Wireless Biomedical Sensor Networks for Healthcare Monitoring

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Abstract.

Driven by technology advances in low-power networked systems and medical sensors, we have witnessed in recent years the emergence of wireless biomedical sensor networks (WBSNs) in healthcare. The future will see the integration of the abundance of existing specialized medical technology with pervasive, wireless networks. They will co-exist with the installed infrastructure, augmenting data collection and real-time response. Examples of areas in which future medical systems can benefit the most from wireless sensor networks are in-home assistance, smart nursing homes, and clinical trial and research augmentation. Wearable sensors will allow vast amounts of data to be collected and mined for next-generation clinical trials. Data will be collected and reported automatically, reducing the cost and inconvenience of regular visits to the physician. Therefore, many more study participants may be enrolled, benefiting biological, pharmaceutical, and medical-applications research. Also, biosensors are key part of wearable sensors playing important roles in detecting a lot of diseases, which cause death of millions people all over the world. Their key characteristics are given below and has been mentioned some type of biosensors.

Keywords: *Wireless Biomedical Sensor Networks (WBSNs), Healthcare Monitoring, Wearable Sensors*

1 Introduction

In a wireless biomedical sensor network, hundreds, or even thousands of tiny, battery-powered computing devices are diffused throughout a physical environment. Each device is competent of monitoring—sensing—and/or displaying—actuating—Information. Sensing may include the collection of values for temperature, humidity, vibration, electrocardiogram, blood pressure, pulse, or other health-relevant data. An actuating device may cause an LED to blink, turn on lights, change colors on a display, display textual information, or any trigger other action that prompts a response or informs a human. WSNs are used in commercial, industrial, environmental, and healthcare applications to monitor data that would be difficult or expensive to capture using wired sensors. A variety of applications have been presented in the literature for wireless sensor networks.

When applied to biomedical type applications they are often referred to as wireless biomedical sensor networks (WBSNs) [7], which have a number of characteristics that differentiate them from standard WSNs and WLANs.

A WBSN device is a packaged data collecting or actuating component, which includes a sensor and/or an actuator, a radio stack, an enclosure, an embedded processor, and a power delivery mechanism. Depending on the device, it may also include an antenna. Devices are held within an enclosure. A transceiver module is a class of device that is not packaged within an enclosure. A transceiver module usually combines an embedded processor, radio stack, antenna, and sometimes sensor and actuators, usually not packaged in an enclosure. Motes and the SHIMMER baseboard are two examples of transceiver modules. A sensor or actuator module combines the sensing and I/O on a plug-in board for the transceiver module described above. By combining a transceiver module, a sensor module, an enclosure, and a battery, one would get a WBSN device.

A sensor is the small piece of technology that actually interacts with the environment and which sends an appropriate signal to the embedded processor (microcontroller unit). Thus, for example, ECG sensor will note the rhythms of the heart, and send a signal to the embedded processor. Depending on the design and the choice of technologies, the sensor may be within the same transceiver module as the processor, or it may be a plug-in addition to the transceiver module.

The microcontroller unit (MCU) may decide to forward the sensed signal to an aggregator, or to do some processing, sleep for a while, or wait until the next cycle to forward the information from the sensor. When ready, the MCU sends the signal to the radio stack; the radio stack then uses a communications protocol (e.g., IEEE802.15.4), and a transport protocol (e.g., ZigBee) with a data protocol (Continua or IEEE 11073) to pass the information to an aggregator (PC or cellular phone). The aggregator must, of course, have a compatible radio stack. The data is sent out of the radio stack to an antenna and thereby received by another antenna. The communication protocol layers transmit on a given frequency and format; for example, a 2.4-GHz FM transmission, using a 1-MHz-wide spread spectrum in the case of IEE 802.15.4.

Progression in telecommunication technology has made possible data transmission over the wireless system. This has enabled remote patient monitoring which collects disease-specific metrics from biomedical devices used by patients in their homes or other settings outside of a clinical facility. Remote monitoring systems typically collect patient readings and then transmit it to a remote server for storage and later examination by the healthcare professionals. Once available on the server, the readings can be used in numerous ways by home health agencies, clinicians, physicians, and other authorized informal healthcare care providers [2].

2 Wireless Biomedical Sensor Networks

Wireless Biomedical Sensor Networks (WBSN) is a group of wireless network comprising low powered bio-sensor devices known as "motes" or "nodes” i.e., the convergence of biosensors using network technology in wireless ambience. In principle, it is an integration of embedded microprocessors, a radio device with limited amount of data storage [3]. Recent development of high performance microprocessor and novel sensing materials has stimulated great interest in the development of smart sensors -physical, chemical or biological sensors combined with integrated circuits [4]. Although the field of biomedical sensors is relatively new, there has been numerous significant works previously where traditional sensor technologies have been applied in making biomedical measurements. This has helped to define the limitations as well as to set new direction for further research.

