

Application of Wireless Sensor Networks to Healthcare Promotion

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Abstract - Born on military applications, wireless sensor networks (WSNs) application grew on the promise of environment sensing and data processing capability at low cost. These networks can hold hundreds or even thousands of smart sensing nodes with processing and sensing capabilities and even integrated power through a dedicated battery. This paper surveys on the application of wireless sensor networks to healthcare promotion, namely with the use of biosensor technology applied to body sensor networks. On a wireless body sensor network, a person wears biosensors to gather data, while doing their daily activities. Currently, engineers and medical staff are cooperating on finding new ways to properly gather meaningful data on-site and achieve a convenient way to process these data for research and on-site medical decision. New challenges that such approach brings are also considered. Moreover, it is shown that wireless sensor networks provide the technology to built wireless sensing and create a convenient infrastructure for multiple data gathering in healthcare applications. Together with real successful examples, we demonstrate the great usefulness of wireless sensor networks in healthcare promotion. The paper concludes with some guidelines for future work.

Keywords - Wireless Sensor Networks (WSNs); Healthcare; Body Sensor Networks (BSNs); m-Health; Biofeedback; Smart Biosensor.

I. INTRODUCTION

Wireless sensor networks (WSNs) are finding applications in many areas, such as medical monitoring, emergency response, security, industrial automation, environment and agriculture, seismic detection, infrastructure protection and optimization, automotive and aeronautic applications, building automation, and military applications [1-3].

A wireless sensor network can be composed of a large number of nodes, constituting a multi-hop network, where vicinity nodes communicate with each other, with routing responsibilities. Advances in wireless communication and micro-electro-mechanical systems (MEMS) [3-5] allow the establishment of a large scale, low power, multi-functional, and (ideally) low cost network. Since a wireless sensor network can have many sensing nodes, they have advantages over traditional sensing methods like increase in the

robustness, fault tolerance and increase in spatial coverage.

A wireless sensor network can be easy to deploy in the desired environment [6], and the information can be gathered, processed and sent to a desired location.

Currently, wireless sensor networks deployment is starting to be deployed at an accelerated pace. It is reasonable to expect that the world will benefit from services of Wireless sensor networks with Internet access. This technology has great potential for numerous application areas including pervasive computing, namely with smart spaces. The basic mode of operation of wireless sensor networks is significantly different from traditional computer networks, due to their tight integration with the physical world. Additionally, sensor networks have some unique characteristics that make the development of applications non-trivial [7].

Wireless sensor networks are significantly different from traditional wireless networks such as wireless local area network (WLAN), mobile ad-hoc network (MANET), or cellular networks. In these networks, the tasks of organization, routing and mobility management are used to optimize quality of service (QoS) and heighten bandwidth efficiency [8]. These wireless networks aim to provide excellent throughput and delay characteristics under high mobile conditions, but energy consumption takes up secondary importance. On the contrary, a wireless sensor network is designed for unattended operation and energy saving for prolonging lifetime is a critical parameter. The majority of nodes do not communicate directly with the nearest base station, but with their local peers. Wireless sensor networks form a new kind of wireless networks with a new set of characteristics and challenges [9].

A patient doing his daily activities at home or workplace and at the same time being monitored for any health abnormalities [10-25] is now being realized more efficiently and with cost savings with the adoption of wireless sensor networks. The wireless capability and node size allows greater mobility, less patient restrain and, in conjunction with wearable computing, an almost invisible way of patient monitoring [26]. As an example of wireless sensor networks importance, Intel® Proactive Health believes that wireless sensor networks may be “crucial to address the pending global age wave and public health crisis” [27]. Wireless sensor networks can be effectively used in healthcare to enhance the quality of life provided for the patients and also the quality of healthcare services [28]. For example, patients equipped with a body sensor network (BSN) need not be physically present at the physician for their diagnostic. A body sensor network proves to be adequate for emergency cases, where it autonomously sends data about patient health so that physician can prepare for the treatment immediately [10-25]. In this sense, this paper

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surveys applications of wireless sensor networks to healthcare and point out open issues for further research works.

In the remainder of this paper, Section II reviews a snapshot of wireless sensor networks. Section III discusses some challenges and general aspects related to the application of wireless sensor networks to healthcare, while section IV digs into some of its current applications and systems. Finally, section V concludes the paper and point directions for future work.

