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A REVIEW OF WIRELESS SENSOR NETWORKS: APPLICATIONS, CHALLENGES AND PROSPECTS IN BIOMEDICINE

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ABSTRACT

In this paper wireless sensor networks, their applications and challenges in biomedicine and healthcare are examined. Future prospects of wireless sensor networks in biomedicine are also examined. The methodology involves the review of related literature and synthesis of relevant information from these literatures to precipitate the application, challenges and prospects of wireless sensor networks in biomedicine. It was found that wireless sensor technologies are used generally for gathering data for medical research and for monitoring of physiological signs as well as motion analysis of patients both in hospital and at home. Numerous challenges facing wireless sensor technologies where identified. However, energy, security and privacy seemed to be the major ones. The research found that there are bright prospects for wireless sensor technologies in biomedicine and healthcare.

Keywords: network, sensor, wireless, computer, biomedicine, health.

1. INTRODUCTION

The past decade has witnessed tremendous development in wireless communication technology. A number of standards for wireless communication have also been developed over the years. A brand of wireless communication technology that is gaining prominence by the day is the Wireless Sensor Networks (WSNs). Like other wireless communication technologies, wireless sensor networks have evolved over the years especially with the growth in Micro-Electro-Mechanical-Systems (MEMS) technology that have culminated in the development of smart sensors (Srivastava, 2010). With this evolution have come new and innovative applications of WSN technologies. Some of the applications of wireless sensor networks include building automation, automotive and aeronautic applications, medical monitoring, emergency response, military applications, environmental and agricultural applications, infrastructure protection and optimisation, industrial automation and seismic detection (Neves *et al*., 2008). This research paper focuses on the medical applications of wireless sensor networks.

An increasing world population coupled with the industrialization of countries like China and Brazil have resulted in an increase in the number of elderly people around the world thereby creating a new challenge of providing a safe, healthy and sound living environment for these fragile aged people (Gaddam *et al.,* 2008). Also considering statistics from the World Health Organisation, more and more people will come down with conditions such as diabetes and obesity in the future (WHO, 2013). This means that the medical conditions of more and more people will need to be monitored in the future. This is where wireless sensor networks have proved very useful in healthcare - patients' monitoring. WSNs have been utilized in monitoring patients' vital signs both in the hospital and at home. Different wireless sensor based systems have also been designed for remote monitoring of patients. Research is still underway to develop more efficient systems to aid remote monitoring of vital conditions of patients.

Despite the marked developments that have been achieved in wireless sensor technologies, there still exist some challenges that are hindering the effective and efficient utilisation of WSNs. Some of these challenges include interoperability, reliability and robustness, privacy and security, data management, obtrusive nature of some sensors and cost *(Gaddam et al.,* 2008). As mentioned in the preceding paragraph, research is underway to develop more effective and efficient wireless sensor systems to eliminate most if not all of these challenges.

This research paper has set out to highlight the applications of wireless sensor networks in biomedicine and also the challenges facing its optimisation in healthcare. This will be achieved by a careful and guided review of literature bordering on the application and challenges of wireless sensor networks in biomedicine and healthcare. To give insight into the nature of wireless sensor networks, a general overview of wireless sensor networks is considered. Some prototype wireless sensor based monitoring systems are discussed. In the end, the prospects and future advancements of wireless sensor networks in biomedicine are assessed.

2. LITERATURE REVIEW

Quite a number of literatures on the broad field of wireless sensor networks abound. However, this section focuses on literature that relates to the applications, challenges and prospects of wireless sensor networks in biomedicine in line with the objective of this research paper.

Bonato (2010) writes that researchers first identified the benefits accruable through field monitoring of patients with Parkinson's disease in the early 1990s. Limitations in technology as at the time inhibited the realisation of this potential. Bonato stresses that researchers have continued to work assiduously to develop unobtrusive ways of monitoring vital signs with particular focus on cardiac activity. Their concerted efforts resulted in the design and development of some biomedical sensors such as the ring sensor and the ear sensor.

According to Feng (2011), wearable medical sensors are vital for health monitoring. When a group of sensors operate over a confined area such as the body of an individual, the result is a wireless body area network (WBAN) which is essentially a Personal Area Network (PAN) on a body. Feng advocates the utilisation of such technologies in collaboration with telemedicine to provide healthcare and a deviation from the in-hospital model of healthcare delivery considering its associated cost.

