Using Wireless Technologies for Healthcare Monitoring at Home: a Survey

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***Abstract*—The use of cable-free communications between distributed and small sensor devices in healthcare application offers many advantages to monitor people and their surrounding physical environment. In this paper we present a comparative analysis of wireless technologies for healthcare monitoring in heterogeneous Wireless Sensor Network (WSN) context. The study presents analysis on how to choose the suited technology taking into account the application requirements. The choice depends on some criteria like delay and quality of service requirements, topology, energy consumption, and other factors. This paper gives advantages and drawbacks and compares standardized and proprietary wireless technologies.**

***Index Terms*—Healthcare monitoring, wireless technologies, wireless sensor networks (WSN), body sensors, energy, quality of service, performance analysis.**

I. Introduction

Over the past decade, advances in wireless communication, sensor design, and energy storage technologies have meant that the concept of a truly pervasive Wireless Sensor Network (WSN) is rapidly becoming a reality [1, 2]. So far, a range of applications have been proposed for the use of WSNs and they are likely to change every aspect of our daily lives. Nowadays, it is vital to develop advanced tools and information management that allow monitoring elderly/frail people at home and patients in hospitals. This permits to monitor movements, to control the human physiological data, and to track patients, and physicians. Indeed, WSNs are an enabling technology for the application domain of unobtrusive medical monitoring. This field includes: continuous cable-free monitoring of vital signs in intensive care units, remote monitoring of chronically ill patients, and providing remote assistance of people in their everyday lives (to provide early detection and intervention for various types of diseases) [3, 4].

Low cost, low power and small sensors with multifunctional sensing modalities share their knowledge to achieve common goals. These sensors can be used for continuous sensing data from targets and communicate between each other wirelessly to reach a supervisor. Their deployment at home depends on the network topology. Sensors may be embedded on the person's body to build a Wireless Body Area Network (WBAN) [3] allowing to sense different kinds of vital signs: ECG (ElectroCardioGram), EEG (Electro-EncephaloGraphy), pulse, temperature, etc. In order to supervise and control the surrounding physical environment (home, etc.), other sensors can be deployed including infrared sensors, multimedia sensors (cameras), smoke sensors, etc. Thus, the structure of the transmitted data can be as different as video and audio streams.

Multimedia contents are exchanged over the Wireless Multimedia Sensor Network (WMSN). These contents need more requirements than those in traditional WSNs, including QoS, energy, high bandwidth, multimedia source coding techniques, processing, and other needs discussed in [1]. Energy and media transmissions came in the first level of factors influencing a WSN design for healthcare monitoring. A sensor node loses maximum energy in data communication (transmission and reception) then data processing and sensing [1]. Today, many wireless medium enable links between sensors, including: radio, infrared and optical transmission media. The aim of this paper is to focus on selecting wireless communication technologies optimizing the factors listed above.

The reminder of this paper is organized as follows. In section II, healthcare monitoring requirements are presented and WPAN technologies are described along with their advantages and drawbacks. In section III, we take a step back to compare these technologies and address recommendations according to heterogeneous three tier architecture. The last section gives conclusions and future directions.

II. Problematic

A. Healthcare requirements

Performance criteria of WSN in healthcare monitoring include: energy consumption, QoS requirements, wireless links reliability, network throughput, etc. Below we summarize some of these criteria:

• Quality of service: is one of the most important aspects. It should be considered especially to transmit multimedia contents such as video streams and still images (localization, fall of person, etc.). The QoS is related to the bandwidth allocation, delay of transfer, jitter, and packet error rate parameters.

• Energy consumption: it is a crucial factor impacting the network lifetime. It has certainly not the same impact as in very dense WSN. However, the less energy consumed by the nodes, the longer the network lifetime will satisfy the application running [5].

• Scalability: a good WSN solution has to be scalable and adaptable to future changes in the network topology. Thus, scalable protocols should perform well as the network grows larger or as the workload increases.

Furthermore, in order to control human behavior and to monitor physiological parameters with respect to the performance criteria, research has identified several requirements that must be satisfied. These requirements are:

• Mobility: managing persons and sensors mobility to maintain the network connectivity.

