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# Sensor Networks and its Application in Electronic Medicine

## Detailed Analysis of its Prospects, Challenges, and Socio-Economic Impact

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***Abstract*— In recent times, there has been a tectonic shift in the manner through which medical services are being rendered and the organization of the practice of Medicine as a whole. This tremendous diversification in the techniques employed for medical service delivery has noticeably been achieved through the integration of Engineering with medical sciences and the efficient latch of Medicine on constant improvements across the field of Computer and Electronic Engineering. Treatment of patients, medical research, education, disease tracking and monitoring of public health have been efficiently optimized through innovations in Engineering. To this effect, medical practices in advanced countries have now transitioned from being largely one-to-one/human-to-human interactivity to a characteristic distributed healthcare delivery system whereby patients can receive both remote health advice as well as remote medical treatments usually through electronic gadgets operating within a standardized Sensor Network (SN) architecture. This paper seeks to explore the concept behind Sensor Networks, the technology framework, its application in the field of Electronic Medicine, prospects, challenges, ethical issues and a thorough analysis of the socio-economic impact of this new application of Electronic and Computer Engineering in Medicine**

***Keywords-component; Sensor Networks, E-Health, Medical Electronics, RTOS, Wi-Fi, Bio-sensors, Socio-Economic Impact***

## I. Introduction

As with any other initiative, the revolution of medicine through the introduction of electronic healthcare delivery and monitoring has brought about visible economic and social impact which is perceived by citizens of different countries in different lights, mostly based on how well they feel the recent innovations have improved the kind and quality of healthcare services delivered to them. Some countries like the United States of America (USA) have recently invested billions of dollars in electronic healthcare schemes. In 2009, the Obama administration approved a $27 billion stimulus package to accelerate health-care information technology in the United States [1] and countries like the United Kingdom (UK) and Netherlands are known to have been spending an average of about 8.5% of their annual Gross Domestic Product (GDP) on healthcare since 2013.

Although acceptance levels for Electronic Medicine (Information and Communication Technology based healthcare delivery) initiatives are high in many countries, Governments still seek to justify and ascertain that the required capital needed to stabilize this industry in their countries is worth the tax payers' money while also keeping abreast the possible far-reaching impact this industry might hold for the nearest future. This paper takes a holistic look at Sensor Networks (SN), its application to Electronic Medicine and seeks to discuss other important factors associated with this new form of medical service delivery.

In a nutshell, the remaining sections of this paper prove an overview of Sensor Networks followed by highlight of its application to Electronic Medicine and then concludes with a thorough analysis of the challenges, risk, ethical issues, socio-economic impact, prospects and cost-benefit analysis of Electronic Medicine to modern economies, especially the UK.

## II. Overview of Sensor Networks

Sensor networks which are either wireless or wired are a network of sensors consisting of spatially distributed autonomous devices (nodes) which use sensors to monitor physical, physiological or environmental conditions [2]. These nodes cooperatively work together to engineer the flow of measured data between themselves and ultimately to a gateway which provides connectivity back to the central processing server and in some cases, other distributed nodes. The nodes in the Sensor Network usually range from a few to several thousands, depending on the scale at which the sensor network is to be implemented and the required performance level. Most times, each node is connected to not just one other sensor, but several more, to form a star, tree, ring or mesh topology where information is propagated through either proper routing or share flooding of data [3][4]. This is made possible, as each network node has typically several technical components such as controller circuits, transceivers, batteries and electronic circuits for interfacing with the energy source and sensors.

The dynamism of operation of these components most times require the SN Architect to make important trade-offs between characteristics such as battery life, transmission data rates, security, mobility, transmission latency and maximum network range per node. As we know, higher radio data rates in battery powered systems and recurrent radio use lead to the consumption of more power, consequently the depletion of the node's battery life. In the case of Wireless Sensor Networks (WSN) - a subcategory of Sensor Networks, in order to meet the long battery life requirement, many Architects opt for the ZigBee wireless network module for the wireless connectivity of the sensor nodes and inter-node data transfer, as this networking standard offer fairly fast transmission data rate with less power consumption as against standards such as Wi-Fi and Bluetooth, even though these offer faster data transmission rates.

Ultimately, these networked sensors enable dense spatiotemporal sampling of physical, physiological, psychological, cognitive, and behavioural processes in spaces ranging from small personal space to large spaces such as in buildings. Such dense sampling across spaces of different scales has today been adapted and the concept harnessed for sensory information based healthcare applications [5].