Work done by Ko *et al.* (2010), Chin *et al.* (2012), Alemdar and Ersoy (2010), and Neves *et al.* (2008), all highlight the applications and challenges of wireless sensor networks in biomedicine and healthcare. On synthesis of these sources, some of the recurring applications of wireless sensor networks in biomedicine include vital signs monitoring in-hospital and at-home, assistance with motor and sensory decline and medical research. On the other hand, some of the recurring challenges of wireless sensor networks include security, privacy, reliability and interoperability. The list is in-exhaustive.

Srivastava (2010) believes that in the future, wireless sensor networks will have the capability to

- integrate with existing medical practices and technologies.
- provide real time, long term remote monitoring
- be miniaturized and wearable and
- assist elderly and chronic patients.

This is a viewed shared by Patel and Wang (2010), who believe that sensor networks have the potential of revolutionising healthcare delivery ranging from emergency rooms to clinics and homes.

3. OVERVIEW OF WIRELESS SENSOR NETWORKS

In this section, an overview of wireless sensor networks is undertaken. The nature of wireless sensor networks will also be examined in this section. What really is a wireless sensor network? In order to answer this question, perhaps it is imperative to first understand what a sensor is. Feng (2011) defines a sensor as "a device that detects the presence and/or the variation of some physical phenomenon, such as voltage or current, and converts the sensed quantity into a useful signal that can be directly measured and processed". Sensors actually work with actuators. Actuators produce some kind of movement when they receive information. Some sensors are termed "smart sensors". These kinds of sensors possess additional capabilities that go beyond sensing or detecting the presence or variation of a quantity. A smart sensor may be able to process, store or make decisions (Feng, 2011).

Quantities that can be measured or detected by sensors include physical quantities (such as temperature and flow), motion (such as velocity and acceleration), contact quantities (such as force and vibration), presence (such as distance or proximity), biochemical quantities and biometric or identification properties (Feng, 2011).

Now that we have defined what a sensor is, we can attempt to answer the question raised earlier by referring to Srivastava (2010). According to Srivastava (2010), a wireless sensor network "consists of a number of sensor nodes (few tens to thousands) working together to monitor a region to obtain data about the environment."In this case, nodes may be considered as synonymous to nodes in a computer network. A wireless sensor network usually has little infrastructure. In addition, Rashid et al. (2008) defined a Wireless Biomedical Sensor Network as the convergence of biosensors, wireless communication and networks technologies that consists of a collection of wireless networked low-power biosensor devices called "motes" or "nodes", which integrate an embedded microprocessor, radio and a limited amount of storage. Wireless sensor networks have what could be considered as subsystems, two of which are very important. These are (Wireless) Body Area Networks (WBAN) and Personal Area Networks (Alemdar and Ersoy, 2010).

The genesis of the wireless communication phenomenon was in the 1980s. However, wireless sensor networks physically berthed in 1999 (Srivastava, 2010). Wireless sensor networks were originally conceived for military applications but they later found application in other areas including healthcare, agriculture, environmental monitoring and industrial monitoring (Neves *et al*., 2008). According to Srivastava (2010), there are basically five types of wireless sensor networks. These are:

- Terrestrial WSN
- Underground WSN
- Underwater WSN
- Mobile WSN and
- Multimedia WSN

The first three types of wireless sensor networks are out of the scope of this paper. The mobile wireless network is that which is employed in healthcare and biomedicine. One distinguishing feature of this type of WSN is the fact that sensors can move - or can be moved - and can interact with the physical environment. Another important fact of the mobile wireless sensor network is that sensor nodes can reposition and organise themselves in the network (Yick *et al*., 2008). Like static nodes, mobile nodes have the ability to sense, compute and communicate (Srivastava, 2010).

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The multimedia wireless sensor network is a proposed type of WSN. This type of WSN will monitor events in the form of multimedia (video, audio and images). It consists of low cost sensor nodes that have microphones and cameras embedded in them. These sensors are interconnected through a wireless network to enable data retrieval, processing and compression (Srivastava, 2010).

3.1 Characteristics of sensor networks

Sensor networks have characteristics. These characteristics are a peculiar trait in all sensor networks. Some of the characteristics of sensor networks include:

Application Specific: sensor networks are application specific. The type of sensor network to be deployed depends heavily on the intended use of the network. A sensor network used in monitoring vital signs of a patient cannot be used to monitor environmental conditions. Different sensor networks process different signals; therefore, a single routing protocol may not be application in multiple sensor networks (Yong-Min et al., 2009).