II. WIRELESS SENSOR NETWORKS

A Wireless sensor networks consists of many spatially distributed autonomous devices, called smart sensor nodes that cooperatively monitor environmental or physical conditions at different locations [29].

Initially wireless sensor networks were developed for military applications, spreading across civilian application areas such as environment monitoring, habitat monitoring, medical applications, home automation and traffic control [7, 29]. Even games can benefit from wireless sensor networks technology [30]. Also, commercial applications are also beginning to surface [2].

II.1. Typical node and network structure

A wireless sensor network smart node has communication capabilities, a processing module with memory, the sensing unit itself, and a power module that allows autonomous operation. The sensing unit may be composed of one or more sensors and an analog to digital converter (ADC). In order to understand the different modules interconnection, figure 1 presents a basic block diagram of the typical wireless sensor network smart node.

The size of a sensor node can vary from the size of a shoe-box to the size of a microscopically small particle depending on the specific applications [31-33]. The cost of a sensor node ranges from hundreds of dollars to a few cents [29]. The size and cost greatly depends on its resources and the sensor itself. This leads to different sensor node’s architectures and functionality [34].

A sensor network may have one or more sink nodes (also referred as base station or gateway) that relay data to the outside world. In some rare cases the network can be sinkless, that is, have no sink node.

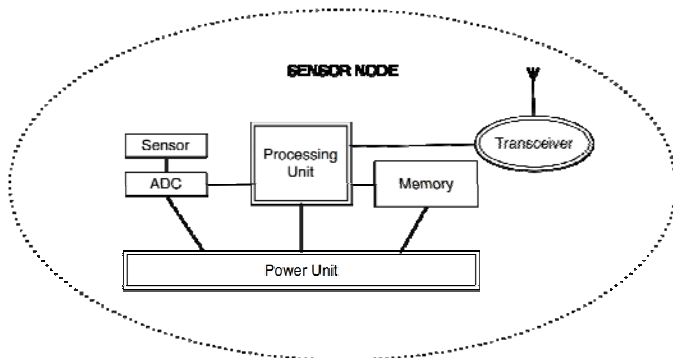


Fig. 1. Basic components of a smart sensor node in a Wireless Sensor Network.

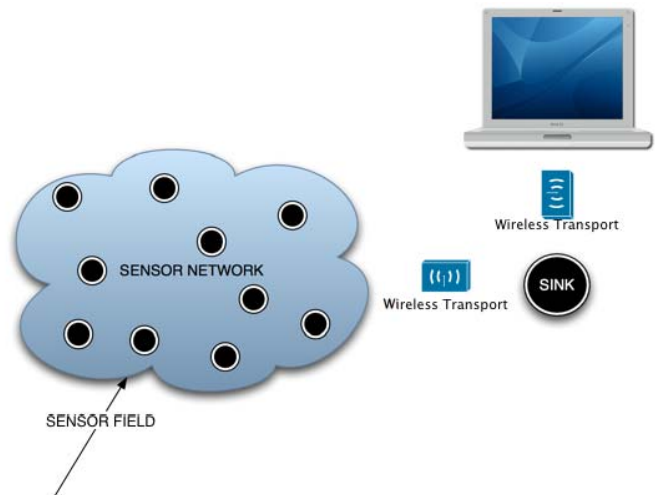


Fig. 2. Example of one sink wireless sensor network.

The sink node(s) receive information from the network and allow data aggregation and consumption. Figure 2 presents the typical working principle of a wireless sensor network.

A Wireless sensor network can be easy to deploy in the desired environment [6] as it requires just the placement of miniature smart sensor nodes, and the information can be gathered, processed and sent to the desired location with the convenience of wireless communication.

Node location is employed by routing protocols that use spatial addresses, and by signal processing algorithms that are used for tasks such as target tracking. The underlying algorithm problem is how nodes acquire their location upon network boot-up. When the sensor nodes are deployed in an unplanned topology, there is no a priori knowledge of location. The use of global position system (GPS) in sensor nodes is ruled out in many scenarios because of power consumption, antenna size, and overhead obstructions such as dense foliage. The ad hoc nature rules out infrastructure for many scenarios of localization. To begin with a few nodes might know their position via other means, but at the end of the localization process every node would hopefully know its position.