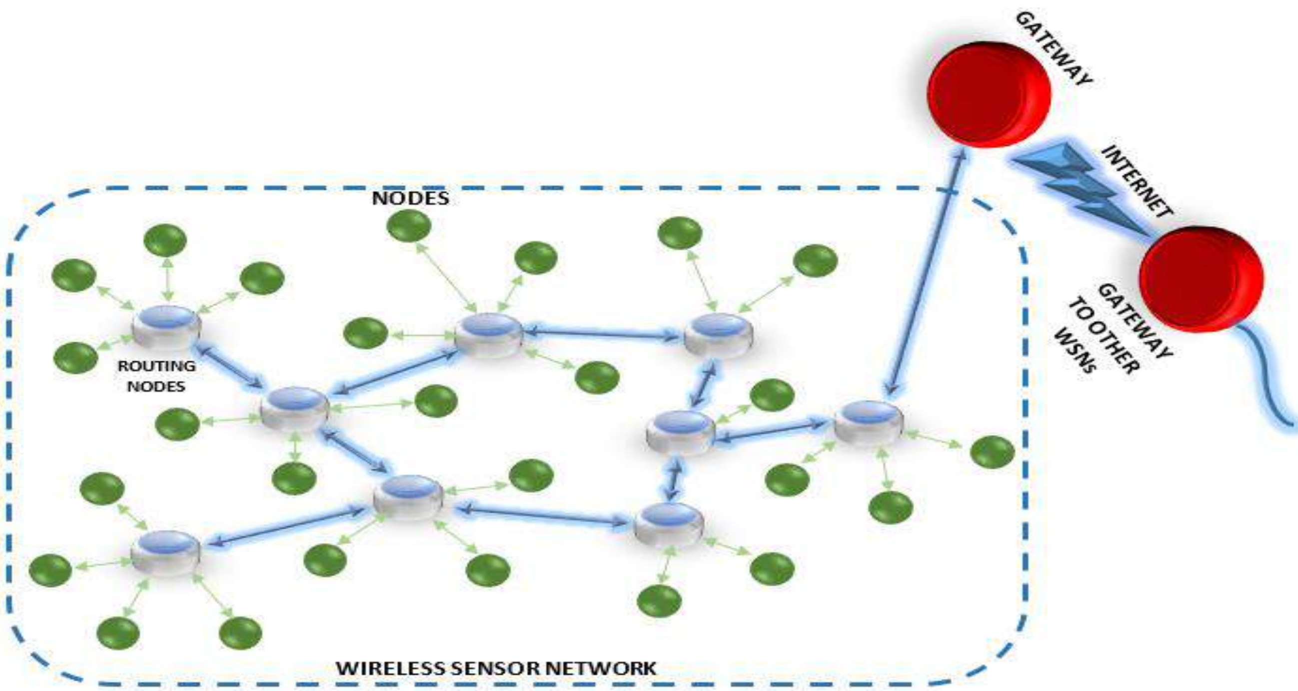


Figure 1. Modelled Sensor Network and Its Distributed Nodes

*A. Nodes, Topology and Architecture*

SN nodes are usually organized in ways which offer the architecture developer a high level of flexibility and allow for its best utilization in the desired task/domain. The sensors in the nodes are usually categorized as either physiological, bio-kinetic or environmental sensors. There are quite a number of SN topologies, however, the three major kinds of topologies include:

- Star Topology
- Cluster Tree Network Topology
- Mesh Network Topology

For the star topology, each node is designed to connect directly to a gateway while in a cluster tree network topology, each node is connected to a node higher in the tree and then finally to the gateway which connects the entire network back to the control centre. The mesh network on the other hand is designed to be more reliable, as its nodes are able to connect to multiple other nodes within the network and also pass data through the most reliable path available. Figure 2 below shows a graphical representation of the 3 major topologies.

