computer or in an embedded system, or a cloud. In the latter space there could be multiple replicas of the physical things or even isolated entities that are nevertheless part of the provisioning of new advanced services which constitute the key of IoT. The very relevant point is communication capability and communication is also the most relevant issue, which this paper is trying to address.

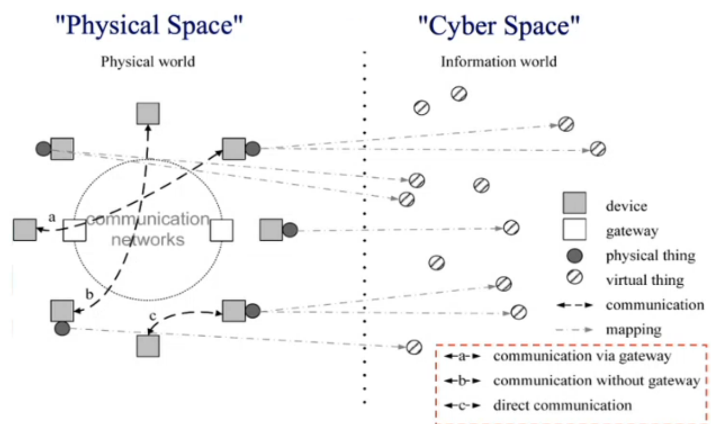

Fig. 1: Virtualization of space in IoT conception.

In real case situations devices are not only able to communicate, they could be needed as well for sensing, actuating, data storing and processing. IoT goal is integration, suitable and accessible globally. Enabling technologies can be adopted in several different domains from agriculture to transportation, from education to entertainment, but IoT is not aiming to be a generalist platform: each vertical need to be developed by sector experts to offer a valuable product to the consumer. It means that advanced architectures and technologies should be used in a specific domain. In this work we will address IoT for healthcare.

II. Internet-of-Medical-Things

Internet-of-Things for Medical-Health (m-health/m-IoT) aims to provide a more patient-centric healthcare by delivering medical services directly at home. It has to make possible the acquisition of heterogeneous biological signals, the monitoring in continuous and pervasive healthcare and data processing for precision medicine and digital pathology. Most of the current applications for m-IoT are developed by using Wireless Body Area Networks.

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A Wireless Body Area Network (WBAN) [4] is also referred to as a Body Sensor Network (BSN), which is a technology applied to healthcare, emergency rescue, home care and many other domains. Medical sensors may be worn on the human body or implanted into the body, which can perceive vital signs - for instance heart rate, blood pressure, electrocardiogram, and pulse oximetry.

Telemedicine is the field that takes care of the delivery of health care and sharing of medical data over distances using communication technologies [5]. In telemedicine, communication scenarios typically involve a set of sensor applied on the body of the patient or in environment that are gathering different information about the physiological state of the person and the condition of the surroundings. The biosensor nodes are small in size and equipped with sensing and communication capabilities, nano and micro-technologies, and low power batteries [6].

The collected data are then transmitted through a layered network using low-power RF technology and they will reach end-points which are usually caregivers, biomedical doctor, hospital personnel or specialized medical data centers.

The structure for the Internet-of-Medical-Things can be summarized in three tiers:

1) **Tier I (Beyond BAN communications):** information are gathered via sensors and wearables used by primary-end users (patients).
2) **Tier II (Inter-BAN communications):** intermediary level that act as gateway in which data are processed and aggregated. Those nodes are often referred to as hubs or routers.
3) **Tier III (Intra-BAN communications):** data center/-cloud in which large-scale data computation are performed. Core functions include long-range communications, message routing, device management, data storage, event processing and analysis.