II.2. Wireless sensor network evaluation metrics

Different metrics may be considered to evaluate wireless sensor networks: network lifetime, coverage, cost and ease of deployment, response time, temporal accuracy, security, and effective sample rate. Many of these evaluation metrics are interrelated. Many situations may demand to decrease performance in one metric such as effective sample rate in order to enhance the performance of another metric such as lifetime. Together, this set of metrics constitute a multidimensional space that describes the capabilities of a wireless sensor network [34]. The volume in this multidimensional space represents the capabilities of a platform that contains all of the valid operating points. A single point represents a specific application deployment. A system can perform the specific application if and only if the application requirements point is inside the capability hyperspace. Next paragraphs discuss the importance of each evaluation metric considered.

Network lifetime is one of the most important wireless sensor network evaluation metrics. Since sensors rely on internal battery to operate, lifetime is a critical parameter for a wireless sensor network [2]. In certain application scenarios, the nodes must be placed unattended for a long time. Since the communication part drains battery faster, communication protocols must minimize communication between nodes.

Coverage is the next important evaluation metric for a sensor network next to lifetime. Deployment of a wireless sensor network over a larger area may lead to node number increase. More sensing points imply more data transmission that will lead to an increase on power consumption. Lowering the sampling rate or shutting down some sensor node elements, if possible, can avoid this. Some sensor nodes feature sleep modes that routing protocols in wireless sensor network can take advantage of [35, 36].

Ease of deployment. For instance, medical staff using a sensor network should be relieved from the knowledge about the network itself: the network must be self-configurable. Moreover, the system must also be able to adapt to changing environmental conditions.

Response time is a critical parameter in applications that are alarm-driven. For example, when an intrusion or some event is detected, the system must react with an alarm. For these kinds of applications, nodes must be able to communicate immediate high priority messages even in low power mode. The ability to have low response time affects the lifetime of the network. This feature assumes the introduction of quality of service (QoS) on wireless sensor networks [37, 38].

Temporal accuracy is a major parameter in environment monitoring and tracking applications. In these applications, samples from multiple nodes must be cross-correlated in time to determine the nature of the phenomenon under evaluation. For determining the average temperature of a building, correlation between samples is only to the seconds. However, to determine how a building reacts to a seismic event, millisecond accuracy may be required.

Security is an important concern of sensor networks, especially in wireless sensor network for healthcare. The network must be capable of keeping the collected information private. Security has to be a major concern in sensor networks, namely, patient's data on medical applications [39].

Effective sample rate is a primary application performance metric in a data collection network. It is defined as the sample rate of each individual sensor and its communication to a collection point. However, an increase in sample rate decreases the lifetime of a system.

Apart from system metrics, nodes have their individual evaluation metrics such as power, flexibility, robustness, security, communication, computation, time synchronization, size, reliability, and cost. Similar to system metrics, individual node metrics are also interrelated. The improvement in one node-level evaluation metric often comes at the expense of another.

The wireless requirements of healthcare services are comprehensive coverage, reliable access and transmission of medical information, location management, and support for patient mobility.

Generally, wireless technologies should also take down long-term cost of healthcare and also result in an increased

productivity of healthcare providers. This can be ensured by improved coverage and scalability; dependable and reliable operation, practical, implantable and reusable technologies; and expandable and modifiable wireless technologies for pervasive healthcare [28].

III. WIRELESS SENSOR NETWORK APPLICATION TO HEALTHCARE

Healthcare is always a big concern, since it involves the quality of life a given individual can have. It is always better to prevent an illness than to treat it, so individual monitoring is required as a periodic activity. The aging population of developed countries present a growing slice of government's budget, and presents new challenges to healthcare systems, namely with elderly people living on independent senior housing [40].

Traditionally, health monitoring is performed on a periodic check basis, where the patient must remember its symptoms; the doctor performs some check and formulates a diagnostic, then monitors patient progress along the treatment, if possible. However, some symptoms only manifest themselves in daily activities, where an individual may feel some pain or discomfort. Healthcare applications of wireless sensor networks allow in-home assistance, smart nursing homes, clinical trial and research augmentation [41]. In-home healthcare becomes mandatory for diseases like Parkinson or Alzheimer, providing memory enhancement through medicine reminders, mental stimulation through sounds or images of object's location, control over home appliances, medical data lookup, and emergency situations. Such approach may lead to a multi-tiered architecture, with lightweight mobile computers and smart sensors in conjunction with more powerful computational devices [41]. Before describing and surveying medical applications for healthcare, this section focuses on several challenges and general aspects that characterize this kind of technologies.