• Home constraints: the deployment of the WSN depends on characteristics of the building where the patients are located (architecture, size, walls, building materials, etc.).

• Radio bandwidth: when the number of nodes exceeds a certain threshold it may overload the network capacity. Bandwidth limitations depend also on the type of transmission media and on the kind of the transmitted data (multimedia content or simple data).

• Specific protocols: the aim is to develop efficient medium access and routing techniques in terms of energy and delay delivery, and to provide self-organizing protocols with secured transfer (privacy and reliability of urgent information).

• Heterogeneity: WSN solution design requires taking into account the heterogeneity of hardware and software (operating systems, control and management tools, etc.).

B. Choice of WPAN technologies

The choice of communication media is one of many factors that influence the design of WSN. There are many technologies; some of them are standardized and others are proprietary. Below we describe the most popular ones that cover small areas (WPAN). Table 1 summarizes the different features.

1) Standardized technologies:

<u>a) IEEE 802.15.1 / Bluetooth:</u> At the beginning, this standard [6] was proposed to transmit voice and data. The topology of a Bluetooth network is composed of slaves and masters (Piconet with a kind of TDMA access method). There is only seven active slaves per Piconet (255 in park mode), and 10 Piconets max per Scatternet. Bluetooth is not suitable for WSN or very little used due to the high energy consumption, the high cost of synchronization and the complex network topology (Scatternet concept has never been implemented).

<u>b) Wibree (Ultra Low Power Bluetooth):</u> Is considered as a light Bluetooth and operates at 2.4 GHz frequency band. It is expected that Wibree does not use frequency hopping. It supports a star network topology with one master and seven slave nodes [7]. To reduce power consumption of Bluetooth, Wibree uses low transmission power and low symbol rate. According to Nokia, Wibree can reduce the power consumption of Bluetooth to one tenth. Wibree may have a common RF part of Bluetooth making its integration into sport watches, cellular phones and laptop computers easier. Its principle limitation is the short range: 5-10 m.

<u>c) IEEE 802.15.3 / UWB:</u> It uses radio signals sent with very low intensity and very short pulses [8]. It operates at 3.1-10.6 GHz frequency band. UWB comes to replace Bluetooth (to offer more bandwidth, limited interference to coexist with other technologies, and shorter delay). Currently, two UWB standards exist: UWB Forum and WiMedia Alliance. UWB is used to enable high-speed transmissions with low power consumption (near to 400 mW). This technology offers more advantages than Bluetooth. It requires 50 times less energy to transmit one bit than Bluetooth. It offers also accurate localization services in the order of centimeter. According to [1], the IEEE 802.15.3 standard has become the most interesting candidate to provide QoS in WMSNs. The major drawback of UWB is its short communication range (about 10 m) and the high synchronization constraint.

<u>d) IEEE 802.15.4 / Zigbee:</u> Zigbee operates above IEEE 802.15.4 compliant transceiver (Physical and MAC layers with some dedicated upper layers). It is used in very low power communications with short distances. This technology is used in wireless sensor networks. Regarding to energy consumption, it was shown in [2] that in some scenarios, in the case of non slotted access with "CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance", less than 50% of energy is consumed in data transmission, 25% in listening to the medium and 15% for waiting acknowledgment. Compared to Bluetooth, this technology provides a low latency (the physical layer "DSSS: Direct Sequence Spread Spectrum" allows nodes to switch to sleep mode without losing synchronization). It provides simple forms of guaranteed QoS. Its main limitation is the low data rate to be used in multimedia applications [1].

2) Proprietary WPAN technologies:

<u>a) ANT:</u> ANT is developed by Dynastream Innovation. It operates at 2.4 GHz frequency band. It provides communications at very low power consumption (autonomy can reach 10 years with 1 hour / day operation). ANT is designed to operate in WSN networks with low data rate and short ranges [9]. The medium access method used is TDMA. Header-frames are reduced at 7 bytes instead of 15-35 bytes in IEEE 802.15.4. It supports two kinds of topologies: peer to peer and star (master-slave). ANT is less popular than IEEE 802.15.4.