Use of a battery as energy source: sensor nodes draw energy from a battery. Power is an issue taken into consideration when deciding on the protocols or algorithm to be adopted in a sensor network. The protocols and algorithm are chosen such that they do not draw too much energy from the battery in a sensor node. Power is a major challenge of sensor networks (Yong-Min *et al*., 2009).

Processing capabilities: (smart) sensor networks have processing capabilities. Sensor nodes can perform computations and store and/or transmit data. However, these processing capabilities are limited as a result of the low energy level of the battery. Program and memory space on the sensor node is also limited (Yong-Min *et al*., 2009).

Ability to communicate: sensor networks have the ability to communicate and transmit data between neighbouring nodes within the network. Bandwidth is however limited and some environmental factors may cause interference. It is therefore a requirement that hardware employed in the network must be robust to cope with environmental changes (Yong-Min *et al.,* 2009).

Self-organisation: wireless sensor networks do not require a pre-existing network infrastructure to function. Sensor nodes in a wireless sensor network automatically and independently organise themselves into a network when once the nodes are switched on (Yong-Min *et al.*, 2009).

Multi-hop communication: sensor nodes in a wireless sensor network use multi-hop communication to communicate with other sensor nodes that are beyond their reach. In other words, sensor nodes do not just act as information receivers and senders, they also act as information routers in this regard (Yong-Min *et al*., 2009).

Dynamic: sensor networks should be dynamic. Being dynamic here refers to a situation where it becomes feasible to add and remove sensor nodes from a wireless sensor network with ease without affecting the topology or functionality of the network. This is a topical research area (Yong-Min *et al*., 2009).

3.2 Biomedical sensors

Sensors have always been used in biomedicine. Some of the sensors commonly encountered in biomedicine include thermometers, blood pressure monitors, glucose monitors, electrocardiography (EKG), photoplethysmogram (PPG), electroencephalography (EEG) and imaging sensors (Ko *et al*., 2010). Others are accelerometer/gyroscope, electromyography(EMG), respiration, carbon dioxide (CO_2) and pulse oximetry (Cao *et al.,* 2009). Table-1 gives a summary of biomedical sensors, their uses and data rates while Figure 1 illustrates the deployment of wearable biomedical sensors. Accelerometers sense and measure acceleration with reference to free fall in three axes. They can efficiently measure and register an individual's movement when positioned on the body of the individual. An alternative to the accelerometer is the gyroscope which can be used for ambulatory gait monitoring and analysis (Cao et al., 2009).

The working principle of the EMG and EEG sensors is based on the potential difference that exists between two corresponding parts of the human body. As a result of heart, muscle or brain activities and the conductivity of the human body, an electric current exists on the human skin. Hence, an EMG/EEG sensor senses and measures the magnitude of the potential drop across electrodes attached to corresponding parts of the human body (Cao *et al*., 2009).

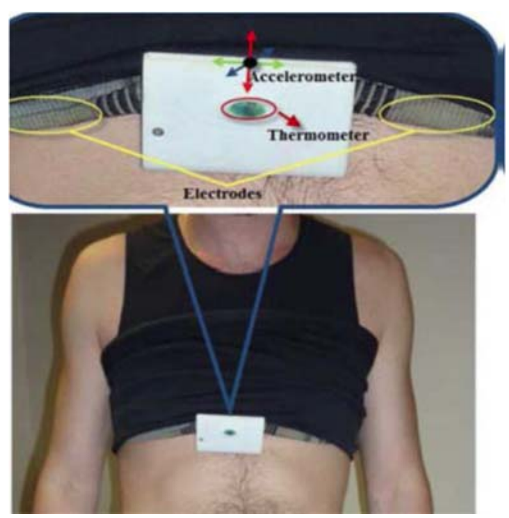

Figure-1. Deployment of wearable biomedical sensors. Source: (López *et al.*, 2010).

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Table-1. Common biomedical sensors and their data rates. Source: (Cao *et al*., 2009).