III.1. Challenges

Healthcare applications present several challenges: low power, limited computation, material constraints, continuous operation, robustness and fault tolerance, scalability, security and interference, and regulatory requirements [42].

The **power challenge** is present in almost every area of application of wireless sensor networks, but limitation of a smart sensor implanted on a person still poses even further challenge, although ongoing research tries to provide power wirelessly. Another challenge in terms of power stems from the operational heat. For instance, in some cases it is not possible to cool down the sensor by allowing contact with the environment. A typical alkaline battery, for example, provides about 50 watt-hours of energy. This may translate to less than a month of continuous operation for each node in full active mode. In practice, for many applications, it will be necessary to assure that a network can remain operational without any replacements [43].

Computation is directly limited due to the limited amount of power. Typically, biosensors are not expected to have the same computational power as conventional wireless sensor network nodes. Since communication is vital and footprint is small, little power remains for computation. A solution can be

data fusion, which entails several nodes pooling their information together for increased computational power processing and accuracy. Moreover, it may be expected that for some applications, such as blood glucose monitoring, the ability to transmit data to an external device will be required for further data processing. Some sensors may have varying capabilities that communicate with each other and send out one collaborative data message [42].

Material constraints is another issue for wireless sensor networks application to healthcare. A biosensor must be in contact with human body, or even on it. If the biosensor is inside a pill, the choice of construction materials must be careful, especially on batteries. Also chemical reactions with body tissue and the disposal of the sensor is of utmost importance.

In many applications, it is possible to discard one or more smart sensors without the need for any operator intervention.

Continuous operation must be ensured along the lifecycle of a biosensor, which cannot benefit from duty-cycle variation techniques. This type of operation and data sensitivity clearly demand robustness and fault tolerance. The biosensor is expected to operate for days, sometimes weeks without operator intervention. Finally, the wireless sensor network must integrate mechanisms for security and interference free functionality.

Carl Falcon stresses the requirements, topologies, selection of a transmission protocol, the environmental requirements, radio and multi-path interference problems, and data integrity check. He concludes that the understanding of protocols and requirements are crucial for the selection of the radio system [44].

Robustness. Rates of device failure will be high whenever the sensor devices are deployed in harsh or hostile environments. Protocol designs must therefore have built-in mechanisms. It is important to ensure that the global performance of the system is not sensitive to individual device failures. Furthermore, it is often desirable that the performance of the system degrade as gracefully as possible with respect to component failures [43]. Particularly, the failure of one node should not cause the entire network to cease operation. A possible solution is a distributed network, where each sensor node operates autonomously though still cooperate when necessary.

Indeed, this mechanism should be employed at the biosensor component level. For instance, if the sensor part is not working, the communication part should be used if it benefits the network and communication is operating as expected.

A possible solution is to have several small components wired together that function as a group. In order to ensure that the proper data is being sent and received, there are a few options that can be used, like checksums, parity check, and cyclic redundancy check [42].

Security and interference is one very important topic to consider, especially for medical systems. Physiological data collected by the sensor network involves personal information whose privacy must be protected, and data consistency maintained. These networks are often deployed in open areas, allowing attacks such as jamming or node capture and tampering [45]. To find the sweet spot between security and other challenges one must consider the attacker motivations

and opportunities. The most often motivation for attacker is benefit from data. Attacker opportunities range from physical access, wireless communication, attacks on coordination and self-configuration, up to network visibility.

Regulatory requirements must always be met, even more with medical applications. There must be some evidence that these devices will not harm; even prototype devices will have to meet the strict standards of patient safety before any human testing can be done. The wireless data transmission must not harm human body and the chronic functioning and power utilization of these devices must also be benign. Design for safety must be a fundamental feature of biomedical sensor development, even at the earliest stages. Reasonable evidence of design efficacy will be required even for prototype devices [42].