<u>b) OneNet:</u> OneNet is a new proprietary open source wireless control protocol designed for low power and high range WSN applications such as control and building automation. It operates at 868 MHz (Europe) and 915 MHz (USA) frequency bands. Three kinds of topologies are supported: star, point to point, and mesh. In a star topology, a master node can be connected to 1-2000 slaves [10]. Among competitors of OneNet, we find IEEE 802.15.4 and Z-Wave. Its principle limitation is the low data rate (around 38.4 Kbps).

<u>c) Z-Wave:</u> Z-Wave can be considered as a light version of Zigbee operating at 868 MHz and 915 MHz frequency bands [11]. Z-Wave is targeted for the control of building automation and entertainment electronics. The maximum number of nodes in a network is 232. Supported network topologies are star and mesh. Some Z-Wave products are presented in [11]. However, it lacks further development kits to test its performances.

<u>d) MiWi:</u> MiWi developed by Microchip is a simple version of Zigbee operating above IEEE 802.15.4 compliant transceiver. MiWi is suitable for smaller networks having at most 1024 nodes. Supported network topologies are star and mesh. Simplification of the Zigbee stack reduces the cost of MCU by 40% – 60%. However, MiWi operates only in the non-beacon mode of IEEE 802.15.4. Hence, MiWi does not support the low duty-cycle mode of Zigbee.

Recently, a new version of Wi-Fi named Wi-Fi Low Power is proposed for sensor networks. It allows to overcome some drawbacks of Wi-Fi in term of energy consumption. This new version is adopted by some companies like: Aginova, Sensicast, STMicro-electronics (ST), Gainspan, Apprion, MicoStrain and Nivis [12, 13]. However, as Z-Wave, it lacks

	WPAN Technologies			WLAN				Proprietary standards
	Zigbee	Bluetooth	UWB	Wi-Fi				
Standard	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.15.3a	IEEE 802.11b	IEEE 802.11g	IEEE 802.11a	IEEE 802.11n	Proprietary
Industrial organizations	Zigbee Alliance	Bluetooth SIG	UWB Forum and WiMedia™ Alliance	Wi-Fi Alliance				N/A
RF Frequency	2.4 Ghz, 868/ 915 MHz	2.4 Ghz (79 channels - 1,6 MHZ)	3.1-10.6 Ghz	2.4 Ghz-5.8 Ghz				433/868/900 MHz, 2.4 GHz
Speed	250 Kbits/s at 2,4 GHz (World) 40 Kbits/s at 915 Mhz (USA) 20 Kbits/s at 868 Mhz (Europe)	1 Mbps - v1.2 3 Mbps - v2.0+EDR	110 Mbps- 480 Mbps (see up to 1.6 Gbps in some applications)	11 Mbps	54 Mbps	54 Mbps	200 Mbps (540 in some applications	10–250 Kbps
Maximum range	10-100 m (see up to 300 m)	10-100 m	3-10 m	10-100m				10–70m
Energy, PE: mw/Mbps	30 mw (1000 mw/Mbps)	100 mw (100mw/Mbps)	400 mw for 200 Mbps (2mw/Mbps)	750 mw (68mw/Mbps)	1000 mw (19mw/Mbps)	1500 mw (27mw/Mbps)	2000 mw (10mw/Mbps)	Very low-low
Battery (TTGB)	3.1 days	2.2 hours	40 sec	1.2 min	2.5 min	2.5 min	40 sec	
Cost	2 $	3 $	7 $	5 $	9 $	12 $	20 $	
Nodes (per Network)	65000 (20 Kbps), 255 (250 Kbps)	8 (7 slave+1 master), 10 piconets	128	32				100-1000
Modulation/ Spread Spectrum	DSSS, BPSK(868/915 MHz), O-QPSK (2,4 GHz)	FHSS, GFSK (It defines three power classes)	OFDM or DS-UWB	Four ≠ Physical Layers: FHSS, IR, OFDM, DSSS				
Main applications	Wireless Sensor Networks, Remote control, home automation Medical assistance	Audio applications, Replaces wires on desktops	Multimedia Applications, industry Health applications	Home Automation Networks Replaces the Ethernet cables				
Advantages	Very low power consumption MAC/PHY layers strong and effective Reliability (CSMA, security ...) Reduced cost Low latrency regarding to Bluetooth Can support several nodes	Widespread Average Consumption It costs 3 times cheaper and 5 times less in power than Wi-Fi	Low cost, low power consumption High data rate Low radiated energy Precise localisation Support the Qos in WSNs Less interference Signals can cross obtacles (doors, etc.) Low delay regarding to Bluetooth Resistance to multi-path networks	High data rate Widespread Wide-ranging radio Security, guarantee of QoS (IEEE 802,11e) Products widely known Ease of deployment, and low cost Keep the same infrastructure				
Drawbacks	Specification that still moving Minimized range at 2,4 GHz (10m)	It is not suitable for WSN Speed limited, important delay regarding to Zigbee Interference with Wi-Fi Protocol rather complex The effect of radiation on health	Technology not yet ratified Lack of UWB products in the market. Limited range (10 m) regarding to Wi-Fi High synchronization constraint	High energy consumption Latency potentially important Multiple variants Limited use for WSN				