Sensor	How it works	Data rate
Accelerometer	Measures the acceleration relative to free fall in three axes.	High
Gyroscope	Measures the orientation based on the principle of angular momentum.	High
EEG/EMG	Measures the potential difference across electrodes put on corresponding parts of the body.	High
Pulse Oximetry	Measures ratio of changing absorbance of the red and infrared light passing from one side to the other of a thin part of the body's anatomy.	Low
Respiration	Uses two electrodes, cathode and anode covered by a thin membrane to measure the oxygen dissolved in a liquid.	Low
Carbon dioxide	Uses the infrared light and measures the amount of gas presented.	Low
Blood pressure	Measures the systolic pressure (peak pressure) and diastolic (minimum pressure).	Low
Blood sugar	Traditionally analyses drops of blood from a fingertip. Recently, uses non-invasive methods including a near infrared spectroscopy, ultrasound, optical measurement at the eye and the use of breath analysis.	Low
Humidity	Measures the conductivity changes of the level of humidity.	Very low
Temperature	Uses a silicon integrated circuit to detect the temperature changes by measuring the resistance.	Very low

Most medical equipment and instruments also have sensors embedded in them. In order to obtain an estimate of the features that give an indication of the state of health of an individual, biomedical sensors employ a combination of transducers (devices that convert signals in one form to another) that detect electrical, thermal, optical, chemical, genetic and other signals emanating from physiological phenomena and signal processing algorithms (Ko *et al*., 2010).

Wearable medical sensors are used to monitor certain ambulatory parameters in different fields of medicine. Some of these parameters include but are not limited to the following (Feng, 2011):

- Acceleration during exercise
- Body temperature
- Heart rate
- Body weight
- Arterial oxygen saturation
- Virtual capacity

3.2.1 Requirements for Wireless Biomedical Sensors

Wireless biomedical sensors are frequently employed in healthcare. There are certain requirements that are expected of a wireless biomedical sensor. These include wearability, reliability, security and interoperability (Milenković *et al*., 2006).

Wearability: in order to achieve unobtrusive monitoring, wireless biomedical sensors should be lightweight and small. However, the size of a wireless sensor is directly proportional to its battery size (Milenković *et al*., 2006).

Reliability: it is of critical importance that wireless biomedical sensors are reliable. They should be able to operate as expected and communicate data in a reliable manner (Milenković *et al*., 2006).

Security: wireless biomedical sensors must ensure privacy and data integrity. Security is a major challenge of wireless sensor networks and is discussed later.

Interoperability: wireless biomedical sensors should be capable of seamless integration with existing standards and systems (Milenković *et al*., 2006).

4. APPLICATIONS OF WIRELESS SENSOR NETWORK IN BIOMEDICINE

In this section, some of the applications of wireless sensor networks in biomedicine are discussed in detail. Wireless sensor networks facilitate dense spatiotemporal sampling of physical, physiological, psychological, cognitive and behavioural processes in spaces ranging from personal spaces to spaces within buildings and even larger scales (Ko *et al*., 2010). Some of the applications of WSNs include data mining for medical research, aged care, remote patients' monitoring, monitoring in mass casualty disasters, in-hospital vital signs monitoring, at-home monitoring, fall and movement detection and medication intake monitoring (Ko *et al*., 2010, and Alemdar and Ersoy, 2010). The following sections explain these applications.

4.1 Data mining for medical research

Ko *et al.* (2010) in their research paper posited that wireless sensor networks have begun to revolutionized medical data mining. According to them, body worn sensors coupled with internet enabled smart devices have enabled continuous collection of large chunks of medical data from a large distribution of subjects as they lead their daily lives. The unique ability of wireless sensor networks to provide data on the state of a subject which cannot be measured with the aid of computer assisted retrospective methods or replicated under controlled clinical and laboratory settings make wireless sensor networks a vital tool in medical research.

The role of wireless sensor networks in data mining has become very prominent so much so that the National Institute of Health (NIH) and Genes and Environmental Initiative (GEI) both in the United States hatched plans to deploy such sensing tools to objectively measure exposures to environment (e.g. occurrences like psychosocial stress, behaviours such as addiction, diet and physical activities and environmental factors like toxicants) automatically at extended periods in a participants environment (Ko *et al*., 2010).