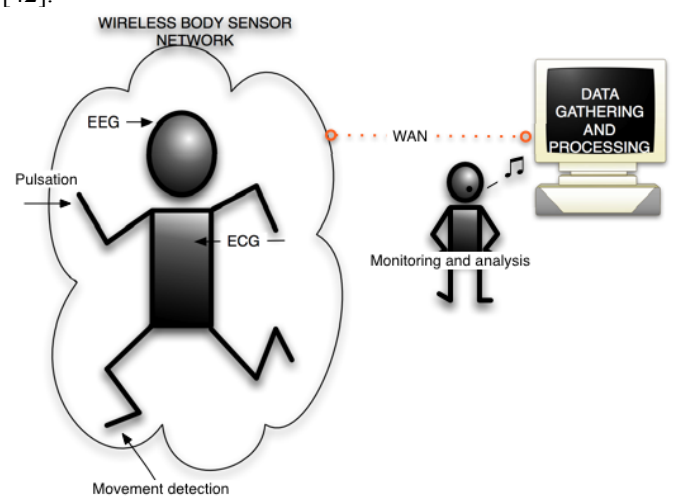


Fig. 3. M-health concept with body sensor networks.

The sampling rate must be appropriate for the current application. In healthcare applications, this typically implies real-time data acquisition and analysis (if possible). This raises concerns like event ordering, time sampling, synchronization and emergency response.

III.2. Body sensor network

Figure 3 presents a scenario where a given individual is monitored in its daily activities. The application of a wireless sensor network directly on the patient presents raw data processing advantages over other approaches [46]. To successfully deploy such systems, cooperation between engineers and medical staff is required, which is not trivial since technical expectations are sometimes difficult to meet.

A body sensor network constantly monitors health parameters using in-body sensors, providing *biofeedback* services [47]. A body sensor network enables mobile health (m-health), since an individual may use the network while doing its daily activities, enabling health in motion. The integration of mobile computing and body sensor networks provide the required technology for a true ubiquitous mobile health platform.

The lowest level of data flow hierarchy of m-health consists of intelligent physiological sensors, such as, ElectroCardioGrams (ECG), Electromyogram (EMG), Electroencephalograms (EEG), and motion sensors. In the next level data from all sensors is sent to the mobile sink. The sink device may have enough computational power to store, process and present

data. However another communication level is typically added to enable data processing and presentation through a remote server. A personal server application could be run on a PDA, cell phone or personal computer. Typically, all messages from sensor node are saved and retransmitted to the medical server. Communication between personal server and an Internet gateway is carried out using standard data networks like cellular and/or WLAN [46].

M-health allows more mobility to the patient. Possible medical applications include the following: wearable systems and personal health-care monitoring; monitoring of soldiers in the battlefield; emergency medical care and mass casualty event; home monitoring; computer-assisted rehabilitation and therapy; and social networking of relatives and peers of chronically ill patients [45].

Information technology companies notice a great interest and a demand for this technology and they are designing m-health solutions such as eWatch [48] or LifeShirt [49]. As a result, wireless sensor networks application to healthcare presents effective commercial solutions to the general public and not only hospital research facilities.

IV. HEALTHCARE APPLICATIONS

Although the technology for biomedical smart sensors is still young in age, some applications surface. Current healthcare applications of wireless sensor networks target heart problems, using e.g. continuous ECG monitoring to detect possible problems in advance [10, 20, 23], asthma [12, 50, 51], emergency response [52], stress monitoring [53], among others. A great concern among doctors is the post-operator period [54], since patients are at risk due to post-operative pain.

The integration of existing specialized medical technology with pervasive wireless networks will be seen in the near future [54]. Medical applications benefit from wireless sensor networks in many ways. The recent advances in miniaturization of smart biosensors will open up new opportunities for continuous monitoring of patients. Unobtrusive, tiny wearable sensors will allow collection of vast amounts of data automatically, reducing the cost and inconvenience of regular visits to the physician. Thus, many more researchers may be enrolled, benefiting all research peers [55].

In [56] the authors present an approach to enable plug and play-like simplicity for wireless medical body sensors (WMBSs), by enabling body-worn sensors to recognize the body they are deployed on.

By confining the smart sensor communication to on-body sensors, no interference is generated between WMBSs. These authors refer in-body communication by body-coupled communication (BCC). Each person must place the appropriate smart sensor array and a “personal identifier”, as shown in figure 4. Following, medical applications will be described by are of interest.

Cancer Detection represents one of the major concerns in healthcare. Nowadays, one of biggest treat for human life is cancer. Cancer is the second leading cause of death in US with rising numbers each year: currently 9 million people had a cancer diagnosis, with 1,221,800 new cases in 1999 [57].