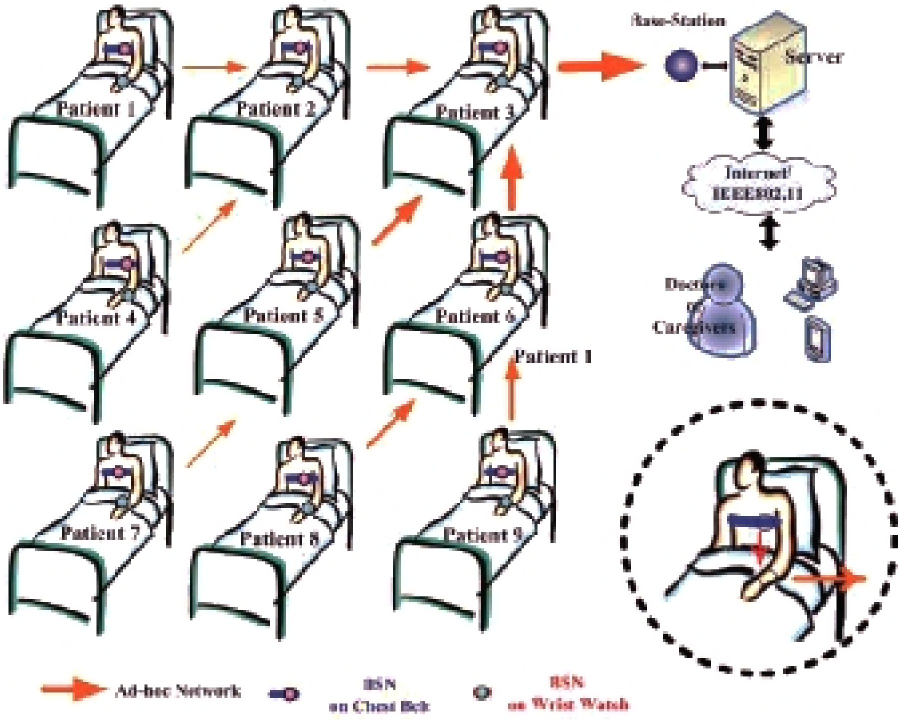

Fig. 1. Architecture of WBSNs Source [2]

WBSN, unlike wired monitoring system, can be used for long-term and continuous monitoring even when people move. The architecture of WBSN is shown above in Figure 1. The wireless mote can be integrated with various biosensors, i.e. ECG sensor, temperature sensor and etc. The physiological signals measured by the sensors are gathered by multi-hop mote wirelessly. The data acquired will be sent to server of a clinical facility via internet. The server stored the patient data into patient data base system. It is also capable of processing and analyzing the patient's data. Any abnormality detected in the patient's data at the server will produce an alert which will be sent to the healthcare professional i.e. using the short message service (SMS) system. Healthcare professionals can have access to the patient data on the server through internet using personal computer or personal digital assistant (PDA). More importantly, healthcare professional can be anywhere to access the patient data after receiving alert from the server

3 Biosensors for health applications and their principles

Biological and biochemical processes have a very important role on medicine, biology and biotechnology. In recent years, thanks to improved techniques and devices, the usage of these products has increased.

A biosensor is a device composed of two elements:

1. A bioreceptor that is an immobilized sensitive biological element (e.g. enzyme, DNA probe, antibody) recognizing the analyte (e.g. enzyme substrate, complementary DNA, anti-

gen). Although antibodies and oligonucleotides are widely employed, enzymes are by far the most commonly used biosensing elements in biosensors.

2. A transducer is used to convert (bio) chemical signal resulting from the interaction of the analyte with the bioreceptor into an electronic one. The intensity of generated signal is directly or inversely proportional to the analyte concentration. Electrochemical transducers are often used to develop biosensors. These systems offer some advantages such as low cost, simple design or small dimensions.

Biosensors are categorized according to the basic principles of signal transduction and biorecognition elements. According to the transducing elements, biosensors can be classified as electrochemical, optical, piezoelectric, and thermal sensors [5]. Electrochemical biosensors are also classified as potentiometric, amperometric and conductometric sensors. The application of biosensor areas [5] are clinic, diagnostic, medical applications, process control, bioreactors, quality control, agriculture and veterinary medicine, bacterial and viral diagnostic etc. A few advantages of biosensors are listed below:

1. They can measure nonpolar molecules that do not respond to most measurement devices
2. Biosensors are specific due to the immobilized system used in them
3. Rapid and continuous control is possible with biosensors
4. Response time is short (typically less than a minute) and
5. Practical

There are also some disadvantages of biosensors:

1. Heat sterilization is not possible because of denaturalization of biological material,
2. Stability of biological material (such as enzyme, cell, antibody, tissue, etc.), depends on the natural properties of the molecule that can be denaturalized under environmental conditions (pH, temperature or ions)
3. The cells in the biosensor can become intoxicated by other molecules that are capable of diffusing through the membrane.