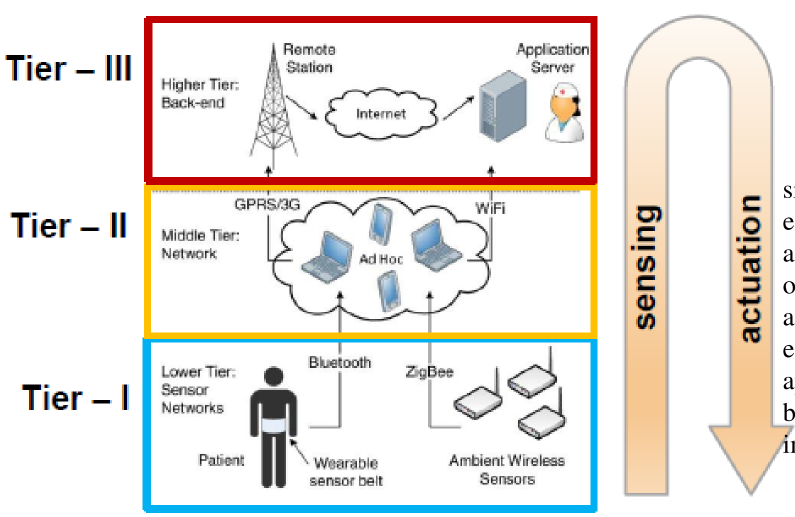

Fig. 2: IoT architecture for healthcare applications.

The network must ensure the best quality of service (QoS) by managing the delay, jitter, bandwidth and packet loss [7]. Those parameters play an important role in network designing depending on the application and the used technologies. General quality of service requirements for healthcare includes [8]:

- low power consumption
- high probability of message delivery
- low latency
- security
- privacy

It is again important to underline that body sensors, due to their size, use miniaturized batteries and the battery life of a sensor node is limited also due to the battery size. Hence, WBANs must sense, process and communicate data in a power efficient manner. Power efficiency, therefore, is of utmost importance and is a key emphasis of design efforts for WBAN protocols. WBANs have attracted worldwide attention of researchers since they can provide remote health monitoring of patients using low power consumption and short range communications. They support variable data rate, depending on the protocol and the desired battery usage. For the latter, the majority of work in this area has been on developing energy-efficient medium access control (MAC) protocols [9]. However, there has been some research in implementing energy efficient methodologies in the higher layers of the ISO/OSI model. In the following figure (Fig. 3) it is shown a simplified version of the protocol stack that it will be addressed for WBAN in the next sections, emphasizing networking solutions and their drawbacks.

APPLICATION	QoS
HME/NME	Network aspects, routing, energy efficiency, mobility, scheduling.
MAC	Channel access, power control, error recovery, retx.
PHY	Modulation, coding, power control, fading mitigation, MIMO.

Fig. 3: Protocol stack.

III. Healthcare Networking Design

In order to provide an efficient design it should be considered the operating frequency of the technologies. The electromagnetic spectrum is regulated by authorized national administrations or agencies. Usually body-sensors networks operate on frequency bands which are internationally available and unlicensed for generic wireless communications. However electromagnetic interference is a recurrent problem in IoT applications since the number of connected devices may be large. Therefore having specific-use frequency bands is important especially for implants.

Many options should be considered:

- **ISM (Industrial-Scientific-Medical:** the band centered around 2.4 GHz is by far the most popular frequency band for BSN-related applications. It's unlicensed, available worldwide and it has fewer restrictions on duty

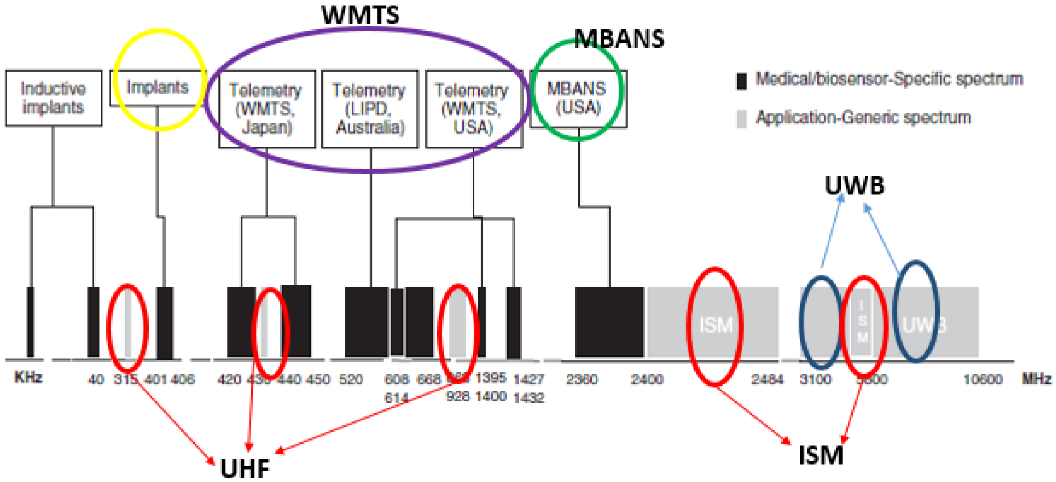

Fig. 4: Electromagnetic spectrum used for healthcare solutions.