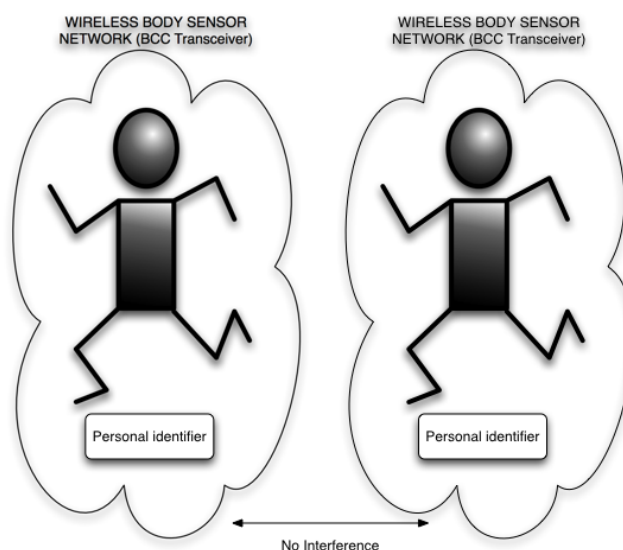


Fig. 4. Wireless Body Sensor Network operation according to [56].

Although, there is no conclusive evidence on how to prevent cancer and early detection is crucial. Studies have shown that cancer cells exude nitric oxide, which affects the blood in the area surrounding a tumor. A sensor with the ability to detect these changes in the blood can be placed in suspect locations. Research is also being conducted on placing sensors on a needle, enabling physicians to diagnose tumors without having to do a biopsy. Sensors used in this device have the ability to differentiate between different types of cells, identifying cancerous ones [42].

Glucose Level Monitoring is essential for controlling another emerging disease: diabetes. The US national institute of health (NIH), US national institute of diabetes, and digestive and kidney disease reported 15.7 million people had diabetes in 1999 in the US. Complications that can arise from diabetes include heart disease, stroke, high blood pressure, blindness, kidney disease, and amputations. Characteristic treatment for diabetes includes a strict diet, exercise, insulin injections, and blood monitoring. Wireless biomedical sensors may present a more effective way to treat diabetes, by providing a more consistent, accurate, and less invasive method for monitoring glucose levels. The current constant pricking on the finger for blood, several times a day over a period of years can damage the tissue and blood vessels in that area. A biosensor could be implanted in the patient once [58]. The sensor would monitor the glucose levels and transmit the results to a wristwatch display for instance. This approach leads to fewer invasions, more accuracy due to multiple readings, and anticipation to insulin needs. Furthermore, insulin could automatically be injected when a certain threshold glucose level is reached.

Asthma. For millions of patients suffering from asthma in the world, sudden allergic morbidity may cause severe threat to their lives [50, 51]. They require administration of Terbutaline in minutes, in order to ease symptoms of rapid-onset asthma attacks, or the attacks may become fatal [50, 51]. A wireless sensor network can help them by having sensor nodes that can sense the allergic agents in the air and report the status continuously to the physician and/or to the patient himself. Hsueh-Ting Chu *et al* [12], developed a portable GPS-based device that continuously consults a remote server and reports

whether the current air condition will threaten user's health. The server also collects information from the network of national air quality monitoring stations. Then, if it finds anything allergic to the patient, an alarm to the patient and/or physician can be triggered.

Preventing medical accidents. Currently, one of the most important issues in medical grounds is preventing medical accidents caused by human error. Approximately 98'000 people die every year due to such errors [59]. Many deaths occur in hospitals because of medical accidents caused by human errors. The "E-nightingale project" uses wearable environmental sensors as components of a sensor network to reduce medical accidents by understanding the nurses' activities [18]. By maintaining a log of previous medical accidents, the sensor network can notify the nurses in case of the occurrence of the same accident, thus many medical accidents can be reduced that can save many human lives.

Cardiovascular diseases cause a large number of deaths in developed countries. Many of the deaths can be avoided, had the physician known beforehand about the current health status of the patient. Some proposals use smart sensor nodes that can be installed on the patient in an unobtrusive way [10, 11, 13, 14, 20-23]. The corresponding medical staff receives the vital information regarding heart rate and irregularities of the heart, treatment preparation beforehand while monitoring the health status of the patient.