3.1 Biosensors for glucose measuring

Glucose can be monitored by invasive and non-invasive technologies. Glucose sensors are now widely available as small, minimally invasive devices that measure interstitial glucose levels in subcutaneous fat. Requirements of a sensor for in vivo glucose monitoring include miniaturization of the device, long-term stability, elimination of oxygen dependency, convenience to the user and biocompatibility. Long-term biocompatibility has been the main requirement and has limited the use of in vivo glucose sensors, both subcutaneously and intravascular, to short periods of time. Diffusion of low-molecular-weight substances from the sample across the polyurethane sensor outer membrane results in loss of sensor sensitivity. In order to address the problem, micro dialysis or ultra filtration technology has been coupled with glucose biosensors.

The current invasive glucose monitors commercially available use glucose oxidase-based electrochemical methods and the electrochemical sensors are inserted into the interstitial fluid space. Most sensors are reasonably accurate although sensor error including drift, calibration error, and delay of the interstitial sensor value behind the blood value are still present [5]. The glucose biosensor is the most widely used example of an electrochemical biosensor which is based on a screenprinted amperometric disposable electrode. This type of biosensor has been used widely throughout the world for glucose testing in the home bringing diagnosis to on site analysis.

3.2 Biosensors for cardiovascular diseases

Cardiovascular diseases are highly preventable, yet they are major cause of death of humans over the world. One of the most important reasons of the increasing incidences of cardiovascular diseases and cardiac arrest is hypercholesterolemia, i.e. increased concentration of cholesterol in blood [5]. Hence estimation of cholesterol level in blood is important in clinical applications. The early evaluation of patients with symptoms that indicates an acute coronary syndrome is of great clinical relevance. Biosensors for cholesterol measurement comprise the majority of the published articles in the field of cardiovascular diseases. In the fabrication of cholesterol biosensor for the estimation of free cholesterol and total cholesterol, mainly cholesterol oxidase (ChOx) and cholesterol esterase (ChEt) have been employed as the sensing elements [5]. Based on number and reliability of optical methods, a variety of optical transducers have been employed for cholesterol sensing, namely monitoring: luminescence change in color of dye, fluorescence and others .Other cardiovascular disease biomarkers are also quantified. CRP measurement rely mainly on immune sensing technologies with optical, electrochemical and acoustic transducers besides approaches to simultaneous analytes measurement incorporated streptavidin polystyrene microspheres to the electrode surface of SPEs in order to increase the analytical response of the cardiac troponin used an assay based on virus nanoparticles for troponin I highly sensitive and selective diagnostic, a protein marker for a higher risk of acute myocardial infarction.

Early and accurate diagnosis of cardiovascular disease is crucial to save many lives, especially for the patients suffering the heart attack. Accurate and fast quantification of cardiac muscle specific biomarkers in the blood enables accurate diagnosis and prognosis and timely treatment of the patients. It is apparent that increasing incidences of cardiovascular diseases and cardiac arrest in contemporary society denote the necessity of the availability of cholesterol and other biomarkers biosensors.

The efforts directed toward the development of cardiovascular disease biosensors have resulted in the commercialization of a few cholesterol biosensors. A better comprehension of the bio reagents immobilization and technological advances in the microelectronics is likely to speed up commercialization of the much needed biosensors for cardiovascular diseases.

3.3 Biosensors for cancer detection

Cancer is the leading cause of death in economically developed countries and the second leading cause of death in developing countries. This disease continues to increase globally largely because of the aging and growth of the world population alongside an increasing adoption of cancer-causing behaviors, particularly smoking. Breast cancer is the most frequently diagnosed cancer and the leading cause of cancer death among females and lung cancer is the leading cancer site in males. Breast cancer is now also the leading cause of cancer death among females in economically developing countries, a shift from the previous decade during which the most common cause of cancer death was cervical cancer [5].

Existing methods of screening for cancer are heavily based on cell morphology using staining and microscopy which are invasive techniques. Furthermore, tissue removal can miss cancer cells at the early onset of the disease.

Biosensor-based detection becomes practical and advantageous for cancer clinical testing, since it is faster, more user-friendly, less expensive and less technically demanding than microarray or proteomic analyses.