4.2 Aged care

As people age, there is a decline in their sensory and motor capabilities. A point is reached where they can no longer take proper care of themselves and require assistance with daily living. According to Ko *et al*. (2010), there is an emergence of new intelligent assistive devices that harness information about a patient's physical and physiological states through sensors embedded in the device, worn or even implanted on the patient and the surroundings. Assistive devices such as canes, crutches, walkers and wheel chair now have the ability to fuse information through internal and external wireless sensors to provide the user with information on how to use the device effectively. Ko *et al*. (2010) further stress that wireless sensing technology has facilitated the development of assistive device with added features such as way finding and navigation.

Some systems have been developed to assist with aged care. These systems are designed to monitor activities of elderly persons such as ironing, watching television and sleeping in order to detect odd conditions and alert when they require assistance (Alemdar and Ersoy, 2010). Examples of such systems include work by Lu and Fu (2009) and the Caregiver's Assistant by Philipose *et al.* (2004). Alemdar and Ersoy (2010) reported that although the former deploys abundance of sensors in the living environment resulting in increasing cost, it is quite effective in detecting activities such as walking, listening to music, watching television, sitting and using the microwave. The later works by attaching a Radio Frequency Identification (RFID) tag to items in the user's home. A tag is also placed on the user's hand. This tag on the user's hand enables monitoring of which items the user picks and details are logged automatically on electronic daily activity forms. Health professionals are able to notice any deviations in the activities of the elderly person being monitored by carefully analysing these forms.

4.3 Remote Patients' Monitoring

Perhaps the predominant application of wireless sensor networks in biomedicine is monitoring. Wireless sensor networks provide health workers with a means of monitoring patients both within and outside the hospital. In this section, different applications of wireless sensor networks in patient monitoring are explored.

4.3.1 Monitoring in mass casualty disasters

Although quite a number of protocols for managing medical emergencies exit, these protocols may collapse with increase in the number of victims. Furthermore, the need to monitor the health status of first responders in the case of mass casualty disasters is of vital importance (Ko *et al.,* 2010). The scalability and deplorability of wireless sensor systems make them an effective tool to continuously monitor and automatically report the triage level of victims and the health status of first responders in cases of mass casualty disasters *(Ko et al., 2010*).

4.3.2 In-hospital vital signs monitoring

It is not an unfamiliar scene to see bundles of cables or wires attached to patients in hospitals in order to monitor their vital signs. This does not only cause discomfort to the patient, but it may also increase anxiety and definitely reduces the patient's mobility, restricting him or her to the confines of his or her hospital bed. In some cases, patients have deliberately disconnected such cables as a result of this discomfort. In other cases, sensors have not been reconnected as patients are moved from one part of the hospital to the other (Ko *et al.,* 2010). The application of wireless sensor technologies helps to address these drawbacks. Wireless sensing hardware eliminates the bundles of wires thereby facilitating mobility and reducing anxiety. Wireless sensing hardware are also less noticeable and maintain network connectivity to backend hospital systems while minimising occurrence of errors (Ko *et al*., 2010).

4.3.3 At-home monitoring

Conditions such as diabetes, asthma, congestive heart failure, obesity, chronic obstructive pulmonary disease and memory loss or decline may prove quite difficult to monitor. People suffering from any of these conditions do not necessarily have to stay in hospital. Taking an active role in monitoring can significantly benefit patients suffering from any of these conditions. Wireless sensors embedded in or carried on people suffering from these conditions is used to provide real time information on the physical and psychological states of the patient and can be used by caregivers to make useful

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inference on ways of managing these conditions. Such data can also be used for early detection and intervention. This is a more economical way of managing these conditions and other age related illnesses (Ko *et al.*, 2010).

4.3.4 Fall and movement detection application

Although fall and movement are classified as activity, the significant amount of research being carried out to enhance the application of wireless sensors in fall detection, posture and gait analysis makes it imperative to discuss this application in a separate section. According to Alemdar and Ersoy (2010), accidental falls is a leading cause of death among persons over 65. This explains the reason for the significant research efforts currently going on to address the situation. Quite a number of systems have been designed to harness wireless sensor networks in fall detection. Some of these systems include the Smart Home Care Network by Tabar *et al*. (2006) which is a multi-modal fall detection system with location identification technique and that proposed in Wang *et al.* (2008) which places an accelerometer on the head level and uses an algorithm to distinguish between falls and daily activities. The later addresses a major problem with fall detection systems which is distinguishing between an actual fall and other fall-like situations like jumping, lying and sitting down quickly on a chair (Alemdar and Ersoy, 2010).

