Chapter 18
Towards Ubiquitous and Pervasive Healthcare

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Abstract. In recent years, Wireless Sensor Networks (WSNs) have attracted a considerable attention from both academia and industry. There is a number of possible applications and great expectations, but at the same time there are some serious issues and challenges related to Wireless Sensor Networks. One of the areas of WSN applications is healthcare and there are a number of health related issues that WSN aims to address. Amongst the main such issues are: the aging population that causes a growing pressure on economy and the healthcare system supported by a declining number of working-age people as well as an increase in chronic diseases, which includes obesity frequently attributed to a lack of fitness and weight management due to busy lifestyles. Staying physically and mentally healthy is of the greatest importance to every individual and to the society. There is a growing interest in a new approaches to the support of the overstressed healthcare system. The fundamental concept is to shift some of the responsibilities from the clinicians, health centres and hospitals of the traditional system to the patients and their home environment. People themselves are able and should play a greater role in monitoring and maintaining their own health, provided that they are supported by an adequate technology and have a proper knowledge of how to use it. There are already a number of applications of computing and communication technologies related to healthcare including (but not limited to) the pervasive health monitoring, mobile telemedicine applications, the intelligent emergency management services, health aware mobile devices, the medical inventory management, the pervasive access to health information and the lifestyle management . In this chapter, we discuss a several of new generation of services and applications in the area of pervasive and ubiquitous healthcare that are enabled by sensor networks. We shall provide an overview of the new trends and introduce innovative ideas around the self-adapting ambient intelligence combined with specialised system requirements.

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18.1 Introduction

Pervasive Healthcare is a very broad and multidisciplinary subject. In this chapter and our research we focus mainly on wireless networking technologies enabling pervasive personal healthcare systems.

This paper consists of 4 parts.

- Part 1 we give an introduction and the definition of terms.
- Part 2 is the detailed description of Body Sensor Networks.
- Part 3 is the discussion of existing challenges facing Pervasive Healthcare Systems.
- Part 4 is the final conclusion and future works related to the subject.

18.1.1 Definitions of Terms

Following there is a number of terms explained for better understanding of the subject.

UBIQUITOUS COMPUTING

The term "ubiquitous computing" was coined by Mark Weiser of Xerox PARC in 1991. Weiser observed that humans consider walking around trees and staying close to a natural environment most relaxing while, at the same time, people find working with computers rather frustrating, and hence his remarks, that "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it” [1]. This vision has become the foundations for the future work related to ubiquitous and pervasive computing. The term ubiquitous is something that is available anywhere anytime, while pervasive is something that is permeated in our environment.

PERVASIVE HEALTHCARE

(*Also known by the European Union term: ambient assisted living*) is a vision for the future of healthcare. The Body Sensor Networks based technology is expected to play a very important role in delivering pervasive healthcare to the masses [2]. Despite the fact, there is a significant demand and a number of prototypes already available, we seem to be still far away from providing an effective pervasive healthcare. There are a number of reasons for such a situation, including an inadequate and in-advanced technology, an immaturity of ethical and legal concepts as well as related sociological and psychological issues Pervasive Healthcare (or the European Union term: ambient assisted living) can be considered as an answer to health related challenges like increasing elderly population, increasing number of chronic and lifestyle diseases and increasing lack of medical professionals [4]. Pervasive Healthcare "has the potential to integrate health consideration and health promoting activities for patients and non-patients in their everyday conduct and provide added value to life quality for individuals" [3]. Body Sensor Networks are expected to play an important role in delivering pervasive healthcare to the masses.

WIRELESS SENSOR NETWORK (WSN)

Is a network made of number of small intelligent objects called motes or smart objects. Smart object is an item equipped at least with a form of sensor and/or actuator, a microprocessor, a communication device (radio transceiver) and a power source [5]. Additionally smart object might contain other modules for example data storage. Figure 1 shows the general architecture of WSN.