However, significant technical development is still needed, particularly for protein based biosensors. For cancer diagnosis multi-array sensors would be beneficial for multi-marker analysis. A range of molecular recognition molecules have been used for biomarker detection, being antibodies the most widely used. More recently, synthetic (artificial) molecular recognition elements such as nanomaterials, aptamers, phage display peptides, binding proteins and synthetic peptides as well as metal oxides materials have been fabricated as affinity materials and used for analyte detection and analysis [8]. Antibodies (monoclonal and polyclonal) have been applied in cancer diagnostics tests targeting cancer cells and biomarkers. Polyclonal antibodies can be raised against any biomarker or cells and with the introduction of high throughput techniques, applying these molecules in sensors has been successful.

Breast	ER,PR, HER2, CA15 3, CA125, CA27.29, CEA BRCA1, BRCA2, MUC-1, CEA, NY-BR-1, ING-1
Bladder	BAT, FDP, NMP22, HA-Hase, BLCA-4, CYFRA 21 1
Cervix	P53, Bcl-2, Brn-3a, MCM, SCC-Ag, TPA, CYFRA 21-1, VEGF, M-CSF
Colon	HNPCC, FAP, CEA, CA19 9, CA24 2, p53
Esophagus	SCC
Leukemia	Chromosomal aberrations
Liver	AFP, CEA
Lung	NY ESO 1, CEA, CA19 9, SCC, CYFRA21 1, NSE
Melanoma	Tyrosinase, NY ESO 1
Ovarian	CA125, AFP, hCG, p53, CEA
Pancreas	CA19 9, CEA, MIC 1
Prostate	PSA, PAP
Solid tumors	Circulating tumour cells in biological fluids, expression of targeted growth factor receptors
Stomach	CA72-4, CEA, CA19-9

Table 1. Cancer Biomarker Source [5]

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4 Security Issues in Biomedical Wireless Sensor Networks.

Biomedical sensor network has distinct features, like mobility of sensors and sensitive nature of data, which aggravate the security challenges. It is important in such networks that only authorized users can query or monitor the network and that medicaldata remain protected and uncorrupted.

Security and privacy in biomedical sensor networks has not been investigated in much depth before.

The particular threats that a biomedical sensor network has to face can be categorized into outsider and insider attacks. In an outsider attack (intruder node attack), the attacker node is not an authorized participant of the sensor network.

Authentication and encryption techniques prevent such an attacker to gain any special access to the sensor network. The intruder node can only be used to launch passive attacks, like: [11] passive eavesdropping, where the attacker eavesdrops and records encrypted messages, which may then be analyzed in order to discover secret keys; [12] denial of service attacks, where an adversary attempts to disrupt the networks operation by broadcasting high-energy signals, jamming the communication between legitimate nodes; and [13] replay attacks, where the attacker captures messages exchanged between legitimate nodes and replays them in order to change the aggregation results.
More dangerous from a security point of view is an insider attack, where an adversary by physically capturing a node and reading its memory, can obtain its key material and forge node messages. Having access to legitimate keys, the attacker can launch several kinds of attacks without easily being detected: [11] unauthorized access to health data; [12] false data injection, where the attacker injects false results, which are significantly different from the true health data determined by the biosensors; [13] selective reporting, where the attacker stalls the reports of events by dropping legitimate packets that pass through the compromised node; and alteration of health data of a patient, leading to incorrect diagnosis and treatment.

4.1 Requirements for Security

Usually in wireless biomedical sensor networks (WBSN) there exist one or more base stations operating as data sinks and often as gateways to IP networks. In general, a base station is considered trustworthy, either because it is physically protected or because it has a tamper-resistant hardware. Concerning the rest of the network, we now discuss the standard security requirements we would like to achieve by making the network secure.

- Confidentiality: In order to protect sensed data and communication exchanges between sensors nodes it is important to guarantee the secrecy of messages.
- Integrity and Authentication: Integrity and authentication is necessary to enable sensor nodes to detect modified, injected, or replayed packets.
- Availability: In many sensor network deployments, keeping the network available for its intended use is essential.

Thus, attacks like denial-of-service (DoS) that aim at bringing down the network itself may have serious consequences to the health and well being of people

5 Conclusions

In this paper we have discussed the application of wireless biomedical sensor networks in medicine. We show that wireless biomedical sensor networks can be widely used in healthcare applications. This research area is in a high activity phase and in future it will be more implemented at hospitals with the only goal to help a lot of people to reach medical services quickly.
We presented architecture of WBSNs where we described detailed structure of the network. Also biosensors, their principle and applications were described, considering many types of them implemented nowadays, saving a lot of lives all over the world.
One of the biggest problems of WBSNs is security, where a lot of eavesdroppers want to "listen" traffic and capture a lot of faithful data. We have mentioned key aspects of security and described threats which can be found at networks.

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