Alzheimer, depression, and elderly people monitoring. As the world population ages, the number of elderly people increases. Alzheimer is a common disease in elderly people who often feel lonely and depressed and has little or no interest in physical activity and social contact. Wireless sensor networks offer a means to counteract this outcome with home automation integration, detection of abnormal situations (e.g., a fall), or even alerting neighbors, family or the nearest hospital.

In [60] an accelerometer-based approach for abnormal movement detection is described, that can be used to detect seizures, in a non-invasive, non-intrusive manner. The authors developed an algorithm using ZigBee protocol devices that detect brush, wash and shave activities.

Another proposal is presented in [61]. The authors use a mobile phone and a wireless sensor network based approach to help homebound people. The system is able to use a ZigBee or Bluetooth enabled wireless sensor network and provides real-time alerts and notifications.

Stroke and post-stroke. Strokes affect a person's cognitive, language, perceptual, sensory, and motor abilities. Strokes affect 700,000 people each year in the US and about 275,000 die from stroke each year [57]. Recovery from stroke is a long process that continues beyond the hospital stay and into the home setting. Models based on features extracted from the wearable sensor data can predict clinical assessment scores. Wearable sensors allow monitoring of in-home bounded people, and provide accurate assessments to guide the rehabilitation process. Wearable systems have the ability to measure motor behavior at home for longer periods, and can be used to predict clinical scores. Some research and test with person's participation can be found in [62].

Artificial Retina. Loss of vision clearly deteriorates a person's quality of life. Wireless sensor network technology

can also help blind people. Loren *et al.* [42] propose a biomedical application, called artificial retina. In the smart sensors and integrated microsystems (SSIM) project, retina prosthesis chips that consist of 100 micro-sensors are built and implanted within a human eye. This solution allows patients with no vision or limited vision to see at an acceptable level. The wireless communication is used to suit the need for feedback control, image identification and validation. Sensors in the eye produce electrical signals, then the underlying tissue converts signals into a chemical response, mimicking the normal operating behavior of the retina from light stimulation. The chemical response is digital (binary), essentially producing chemical serial communication.

Home monitoring. Examples of areas in which future medical systems can benefit the most from wireless sensor networks are in-home assistance, smart nursing homes, clinical trial and research augmentation. Patients gain benefits such as privacy, dignity, and convenience, and are supported and enhanced by the ability to provide services at home. Family members and the smart homecare network itself become part of the healthcare team. Memory aids and other patient-assistance services can restore some lost independence, while preserving safety.

Heart Rate Monitoring is a research domain that it will save many lives. It is well known that every year 40% to 45% of firefighters die of heart attacks compared to 25% for the normal population. Monitoring the firefighter's vital signs and the environment could revolutionize the way they train, are selected for each job assignment, and allowed to work on a high-risk assignment. Current heart rate monitors require time and attention for their placement such as the chest straps with electrodes that need moist skin contact. There are also wrist watches with electrodes that take non-continuous measures and act only when triggered, or photoplethysmographic sensors for the finger that are very sensitive to motion artifacts and loose accuracy specially when doing manual work. However there is no practical monitoring system a person can easily wear while on the job. In [63] the challenges and the difficulties of placing heart rate sensors in the worker's uniforms are presented.

Some real systems employing wireless sensor network technology can be used today. Following, we outline some of them.

CodeBlue is a wireless infrastructure intended to provide common protocol and software framework in a disaster response scenario, allowing wireless monitoring and tracking of patients and first responders. The system integrates low-power wireless wearable vital sign sensors, handheld computers and location tracking tags. Protocols for resource naming and discovery, publish/subscribe multi-hop routing, authentication and encryption provisions are provided. It also offers services for credential establishment and handoff, location tracking, and in-network filtering and aggregation of sensor-produced data. A simple query interface allows emergency medical technicians to request data from groups of patients. CodeBlue is designed to scale across a wide range of network densities, and operates on a range of wireless devices, from resource-constrained motes to more powerful PDA and PC-class systems [46, 64].

Vital Sign Monitoring System. Authors of [65] propose a healthcare system built on the idea of using non-obstructive body sensors, obtaining the sensor data and transferring it to a remote base station connected to PC/PDA for real time health monitoring.