cycle and channel spacing than the *Ultra-High-Frequency (UHF)* band. ISM can also be centered around 5 GHz.

- **UHF (Ultra-High-Frequency):** this band is international, but it is not centered in the same regions everywhere; it can be around 315, 433, 868-928 MHz. Some regions impose strict duty cycle restriction, but the band could still be beneficial for applications that send small amounts of data since the channel has very good propagation characteristics.
- **UWB (Ultra-Wide-Band):** the frequency ranges in $[3.1 - 10.6]$ GHz, so the bandwidth is large whereas the power density over it is very low. This band allows high communication data rates with low power operations, radar and ranging capabilities. On the other hand, there is a slow progression in the process of standardizing it and a significant cost for the initial implementation.
- **Implants:** implants have a specific band in $[401 - 406]$ MHz and different standards across different countries. It is important that implants have their own band to avoid any kind of interference, that for these devices could result in fatal consequences for the patient.
- **MBAN (Medical Body Area Networks):** MBAN is a standard only in the USA and it is intended for short-range telemetry. It consists of two sub-bands: $[2.36 - 2.39]$ GHz interval, devoted to registered healthcare facilities, and $[2.39 - 2.4]$ GHz interval, reserved for patient homes and ambulances. There is an on-going process to standardize it also in the EU.
- **WMTS (Wireless Medical Telemetry Service):** it ranges in several frequency bands, depending on the country; until now, there is no equivalent for it in the EU. It is mainly used inside hospitals, for short-range but high power consumption communications.

Network design: As already stated, low power wireless networks are the most common type of networks within healthcare systems. Among its standards there can be found different networking protocols:

1) ***Bluetooth low energy (BLE)*** [10] also known as Bluetooth SMART, Bluetooth 4.0 or Wibree, expands the functionality and applicability of Bluetooth by making it more energy efficient and this makes it a suitable choice for a health monitoring system. It operates in 2.4 GHz ISM frequency band with bitrate of 1 Mbit/s [11]. Bluetooth has an high interoperability and fast device discovery. However one of the most importan limitation is that default BLE specifications support only the **star network topology**.
2) **IEEE 802.15.4** [12] defines Physical (PHY) and medium access control (MAC) layers for low power wireless networks. It provides three frequency bands of 868MHz, 915MHz and 2.4GHz with a data rate of 250kbps. It defines two topologies: **star topology**, very common in health monitoring applications, and **peer-to-peer topology**.
3) ***ZigBee*** [13] complements the IEEE 802.15.4 standard with network and security layers as well as application profiles. ZigBee supports **mesh topology**.
4) ***IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN)*** [14] is an open standard for supporting low power wireless networks, which has been integrated within IEEE 802.15.4. It supports different frequency bands, such as 13.56MHz, 2.4GHz and 2.5GHz, with the data rate 1 to 2 Mb/s. As topologies we have **piconet** and **scatternet**.
5) **IEEE 802.14.6** [15] defines a MAC layer that supports several PHY layers, such as narrowband, ultra-wideband and human body communication, while the data rate varies from 75.9kb/s to 15,6Mb/s. Sensor nodes are organised in a **one- or two-hop star topology**.