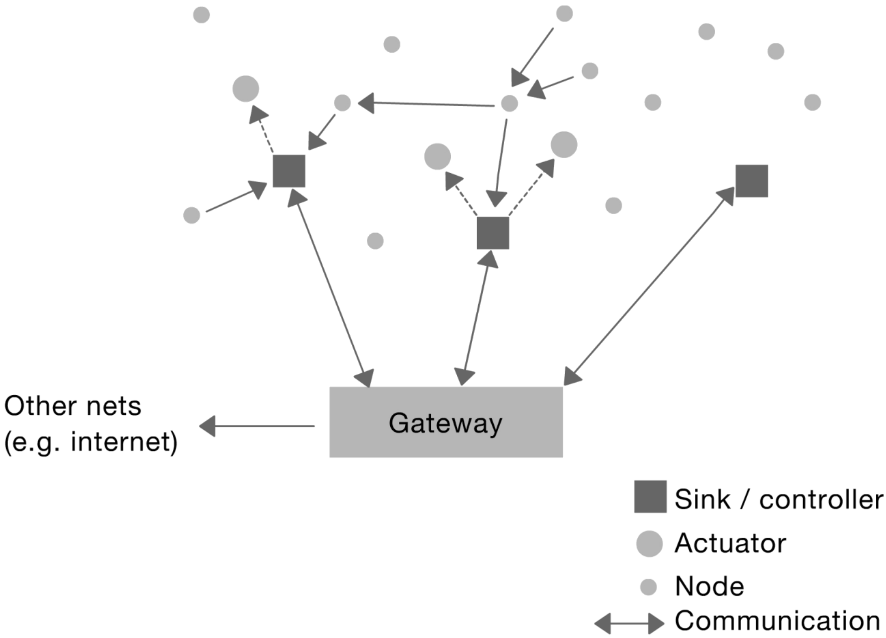

Fig. 18.1. General Architecture of Wireless Sensors and Actuators Networks

WSN NODES (MOTES, SMART OBJECTS)

The nodes that form the WSN, often called motes, are typically made of the following parts: sensors and actuators, a microcontroller(s), a radio transceiver and power supply sources. More advanced motes may include additional components such as:

a serial flash, aMicroSD card and an LCD glass module. Figure 2 shows a general architecture of a typical WSN node and Figure 3 depicts a commercially available WSN development kit.

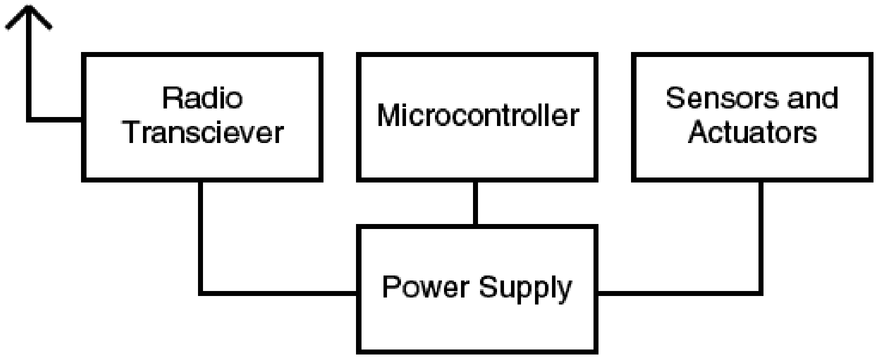

Fig. 18.2. General Architecture of the Sensor Node

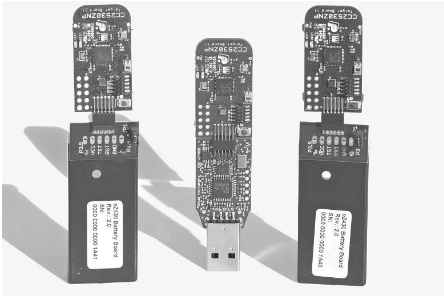

Fig. 18.3. CC2530ZDK-ZNP-MINI is a ZigBee Network Processor Mini Development Kit from TI (Source from *ti.com)*

Sensors and Actuators

A *transducer* is a device that converts energy from one form into another and a sensor is a transducer that converts energy in a physical world into electrical energy. An *actuator* is a device performing a reverse type of energy conversion (from electrical to another form). The symbolic representation of sensing and actuating is shown in Figure 4.