LifeShirt [45, 49] is a miniaturized, ambulatory version of an in-patient system, and is available as a commercial prescription medical device. The system consists of the LifeShirt garment with embedded sensors, data recorder, and the VivoLogic analysis and reporting software. LifeShirt functionality includes respiratory function, ECG, accelerometer, blood pressure, blood oxygen saturation, EEG, EOG (electrooculography), periodic leg movement, core body temperature, skin temperature, end tidal CO₂, and cough. The system collects and analyzes the data, and integrates subjective patient input from an on-board digital diary. A PDA continuously encrypts and stores the patient's physiologic data on a memory card. Data can be uploaded via the Internet or read from data cards.

MobiHealth is an European Union project that aims to provide continuous monitoring of patients outside the hospital environment [66]. MobiHealth targets improving the quality of life of patients by enabling new value added services in the areas of disease prevention, disease diagnosis, remote assistance, clinical research, physical state monitoring and even clinical research.

Multi-Electrophysiological System. The transformation of the periphery spontaneous nerve can indicate the state of human emotion. Using biological and medical signal (BMS) measurement technology, wireless sensor networks technology, and wearable calculation technology, the system can operate without disturbing human activities. A wireless sensor network captures signals from the subject, and sends the data to the signal conditioning circuits. Finally data is sent to the remote host system.

In [22] multi-electrophysiological equipment is used in emotion recognition experiment. The ECG data is recorded and transferred to the computer and then heart rate is calculated. In order to classify different emotion states, they analyze heart rate variability, and pick-up the eigenvalue of the power spectrum density.

UbiMon [67] aims to provide a continuous and unobtrusive monitoring system for patient in order to capture transient events. A number of biosensors were developed such as a 3-lead ECG, 2-lead ECG strip, and SpO₂. The system architecture is divided in the body sensor network nodes, the local processing unit, the central server, the patient database and the workstation. The sensor data is collected and transmitted to a server via WiFi/GPRS network for long-term storage and analysis.

eWatch. A wearable sensing, notification, and computing platform built into a wristwatch form factor. eWatch [48] senses light, motion, audio, and temperature, providing visual, audio, and tactile notification. The eWatch system can sense if the user is in distress and then query to confirm that it is an emergency. If the user does not respond, then the eWatch could use its networked abilities to call for help. eWatch communicates wirelessly using a Bluetooth module and an infrared data port for control of devices [48].

A Portuguese company named Biodevices, presents the **VitalJacket** [68]. The garment features ECG, heart rate, oxygen saturation, activity sensors and body temperature. Moreover, the garment can be used to connect more sensors, and act as a "motherboard" for several sensors. Data is sent wirelessly to a PDA device for immediate analysis.

V. CONCLUSIONS

This paper proves that wireless sensor networks can be widely used in healthcare applications and that this research area is in a high activity phase. It surveyed a big set of systems and applications for healthcare, and described the major challenges and evaluating metrics of wireless sensor networks. As the industry provides smaller and feature-rich sensor nodes, the further these new small body networks may evolve, turning their use as natural as cloth wearing.

Remote patient monitoring is not a new goal, powered by the advent of mobile systems. However wireless sensor networks provide a low cost means to sensor a given environment and for their wireless nature it proves to be adequate for unobtrusive deployment on the patient. Although there are some sensor networks implemented for the medical applications, most of them are still at prototyping level. The smart biosensors used are still expensive and the vision of a discard able sensor is not in our near future. Another issue is the power that smart biosensors need: recent advances allow very low power consumption, but batteries are not scaling up as needed.

Wireless body sensor networks are the way to go, but wireless communication poses significant challenges from the usable spectrum, to the effects on human body. In terms of protocols, several issues like robustness, security and interference-free communication are key requirements.

We believe that the role of wireless sensor networks in medicine can be further enlarged. In the near future, smart spaces enabled with wireless sensor networks can sense environmental conditions and take preventive actions based on the humans present in those spaces. The system can therefore reach ubiquity, where each individual would have a computational module able to seamlessly interact with the smart space's system and prevent health problems.

The application of IP as a protocol to connect the body sensor network to the world seems to be promising [69]. The integration of IP inside the smart sensor nodes may present advantages in self-configuration and data capture, but presents communication overhead when compared to the current proprietary approach, and moreover may compromise the real-time behavior that we expect such systems to exhibit. We are currently pursuing this research trend.

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