Table I: Comparison between wireless technologies

currently development kits with multifunctional sensors, like those developed by Crossbow and DustNetworks companies that provide multimedia cards based on IEEE 802.15.4.

MICS (Medical Implant Communications Service) is a technology used in many works. Its advantages are presented in [4]. It operates between 402 and 405 MHz frequency bands (ten channels of 300 KHz). This band covers some limits of IEEE 802.15.4 and Bluetooth in terms of energy consumption and data rate for WBANs. However, this technology has shorter communication range than IEEE 802.15.4.

Currently, an evolution to 60 GHz networks is appeared. These networks provide more advantages in terms of bandwidth, QoS, energy conservation, and reduced interferences. WirelessHD technology is an example [14]. It proposes low power and low cost solutions to transfer video streams with QoS. However, its range is limited to 10 m.

In this section we discussed on the most popular standardized and proprietary WPAN technologies. Other technologies for healthcare exist [15, 16] like: IEEE 802.15.6, Rubee (IEEE 1902), IETF 6lowPAN, IrDA, WUSB, RFID, Wavenis (Coronis), Addinet (Alciom), WirelessHart, Sensium and Insteon. In this section we presented the most used. In the next section, we discuss the suited technology for our application.

III. WSN DESIGN FOR HEALTHCARE MONITORING

Many solutions were proposed to monitor specific environmental applications with heterogeneous sensors. However, the healthcare monitoring at home is much more complex because of specific home constraints and people habits described above. Energy and delay are ones of the most critical performance criteria for healthcare. To present a comparative analysis we need to define preliminary the sensor network scenario then we discuss about the network performance.

A. System description and assumptions

Each scenario has its specific requirements. Our recommendation is to study the global network among three levels [17]. We distinguish a lower level representing the mobile WBAN (including all physiological embedded sensors like temperature, pulse, etc.), a level describing the WMSN with fixed multimedia Beacon nodes (environmental sensors and camera), and the higher level that represents the supervisor/sink (remote medical assistance, physician, etc.). We assume a hierarchical and centralized deployment of heterogeneous sensors with distributed sensing, processing and storage (some nodes are gathering data and others just manage/forward data through multi-hop communications toward the sink). The network is composed of four groups of nodes: Medical (M), Coordinator (C), Beacons (B), and Sink (S). All nodes are in the same range. Two kind of traffic is enabled: sporadic (case of alarms triggered by M/B) and periodic (send medical and environmental data). Some configurations of hybrid architectures and their benefits for healthcare are described in our previous work in [17]. Indeed, a multi-tier architecture provides better balance among scalability, cost, coverage, and reliability requirements than single tier architecture as described in [18].