The main sources of energy waste in the design of a

MAC protocol for a WBAN have been identified as collision, overhearing, control packet overhead, and idle listening. There are two main schemes used for MAC protocols of sensor networks. Contention-based MAC protocols, such as carrier sense multiple access/collision avoidance (CSMA/CA), have their nodes contend for channel access prior to transmission. The advantages of these protocols are scalability, adaptability to network changes and no time synchronization constraint. In schedule-based MAC protocols, such as TDMA, access to the channel is divided into time slots that are of fixed or variable duration. Each node is assigned a time slot(s) by a controller, and it will only transmit within that time window. TDMA-based protocols eliminate collision, overhearing and idle listening, and are typically utilized in some form in energy-efficient MAC protocols. In order to streamline the research and implementation efforts in BAN, the IEEE 802.15.4 created a task force in 2007 that would develop the specifications of a radio layer for BAN with emphasis on the allowable radio power levels in the vicinity of the human body. IEEE Standard 802.15.4 defines the physical layer (PHY) and medium access control (MAC) sublayer specifications for low-data-rate WPAN (LR-WPAN), typically operating in the personal operating space (POS) of 10 m [16]. IEEE 802.15.4 has two operational modes: a beacon-enabled mode and a non-beacon enabled mode. In the beacon-enabled mode, the network is controlled by a coordinator, which is responsible for device synchronization. Optionally, the superframe can be subdivided into active and inactive periods. The coordinator may enter sleep mode during the inactive period. The active period contains three components: a beacon, a Contention Access Period (CAP), and a Contention Free Period (CFP). During the CAP period, devices contend for channel access using slotted CSMA-CA. It has been found that IEEE 802.15.4 does not meet all the energy efficiency requirements for WBAN applications, therefore IEEE 802.15 Task Group 6 (BAN) began developing a communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics/personal entertainment and other. In the absence of a standard, several energy efficient MAC protocols specifically designed for WBAN applications have been presented. The 802.15.6 standard is specified for low power, short range and reliable wireless communications which cover the surrounding area of the human body. The purpose of the standard is to define the physical and medium access control layers for WBAN. Usual data rates will be up to 10 Mbps in order to satisfy an evolution of Personal Area Networks which do not meet the combination of reliability, quality of signal, low power, data rate and non-interference required by the WBAN applications. In this specification, all nodes and hubs involved in transmission are to follow some logical organization into subsets, also referred to as body area networks (BANs), and each coordinated by their respective hubs for medium access and power management. Therefore there is only one hub in each ban, whilst the number of nodes in a BAN cannot exceed the maximum BAN size. The topology of the BAN can follow either a one-hop star topology, in which each node is directly communicating with the hub, or a two-hop star topology via a relay-capable nodes.

This protocol defines three different types of physical layer, depending on the requirement of each application it will be used one of them. These layers are: Narrowband (NB), Ultra-Wideband (UWB) and Human Body Communications (HBC). These physical layers share only one MAC layer. In human body communication, the body of the user is itself the communication medium, and devices can thereby communicate without a wire or wireless technology. By simply touching the devices, they are connected to each other via touch-and-play (TAP) technology.

This PHY uses the electric field communication technology which covers the entire PHY protocol for BANs, such as packet structure, modulation, preamble, start frame delimeter. The UWB specification offers a very good performance for BANs, providing high performance, robustness, low complexity, and ultra low power operation. Moreover, the signal power levels are in the order of those used in the MICS band, therefore it provides safe power levels for the human body and low interference to other devices. It also provides a data interface to the MAC layer under the control of the Physical Layer Convergence Protocol.

The supported data rate ranges between 75.9Kbps in NB and 15.6Mbps in HBC [16]. As the range, it is limited to 3m for in-body communication and has to be at least 3m for body-to-body communication patterns. There are two modes of operation: default and high quality of service. The default mode is used in medical and non-medical applications. The high QoS mode is used for high-priority medical applications. There are three possible modulations: The bits of the physical layer protocol data unit can be modulated by on-off modulation, BPSK/QPSK or a combination of continuous-phase BFSK and wideband frequency modulation, depending on the mode used.

The standard network can operate in three different modes:

1) **Beacon mode with beacon period superframe boundaries:** the coordinator or hub must organize access phases in each superframe, which is divided into: Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), Manage Access Phase 1 (MAP 1), Exclusive Access Phase 2 (EAP 2), Random Access Phase 2 (RAP 2), Manage Access Phase 2 (MAP 2), and a Contention Access Phase (CAP). A node obtains and initiates frame transactions in contended allocations in EAP1, RAP1, EAP2, RAP2, and CAP in any active superframe using CSMA/CA or slotted Aloha based random access. In a MAP phase the hub arranges scheduled uplink, downlink and bilink allocation intervals. The hub also provides unscheduled bilink allocation intervals and improvise type-I immediate polled allocation intervals and posted allocation intervals starting in this MAP.