An interesting application of wireless sensors in healthcare is the HipGuard (Iso-Ketola *et al.*, 2008). This is a posture detection system designed specifically for patients recovering from a hip replacement operation. It is intended to be used at home during the recovery period of eight to twelve weeks after the operation. The system has a pair of pants with seven wireless sensors for posture measurement of the operated hip. A central processing (and control) unit placed on the pants collects and analyses data from the sensors and alerts the user when the load on the operated hip approaches set limits. The user is alerted through an audible beep or a haptic vibration or both, depending on the choice of the user. The central processing unit can relay data on measurements to a cell phone or PC via Bluetooth connection or a wrist-top computer via ANT connection. Figure-2 is a pictorial representation of the HipGuard system (Iso-Ketola *et al.*, 2008).

Figure-2. The HipGuard System. Source: Iso-Ketola *et al*. (2008).

4. 3.5 Medication intake monitoring application

One common phenomenon among elderly patient is failure to take medication as and when due. Some of them forget to take their medication while others deliberately refuse to do so. Wireless sensors can help in monitoring medication intake by patients. Some prototype systems have been developed to achieve this. One of such prototype is the iPackage (Pang et al., 2009). This system has the capability of performing both remote medication intake monitoring and vital signs monitoring (Alemdar and Ersoy, 2010). This prototype uses an array of Controlled Delamination Material (CDM) films with added control circuits. The iPackage controls dosage and uses RFID for identification of the correct pill.

5. CHALLENGES OF WSNS IN BIOMEDICINE

There are quite a number of challenges preventing the optimum utilisation of wireless sensing technologies in healthcare. In this section, challenges facing the implementation of wireless sensor network technologies in biomedicine are explored.

Energy

Energy is a major problem for wireless sensor networks, not just in biomedicine but in every other field where they find application (Alemdar and Ersoy, 2010; Gaddam et al., 2008; Ko et al., 2010; and Neves et al., 2008). Since sensor nodes rely on batteries for power, it becomes a problem to provide stable power to the nodes since the batteries will always run out at some point. Alemdar and Ersoy (2010) Suggested that using rechargeable batteries may be the remedy for indoor environments. However, they point out that this may not really work with elderly people as they may forget to recharge the battery. They also state that solar power may not be a solution since sensors are preferred to be placed under clothing. They believe that energy scavenging techniques need to be adopted in addition to design of low-power sensor networks. This view is shared by Srivastava (2010).

Security

Security is another critical issue with the use of wireless sensors in biomedicine. The security requirements of a wireless sensor based monitoring system are confidentiality, data integrity, accountability, availability and access control (Alemdar and Ersoy, 2010). The need to take security issues seriously in the use of wireless sensor networks in biomedicine is highlighted by Ko et al. (2010). Ko et al. (2010) stressed that low-power WSNs are prone to security attacks because of reasons such as strict resource constraint of the sensor devices, minimal accessibility to the sensors and actuators and the unreliable nature of low-power wireless communication. Transient and permanent random failures associated with WSNs further worsen the security challenges faced by WSNs. With these vulnerabilities, it is possible for an attacker to access the network and make modifications to access rights or falsify context. This could have dire consequences such as the patient being denied treatment or even being given the wrong treatment (Ko et al., 2010).

According to Neves *et al*. (2008), attackers are motivated by benefits they may gain from data. And since biomedical wireless sensor networks are always deployed in open areas, attackers may try to jam or capture and tamper with a node in the network. He also mentions that attackers find opportunity to lunch attacks on the network through physical access or wireless communication. Srivastava (2010) adds that information acquired from nodes in a wireless sensor network should be authenticated and its integrity confirmed and users of the system should ensure that information stored on backend devices are protected and kept safe.

Privacy

Ensuring privacy is another challenge with wireless sensor monitoring systems in biomedicine. Considering the fact that physiological data being gathered with the use of wireless sensing technologies contains private information, effort should be made towards keeping such information private and protected from access without permission of the patient.

A special type of privacy leak in wireless sensor systems is addressed in Srinivasan *et al.* (2008). The attack is called the Fingerprint and Timing-based Snooping (FATS) attack. This attack can be perpetrated even with the use of encryption. To perform a FATS attack, the attacker obtains the timestamps and fingerprints of all radio transmissions by monitoring the sensors' radio. Fingerprints is a term given to a set of features of an RF waveform unique to a particular transmitter (Ko et al., 2010). With these, the attacker can link each message to its transmitter and deduce the location and type of each sensor. At this stage, the attacker can access various private user activities and health conditions *(Srinivasan et al., 2008*). Srinivasan *et al.* (2008) propose the use of hybrid schemes to counter this attack and noted that many other types of attacks on privacy in wireless sensor systems should be studied.