The system provides local and remote access to the collected data ((C) and (S) nodes). Making good use of energy and delay is a must in this network scenario. The energy constraint influences on the topology re-organization while the delay is a critical factor required to be minimal (sending urgent data toward the sink). Thus, the selection of the wireless technology should take into account these important metrics.

B. Discussion

1) Wireless technologies VS home requirements: The choice of a wireless technology depends on the services offered and the needs of a network designer. Parameters such as: power, security and the number of supported nodes must be taken into account. We discuss below the relationship between these parameters and the needs of the application.

- As described in the previous section, data rate and network capacity are among parameters having an impact on the network performances. The choice of a high data rate wireless technology can offer more advantages that meet network scalability and increasing the number of monitored persons. In contrast, some wireless technologies offer low power consumption but result significant delays and/or low data rate. The technology chosen will have to provide a compromise between data rate and energy consumption.

- The coexistence of different technologies might be judicious to allow the transfer of heterogeneous contents through the network. As we can see in Table 1, the IEEE 802.15.4 and IEEE 802.15.3 technology offers the best compromise for energy consumption in this application domain. Zigbee technology may be considered for the transmission of medical data with low power consumption and low data rate. UWB technology can be considered to provide services for localization and transfer of multimedia content via video nodes, with less interference, low jitter and a low error rate.

- Sending data through obstacles and walls must also be taken into account (depending on the dimensions of the living environment). Some experiments made by *Surie et al.* in [19], demonstrate the benefits of IEEE 802.15.4. A range of about 33 m is obtained in the presence of a single obstacle (wall type) and 19 m in the presence of multiple obstacles. This technology meets the needs of the application in term of good connectivity with low power consumption.

- The deployment of Bluetooth technology may not be suitable: this may result complex network architecture and energy consumption greater than IEEE 802.15.4 (advantage of the duty cycle). As regards Wi-Fi, despite to the appearance of Wi-Fi low power, is still missing today multifunctional motes in the market. However, traditional Wi-Fi could be used to transmit multimedia content but the energy remains high [20].

2) Recommendation: According to this study, we retain that the technologies that best adapt to our application are IEEE 802.15.4 and UWB. However, the IEEE 802.15.4 standard offers more communication range, less power consumption, and supports greater number of nodes than UWB. In addition, the data rate is acceptable (250 Kbps). This technology is widely used in many works [15]. IEEE 802.15.4 devices are the cheaper ones and provide solutions about data security.

As we can see, a generic network does not exist actually and we think that in the design phase, modeling the global network is necessary to apprehend all data exchanges, and to validate the best architecture of the system. In [5, 17] we proposed a design framework for healthcare with a detailed description of sensors behaviors and inter-sensors communications.

Energy and delay optimization strategies for data collection in the three-tier network are an important issue in healthcare application. The dynamics of the entire network and channel access control among interfering sensors should be defined. There is a need for efficient protocols that minimize collisions, and provide self-organization of the network.

Optimizing activity and sleep periods of sensors to save energy is a challenge. Making nodes in sleep modes requires defining efficient medium access protocol with delay guarantee. This is important to consider since in some scenarios, some nodes may degrade possibly the network performance.

Mobility constraint is an important issue that requires re-association protocols taking into account delay, real time updates, and data fusion (association between Coordinators and Beacon nodes depending on how WBAN nodes are far from a Beacon / Sink). MAC and routing protocols with quality of service are important to improve the network performances.

IV. Conclusion

This paper discusses about wireless technologies for healthcare monitoring at home. The analysis of wireless technologies and the knowledge of home requirements represent the main bricks in the phases of design and implementation of adapted WSN. This study wants to help to design robust, reliable and extended network lifetime. This analysis enables in future works to select the most suitable technology taking into account QoS requirements and to design an energy-efficient network enabling transmission of both data and multimedia contents. Many perspectives can be outlined including the cohabitation between wireless and wired networks (HAN/LAN). Currently, we focus our work in the way of modeling, simulation and implementation of a wireless sensor network with specifications of each level presented in this paper.

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