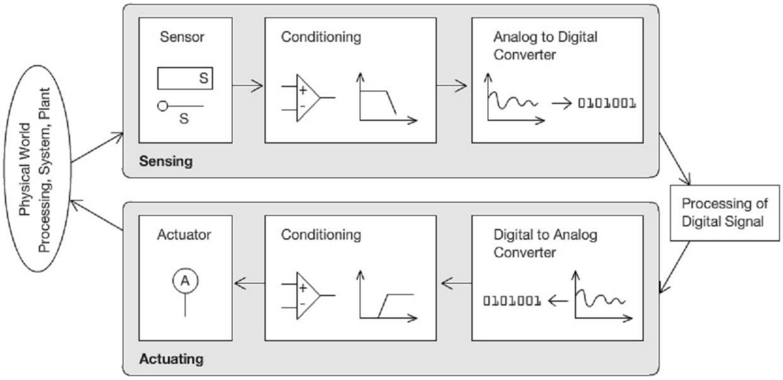

Fig. 18.4. Symbolic representation of data acquisition and actuation showing sensors and actuators

MICROCONTROLLERS FOR WSN

Microcontrollers selected for WSN have lower than other current consumption and ability to switch programmatically their power modes. Another desirable feature is the ability to run from different and scalable clock sources. The examples of popular microcontrollers used in WSN are:

- ATMega32 – 8 bit, Atmel, 16 MHz clock, 32kB flash, 2kB RAM, active current 3.5 mA @ 1MHz, power down < 1uA.
- MSP430F2274 – 16 bit, TI, 16MHz clock, 32kB flash, 1kB RAM, active current 270uA @ 1MHz, standby <0.7uA.
- EFM32G840F64 – 32 bit ARM-Cortex M3, Energy Micro, 32MHz clock, 64kB flash, 16kB RAM, active current 180uA/MHz, stop mode 0.6 uA.

RADIO TRANSCEIVERS FOR WSN

Typically an IC radio transceivers or a modules with integrated antenna are used. Most radio transceivers are programmable giving an option for different frequencies, modulations and power. An example module is shown in Figure 5.

POWER SOURCES FOR WSN

The requirements for power sources in WSN to last for a long time (usually years) and have a very small size at the same time are very difficult to satisfy. In most cases the power sources are batteries. With a very little progress in batteries technologies

Fig. 18.5. An example radio transceiver module A1101R09A from Anaren incorporates TI CC1101 transceiver chip, size 9x16x2.5 mm. (Source *anaren.com*)

(compare to other technologies) there is a growing interest in alternative sources in a form of super capacitors and energy scavenging from the environment.

SMART DUST

Smart dust was originally a concept for miniature wireless sensor networks and a project undertaken at University of California Berkeley. The Defence Advanced Research Projects Agency (DARPA) funded the project, setting as a goal the demonstration "that a complete sensor/communication system can be integrated into a cubic millimetre package" [6]. Tiny, ubiquitous, low-cost, smart dust motes have not yet been realized, however, some reasonably small motes are commercially available [6].

BODY SENSOR NETWORKS

When Wireless Sensor Network is deployed on the human body it is called Body Sensor Network (BSN). Body Sensor Networks are considered to be more challenging than other type of WSNs and extensive research is focusing on biocompatibility, signal propagation, power management [7] and other properties. The primary motivation for Body Sensor Networks (BSN) is to provide long term continuous sensing without activity restriction and behaviour modifications.

CONTEXT AWARENESS

Context information is anything that can characterize the situation of an object, such as a person, a device or a network [8].

Smart Spaces

Smart space is a space surrounded by technology that can sense and act, communicate, reason, and interact with people [2]. Examples of smart spaces are smart homes/houses, smart cars. A Smart Space refers to small intelligent devices embedded in a physical world and connected to the Internet [9]. The things in a physical world will be Internet-enabled via embedded technology and able to interact with one another to provide a smart space that adds intelligence to the environment [9]. One of the examples of Smart Spaces is Smart House with a number of implementations with a Gator Tech Smart House from University of Florida being a pioneering project [16]. Some of the features of it are smart blinds to control ambient light, smart bed to monitor sleep patterns, smart bathroom with sensors for measurement of weight, height and temperature and others. Cooperation can play a crucial role in such spaces as discussed in [9].

The Internet of Things and Smart Object

The Internet of Things is the next stage of the Internet, where a growing number of Smart Object (Things) is connected to the global internet for monitoring and control. The number of people using the Internet becomes significantly lower than a number of Smart Object and the amount of data transferred by Smart Objects becomes much larger then that transferred by people.

IP for Smart Objects

6LowPAN (IPv6 over Low power Wireless Personal Area Networks) is a protocol defining IPv6 packets over IEEE 802.15.4 wireless networks. It uses MAC and PHY layer of IEEE 802.15.4 and IPv6 protocols for the layers above the MAC. 6LowPAN is gaining more interest due to its promise of interoperability with existing IP networks, direct access from the internet ability and improved mobility over other WSN protocols.