Gaddam *et al*. (2008) suggest the use of laws along with the principle of consent to control the flow of data to third parties. They also propose the use of privacy enhancement technologies in wireless sensor systems and proper implementation of privacy impact assessments performed by qualified personnel.

Unobtrusiveness

Since patients still have to carry sensors on their bodies for motion monitoring in healthcare, design of unobtrusive wearable sensors is still a challenge to the application of wireless sensors in biomedicine. By carrying a significant number of sensors on his or her body for fall and motion detection, the combined weight of the sensors may pose a problem to the wearer especially when it is an elderly person. To this end, research is ongoing to integrate sensors into fabric more efficiently and greatly reduce the obtrusive nature of some systems (Alemdar and Ersoy, 2010).

Interoperability

Integrating different sensors from different systems is another challenge in biomedical wireless sensor technology. This is more evident when different protocols are employed in the network. Since communication between devices in the network happens at somewhat different frequencies, there is also the problem of interference. Biomedical monitoring systems should therefore be designed with provision for interoperability between devices on the network (Alemdar and Ersoy, 2010).

Resource scarcity

The limited amounts of resources available in wireless sensor networks qualify them to be termed as scare. Wireless sensor networks have limited energy, communication and computation resources. The lean computation and communication resources can be attributed to the lean energy available to sensor nodes in a wireless sensor system. This resource scarcity means that sensor nodes are made to trade off computation and communications overhead by reducing data transmission requirements (Ko *et al*., 2010).

Data acquisition and management

The development of effective and efficient data acquisition and management techniques are of great importance in biomedical wireless sensor systems. Organising data into meaningful information at the backend in a wireless sensor system is somewhat challenging (Alemdar and Ersoy, 2010). Depending on the situation, a 3-lead ECG may not be adequate for identifying a cardiac arrest. Also, a single 3-axes accelerometer may not capture the entire activities of a patient. The obvious consequence of these cases is the increase in the number of required sensors which ultimately leads to an increase in amount of data acquired and processed (Alemdar and Ersoy, 2010). It becomes imperative to have proper data management procedures in place to handle the large chunks of data expected of such systems. Alemdar and Ersoy (2010) propose the invocation of the concepts of machine learning and autonomous systems to help in this regards.

System reliability

Medical research and healthcare applications require reliable and accurate collection and delivery of data. With reference to the work of Ko *et al*. (2010), it is safe to infer that biomedical wireless sensing systems require high levels of reliability. One of the factors that may affect the reliability of a wireless sensing system is the environment where it is deployed. Some buildings like hospitals are quite hostile environments for RF communication. Another factor that may inhibit the system reliability is the actions or inactions of the users. Quality of data obtained from wireless sensing system may be compromised not only by malfunction of the devices but by the actions of the users (Ko *et al*., 2010). Also, the performance of wireless sensing systems may be affected by artefacts placed around the vicinity of the system especially when the system is deployed at-home. Dealing with measurements collected under conditions that were not envisaged at the design stage of the system is a major challenge to WSNs in biomedicine (Ko *et al*., 2010). In order to enhance reliability, the system has to robust so as to be able to perform optimally in harsh and unexpected conditions (Srivastava, 2010).

Network coverage

Having a dense network coverage makes the area of interest to be monitored more efficiently than when there is sparse network coverage (Gaddam *et al*., 2008). Network coverage here refers to the effective range of sensors attached to the sensor node and the degree of coverage of the area of interest (Gaddam *et al*., 2008). However, having a dense network implies more cost and more sensors to manage. This increases complexity in the network and makes it more difficult to manage. It also affects the information processing algorithm. On the other hand, this may be considered a positive, as having high network coverage makes the system robust and network lifetime may be extended by switching redundant nodes to sleep or power saving modes (Gaddam et al., 2008).

Quality of service

There is a lack of Quality of Service (QoS) requirements of wireless sensing system looking from a biomedical standpoint (Alemdar and Ersoy, 2010). A MAC scheme called MACH which enables emergency traffic to meet its quality of service is presented in Benhaddou *et al*. (2008). The paper presents a scheme that provides the highest and pre-emptive channel access precedence for medical emergency traffic. However, Alemdar and Ersoy (2010) believe that QoS-aware MAC protocols still need to be studied from a biomedical perspective.