In an EAP, RAP, or CAP, or MAP, the hub also improvises future polls or posts starting and ending in a MAP.

2) **Non-beacon mode with superframe boundaries:** the coordinator or hub only operates during the MAP phase.

3) **Non-beacon mode without superframe boundaries:** the hub provides unscheduled bilink allocation intervals type-II polled and/ or posted allocations. Once determined that the hub for the next frame exchange is operating in the same mode, the nodes may treat any time interval as a portion of EAP1 or RAP1 and employ CSMA/CA based random access.

The main limitations of adopting this standard include:

1) the relatively high network join time compared to other standards;
2) the short range of less than ten meters;
3) the finite number of nodes in the network (although very high);
4) the limitations in the topology of BANs (only star-topology).

Since in many medical applications none of the above limitations is critical, this standard can be extremely useful. In case that a more complex topology needs to be implemented, or more distant communication is required, ZigBee or 6LoWPAN with IEEE 802.15.4 standards should be preferred, keeping into consideration data-rate and power usage requirements.

IV. Applications

The IoT has the potential to give rise to many medical applications such as remote health monitoring, fitness programs, chronic diseases, and elderly care [17]. As the demands of an expanding population with an inverted age pyramid grows [18], especially in the most developed countries, new age-related healthcare needs arise: indeed, with age, mobility degrades and the risk of severe brain injuries and neurodegenerative diseases increases. Also, other pathologies frequently coexist in elderly and chronic patients, and the risk of not being able to get frequent access to the hospital might be present as well. The monitoring of health parameters is a promising approach to improve the health condition and quality of life of the population. IoT for healthcare can offer several services and applications. Community Healthcare (CH) is worth to be mentioned since it aims to establish a network covering an area around a local community [19]. This network integrates multiple WBANs to materialize CH. The structure of a community medical network can be viewed as a "virtual hospital" and it can be consisting of a municipal hospital, a residential area, or a rural community. With this framework inter communication between different facilities is also intended: for instance the data gathered from a specific residential area can reach different medical expertise to provide remote medical advice. Long term monitoring is also well addressed by WBANs: traditional monitoring systems track different types of biological measurements (e.g. electrocardiogram (ECG), arterial oxygen saturation (SpO2), and blood pressure) using dedicated sensors. In hospital monitoring, a large amount of data is collected from both routine and sophisticated devices. Data are integrated, in real-time, to determine the current health condition of the patient. Pervasive monitoring can be extended from hospital to the individual's home [20], [21]. In this scenario, cheaper, yet reliable, biosensors can be provided to the user to monitor for the vitals and other physiological activities, e.g., the glucose level. Pervasive monitoring at home includes teleconsultations and speech/cognitive/physical therapy sessions. Here, real-time big data collection, transmission and analysis must be performed by the medical network in fractions of seconds, in order to generate alarms when needed, update the diagnosis, and provide indications to improve the training. Therefore, the latency requirement, together with the massive data transmission, could challenge the network performance: easily, 1 Gb/s traffic can be generated by monitoring a densely populated urban area [22].

V. Concluding Remarks

In this paper the main characteristics of Wireless Body Area Network are underlined, emphasizing their importance in Internet of Things applications. Body area networks have unique characteristics, such as limited energy, different data rates, and complex channel conditions (due to installation locations of sensors, which may be on or in human bodies). Therefore, communication protocols used in general WSNs may be less effective or inapplicable to body area networks. Researchers across the world have started to explore various technological solutions to enhance healthcare provision in a manner that complements existing services by mobilizing the potential of the IoT. The discussion on several important issues such as standardization, network type, business models, the quality of service, and health data protection is expected to facilitate the provide a basis for further research on IoT-based healthcare services. In order to have more insights on the current enabling technologies for the industry of IoT, other solutions as Radio Frequency Identification (RFID) systems should be taken into account. There is definitely scope of improvement.

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