Stigmergy

It is known from the study of biologists, that some social systems in nature can present an intelligent collective behaviour although they are composed by simple individuals with limited capabilities and that is achieved through direct and indirect interactions of these individuals. The word stigmergy is used to describe the indirect interaction occurring between two individuals when one of them modifies the environment and the other responds to the new environment at a later time [10]. Stigmergy is an organizing principle in which individual parts of the system communicate with one another indirectly by modifying and sensing their local environment

[11]. The trace left in the environment by an action stimulates the performance of a next action, so subsequent action are built on each other, leading to systematic activity. The term "stigmergy" was introduced by French biologist Pierre Paul Grasse in 1959. He defined it as: "Stimulation of workers by the performance they have achieved" It is derived from the Greek words stigma "mark, sign" and ergon "work, action".

PERSONAL HEALTH DEVICES

There is no formal definition for the concept of a Personal Health Device (PHD), however in popular terms it is a device that is used for monitoring health, wellness and life activities in home/work environments as well as for various mobile applications. Figure 6 shows an example of a portable medical instrument, called a Neuromonics processor for treatment of tinnitus. The device has a wireless connectivity that uses IrDA mode of communication, however it is not networked.

Fig. 18.6. Example of portable medical instrument (Source: *neuromonics.com*)

18.2 Background Context

18.2.1 Body Sensor Networks as Special WSNs

Body Sensor Networks consists of a number of implantable, wearable, portable and ambient devices, each of them being capable of monitoring/sensing and/or displaying/actuating information [12]. BSNs are a special case of Wireless Sensor Networks and as they are deployed on human body they should feature the following attributes

[12]: Reliability, biocompatibility, portability, privacy and security, lightweight protocols, irretrievability, energy aware communication, prioritized traffic, RF radiation safety. Figure 7 shows general concept of Body Sensor Networks. Some examples of implantable devices are artificial pacemakers, cochlear implants, retinal implants. Examples for wearable sensors are ECG, EEG, accelerometers, inclinometers, blood pressure monitors, and blood oxygen saturation monitors (SpO2). Commercial-off-the-Shelf Personal Health Devices, smart phones, PDAs are the examples of portable devices, while the ambient sensors can be sensors for atmospheric pressure, ambient temperature, humidity and others.

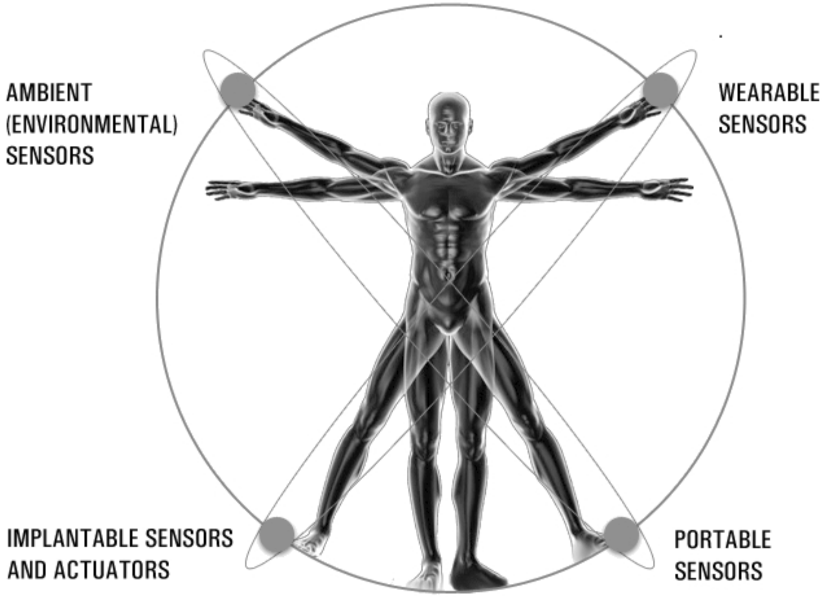

Fig. 18.7. The concept of Body Sensor Networks showing human being in the centre with a number of implantable, wearable, portable and ambient sensors/actuators.

The requirements for BSN are more restrictive than for other WSN including reliability, user friendliness, long lifetime, wearability creating extra challenges.