Sensitivity and calibration

Since wearable wireless sensing devices need to operate in all conditions, there is a need to develop sensors with very high sensitivity that cannot be altered in harsh conditions such as fire and when soaked in sweat (Alemdar and Ersoy, 2010). Conditions such as sweat and fire can affect the sensitivity of sensors worn in such situations. Therefore, there is need to develop self-calibration enhancement algorithms to help maintain the sensitivity of sensors at acceptable levels under such conditions. Highly sensitive vital signs monitoring sensors will become important as pervasive healthcare wireless systems evolve (Alemdar and Ersoy, 2010).

Bandwidth

The bandwidth available for use in wireless body area networks is relatively low compared to other wireless systems (Alemdar and Ersoy, 2010). Duty cycling technique employed in wireless sensing networks actually reduces bandwidth. Compression algorithms to compress data and converse bandwidth are therefore required (Alemdar and Ersoy, 2010).

Ease of deployment and scalability

The development of easily deployable wireless sensing systems is also a challenge. Systems that can accommodate increasing number of users are also required. This is where the scalability factor becomes evident. The use of wireless sensing in healthcare monitoring requires the use of a large number of sensor nodes, communication devices and software. At this point, ease of deployment becomes a problem. Such systems should be designed to enable new sensor nodes to be added to the network with relative ease without resorting to making major architectural changes to the network. Alemdar and Ersoy (2010) suggested the use of software as a service approach to achieve ease of deployment and scalability coupled with the use of small and easily configurable devices.

6. PROSPECTS OF WIRELESS SENSOR NETWORKS IN BIOMEDICINE

Despite the challenges facing the effective utilisation of wireless sensing technologies in biomedicine, there are bright prospects for the future of wireless sensing in biomedicine. Numerous researches are being carried out to overcome the major obstacles of energy, privacy and security in wireless sensor networks. Future smart home environments will have multi-modal sensor solutions. Pervasive healthcare applications will become ubiquitous.

This will be achieved through the combination of different sensing modalities with smart appliances (Alemdar and Ersoy, 2010).

The future will also see the application of wireless sensing in cancer detection. Research work is already underway to develop sensors to be placed on a needle and used to detect cancerous tumours by equipping the sensors with the ability to distinguish between different types of cells, thereby identifying cancerous cells (Neves *et al*., 2008). Wireless biomedical sensors will also find application in glucose level monitoring. It is hoped that instead of constantly pricking a finger for blood, a biosensor could be implanted in the patient once and this biosensor will monitor the glucose level and transmit results to a wristwatch for instance. For asthmatic patients, it is projected that wireless sensor networks will be deployed to monitor allergic agents in the air and alert physicians or patients themselves if there are agents that may trigger an attack in the air (Neves *et al*., 2008).

Another promising development is the plan to incorporate IP into wireless sensor networks. Research is ongoing in this direction and fruitful results are expected. There are plans to further miniaturize the size of wearable sensors (Srivastava, 2010). Integration of wearable sensor technologies with robots is also a future prospect of wireless sensor application in biomedicine. This is with the hope of providing a means of making life easier for patients suffering from complications caused by stroke (Bonato, 2010).

7. CONCLUSION AND RECOMMENDATION

Wireless sensor technologies have attracted the interest of researchers in the past decade. The reason for this has been attributed to the enormous benefit accruable through the effective and efficient utilisation of wireless sensor networks (Bonato, 2010). Wireless sensor systems have found application in biomedicine and healthcare, being used basically for gathering data for medical research and biomedical monitoring. The challenges being faced by wireless sensors in biomedicine are surmountable. With the large volume of research being conducted in the field of wireless sensors, there is hope that a sizable number of the challenges discussed in this research paper will be overcome. The future holds great prospects for wireless sensors in biomedicine. Wireless sensor systems will become ubiquitous and more efficient and effective and will significantly alter the practice of healthcare (Ko *et al.*, 2010).

As a recommendation, research efforts should be channeled towards miniaturising biomedical sensors. If possible, these sensors should be made to be of nano-scale dimensions. This will make biomedical sensing systems less obtrusive and facilitate mobility for users.

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