18.2.2 A Brief History of Body Sensor Networks

Body Sensor Networks consists of Body Sensors. First prototypes of Body Sensor Networks were reported about 10 years ago named WBAN [Jovanovic] and PAN [Zimmerman]. A group from Philips among first to use BAN instead of PAN listing the differences for example: Transmission range for WBAN is ~2m, while for

Table 18.1. Comparison of the Features of WLAN, WSN and BSN

	Traditional Networks	**Typical WSN**	**BSN**
Instance	WLAN	Smart Dust	Smart Ward
Coverage	50m	10m	1m
Density	Sparse	Dense	Dense
Data-centric	Address-centric	Data-centric	Data-centric
Large scale	No	Yes	Yes
Workloads	Unpredictable	Unpredictable	Partially Predictable
Error rates	Medium	High	**Must be very low**
Energy constraints	No	Yes	**Yes**
Hops	Single	Multihop	Optional
Infrastructure	Yes	No	No
Node Failure	No	Yes	**Prohibited**
Deployment	Random	Random	**Planned**

WPAN ~10m. The primary motivation for BSN is to provide long term continuous sensing without activity restriction and behaviour modifications

18.2.3 BSN Integration into Connected Healthcare System

Body Sensor Networks usually do not function as a stand-alone system, but rather as a part of comprehensive and complex health and rescue system [13]. There are currently a large number of electronic devices supporting personal healthcare and most of them are standalone ones not connected into any network. The more advanced (and more expensive) devices have data storage capability for logging parameters and some kind of wireless connectivity (like Bluetooth or Wireless USB) for the transfer of logged data. Despite existing standard (IEEE 1073, HL7, others) and initiatives (Continua Health Alliance, Medical Devices Plug and Play, others) there is still lack of interoperability between different devices.

18.2.4 Sensors and Actuators for BSN*s*

The common definition for a sensor is that it is a device that measures a physical quantity and converts it into a signal, which can be read by an observer or by an instrument [43]. Table 2 lists vital signs and their parameters and Table 3 lists a number of sensors used in WSN and their signals (sources [12], [14]).

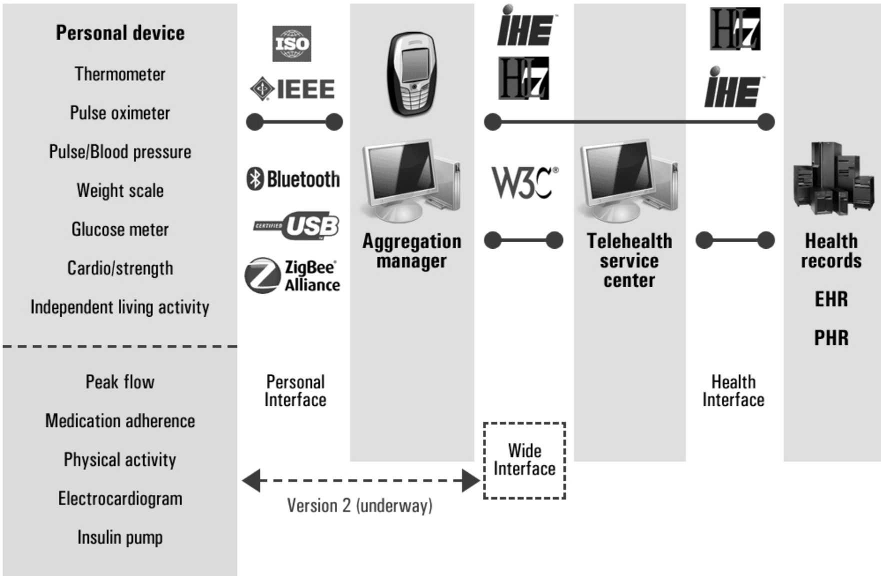

Fig. 18.8. The integration of technologies for Connected Healthcare (adopted from Continua presentation)

Table 18.2. Vital signs and their parameters

Vital Sign (nominal values)	Sampling rate	Quantization	Total bit rate
Electrocardiogram (60-80/min)	240 samples/sec	12-36 bits/sample	2.9-8.7 Kbps
Blood Pressure Sys<120, Dia<80	1 sample/minute	64 bits/sample	1 bps
Oxygen Saturation 95-99%	1 sample/sec	16 bits/sample	16 bps
Body core Temperature 36-37C	1 sample/minute	16 bits/sample	0.3 bps
Breathing rate 12-18/min	1 sample/sec	4 bits/sample	4 bps

18.2.5 Wireless Technologies for BSNs

The existing wireless technologies suitable for BSN are briefly summarized in Table 4 and Figure 9 shows examples of wireless modules of different technologies used for experimentation.

Table 18.3. Sensory devices used in BSN

Measurement Type	Sensing method and implementation example
Acceleration	MEMS sensor sensing dynamic acceleration (shock or vibration) and static acceleration (inclination or gravity)
Blood pressure	Measures the systolic (peak) pressure and diastolic (minimum) pressure using a stethoscope and a sphygmomanometer or pressure sensor
Blood sugar	Analyses drops of blood traditionally or non-invasive methods like near infrared spectroscopy, ultrasound, breath analysis
Carbon dioxide	Measurement of the absorption of the gas by infrared light
ECG/EEG/EMG	Measurement of potential differences between electrodes placed on a body
Pulse oximetry	Measurement of the red and infrared lights absorbance when passing through the body
Respiration	Measurement of oxygen dissolved in a liquid using two electrodes covered by a thin membrane
Temperature	Integrated Circuit uses infrared or resistance changing

Table 18.4. Technologies used in BSN

Wireless Technology	Coverage (Max.)	Bitrate (Max.)	Cost	Comments
6LowPAN	10m	250Kbps in 2.5GHz 25Kbps in sub-GHz	Low	Conforms to IEEE 802.15
Zigbee	10m	250Kbps in 2.5GHz 25Kbps in sub-GHz	Low	Conforms to IEEE 802.15
RFID	1m		Low	
Bluetooth	10m, 100m	900 Kbps	Low	
Bluetooth Low Energy	10m		Low	
Wireless LAN (IEEE 802.11)	100m	54Mbps	Low	
Cellular/3G	Wide area (nationwide)	Several Mbps	High, Carrier usage charge	

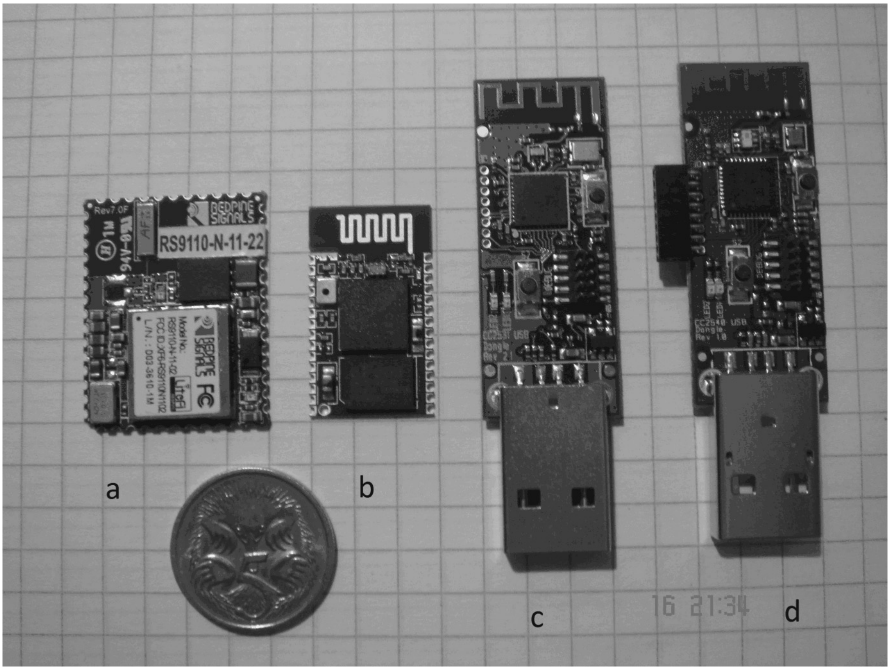

Fig. 18.9. Wireless modules of different technologies used for experimentation
a) RS9110-N-11-22 Wi-Fi module from Redpine
b) BTM182 Bluetooth module from Rayson
c) CC2531 ZigBee module from Chipcon (Texas Instruments)
d) Bluetooth Low Energy module from Texas Instruments

18.2.6 Connectivity Models for BSN*s*

There is a number of portable medical device currently on the market like pulse oximeters, blood test monitors, glucose meters functioning as the stand alone devices. They are able to measure usually one vital sign or other health related parameters and in some cases have some wired or wireless interface to PC for the purpose of data storage, visualization, trend monitoring. The autonomous Body Sensor Network system in the next step (Figure 10) as it combines a number of sensors. It is however not connected to global Internet, but sometimes an external access is possible. An example of such a system is an emergency monitoring system for people with cardiac problems with cellular connection to the service provide or personal cater. The model shown in Figure 11 is the extended internet model of connectivity with body sensor networks in moving between a numbers of smart spaces. The sensors of BSN can be access either directly or through Personal Health Device or through the smart object's gateways/routers anywhere from the Internet.

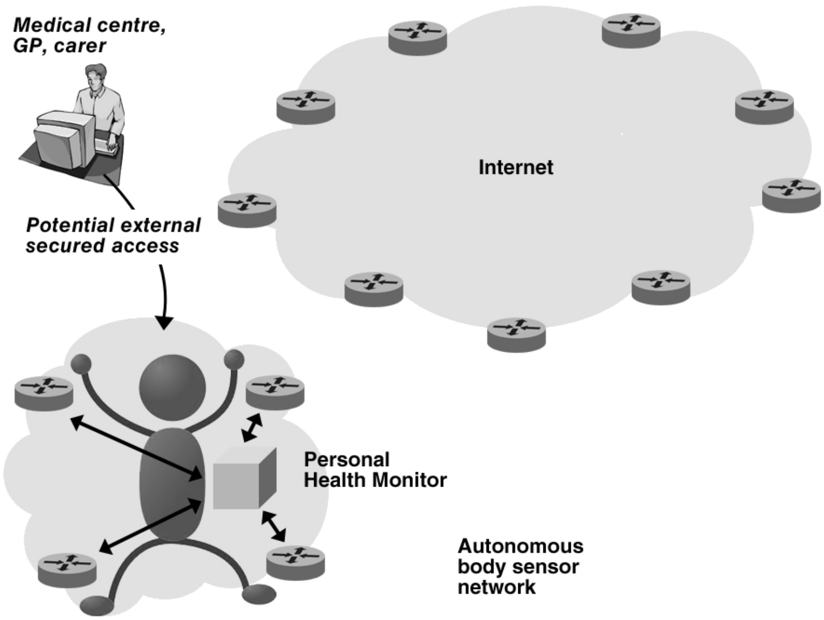

Fig. 18.10. Autonomous Body Sensor Network

18.3 Challenges for Ubiquitous and Pervasive Healthcare

Many authors [2], [15] list the following challenges:

Node-level challenges:

- *Sensor technology.* Despite a great progress in sensors technology mainly to the use of MEMS there is still an unsatisfied need for a number of medical sensors like blood pressure or ECG sensors. The existing sensor are too big and inconvenient to use and the prototypes of smaller devices either do not have satisfying parameters like the MEMS-based ECG sensors or are too expensive like the implantable blood pressure sensors, which need to be placed inside veins by chirurgical operation.
- *Small size (miniaturization):* For implantable, wearable and portable technologies physical size is important
- *Power consumption:* The technology is struggling with providing power sources with capacity enough for the long time reliable operation of BSN. There are different approaches to solve it including lower power electronics, energy harvesting, better batteries and optimizing software for lower power.

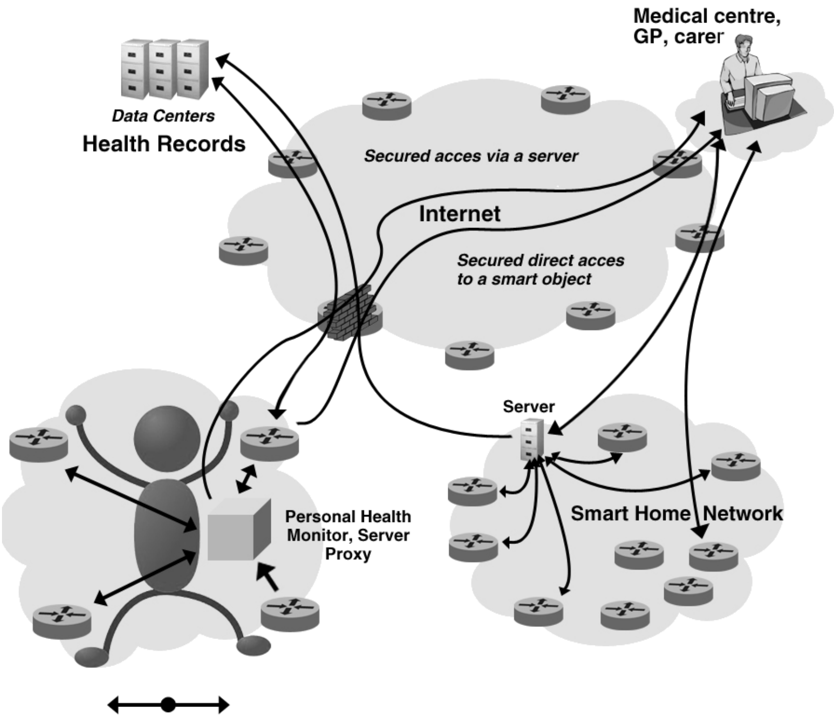

Fig. 18.11. Body Sensor Network as part of The Internet of Things

- *Cost.* It is usually needed to optimize the cost for a network of a very large number of nodes. In the case of BSN that requirement is less critical, however.

Network-level challenges:

- *Unreliable ("lossy") communication media:* BSN like other sensor networks work in the radio environment is often unreliable as being use by other nodes (collision) and other devices (interference) plus a number of other problems like fading, multipath can be taken into account. The network protocols have to include retransmission, channel switching, etc.
- *Network management:* Unlike with traditional WSN there is no option for a node failure with BSN and as such the requirements for network management are more strict.
- *Security:* Medical data has to be protected from unwanted access. The network security imposes an additional overhead on data packets as the encryption has to be implemented. The processing power of network nodes has to be increased to be able to deal with security.

Human–Centric Challenges:

- *Technology Acceptance:* By definition Pervasive Health Care is transparent to the user, doesn't involved any user interaction and as such and acceptance should be easy to achieve. In practice there will be intermediate stages and the normal rules of technology acceptance will apply.
- *Biocompatibility:* The material and components used for medical applications have very strict requirements to be accepted by a human body.
- *Standardization:* Standardization is the process of establishing a technical standard achieve through the consensus of involved parties. Standardization leads to a technology independent of its vendors, producers and users being an alternative to proprietary technology from a single vendor. That gives the equipment manufactures and system integrators the freedom of selection and prevents vendor lock-up.The examples of relevant standards are IEEE802.15.4 and IEEE802.15.6. The new IEEE 802.15.6-2012 standard defines "Short-range, wireless communications in the vicinity of, or inside, a human body (but not limited to humans). It utilises ISM and other communication bands as well as frequency bands that are in compliance with applicable medical and communication regulatory authorities. It allows devices to operate on a very low transmit power for safety in order to minimize the specific absorption rate (SAR) into the living body and to prolong the battery life" [17]. Additionally, the standard supports Quality of Service (QoS) facilities. For example, to provide a support for an implementation of emergency messaging functions. Also, since some communication systems need to transmit sensitive data, the IEEE 802.15.6-2012 provides mechanisms for strong security [17]. There are other standards used in BAN. These are: 802.15.4-based ZigBee and 6LoWPAN and Medical Implant Interface Standard (MICS). For WSNs or BANs, it is uncommon that to create a complete solution that is based solely on a single standard. In this chapter, we provide a brief comparison of different low power wireless standards and their suitability for BANs.
- *Interoperability:* Interoperability is defined as the ability of systems and equipment from different vendors to operate together. To achieve interoperability an agreement on technical architecture and the setup of test and conformance suites is necessary.

18.4 Conclusion and Future Work

Pervasive Healthcare (or Ambient Assisted Living) is a vision for the future of Healthcare. Despite of a great need and a large number of prototype systems that have already been built, we are still away from providing a truly effective solution for pervasive healthcare. In this chapter, we aimed to explain the need for Pervasive Healthcare, provide a review of the underlying technology and discuss the existing challenges towards practical implementations. Body Sensor Networks are expected to play an important role in delivering pervasive healthcare to the society. The expected impact of BSN is to provide monitoring services and assist the traditional healthcare with prevention, diagnosis and rehabilitation. The fundamental requirements of being available “anytime, anywhere and for anyone” and the fact that BSNs are deployed on human body make the implementation of BSNs is much more challenging than most of the solutions base on traditional WSNs. This aspect leads to two major directions of the investigation into improving the performance of BSNs. Firstly, in order for the systems to become smarter, far more research is required into the hardware and software for BSNs to gain more powerful communication (mainly network protocols) and more intelligent computing mechanisms. The second direction of research is to explore how BSNs can be assisted through cooperation with Smart Space concepts and how to provide cognitive-awareness for BSNs, humans and the environment. The authors believe that their present modelling and practical experimentation work supports the above directions well.

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