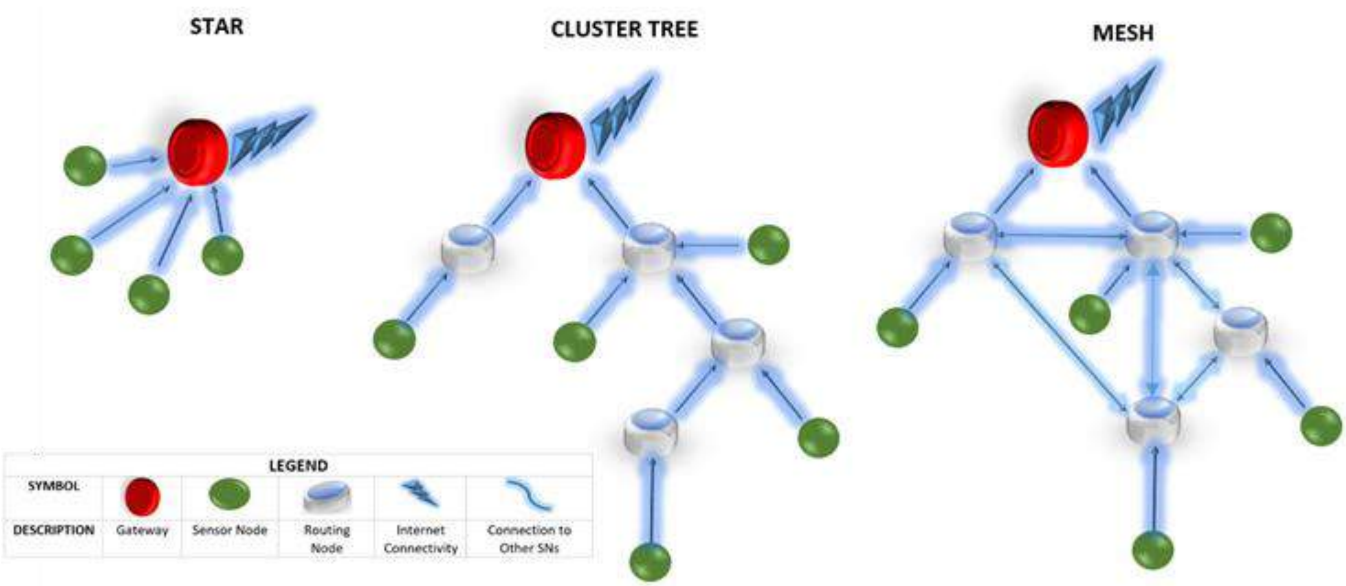


Figure 2. Figure Showing Common Sensor Network Topologies

Figure 3. below shows the diagrammatic representation of the basic components of a sensor node. These nodes usually have microprocessors/microcontrollers which operate on embedded Real Time Operating Systems (RTOS) such as Tiny OS which are responsible for managing the nodes and facilitating communication with other nodes [6].

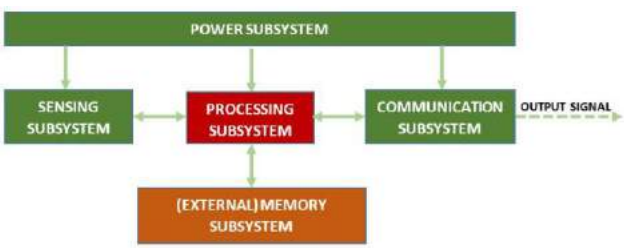


Figure 3. Block Diagram Showing Components of a Typical Sensor Node

### B. *Technical Considerations*

In building a sensor network, especially for medical purposes, various technical considerations need to be put in place, these considerations are usually classified into physical, network and continuous monitoring considerations as explained in the sections below. While SN Architect's strife to meet the long-lasting battery life requirement of the Sensor Network nodes, elements such as the size and weight of the batteries also have to be considered. Although with bigger battery packs, extended battery life can be achieved, most times, in order to extend battery life in Sensor Networks, node are usually designed to periodically sleep, wakes up, transmit required data and return back to sleep with minimal power usage. It is important to note that the processors incorporated in Sensor Network nodes are usually able to efficiently inter-switch between sleep and wake modes while still maintaining effective processing speeds.

#### *1) Physical Consideration*

Considering the fact that Sensor Networks are swarms of multiple interconnected physical devices which are usually attached to carriers (animate or inanimate), some key physical considerations are usually made during the design phase. These considerations include:

- Ergonomics
- Individual needs
- Cultural difference
- Size
- Weight

#### *2) Continuous Monitoring Consideration*

As we know, activities such as remote health supervision, emergency rescue and chronic disease monitoring all require a high level of reliability and security (data integrity & authenticity) as well as low latency and power consumption. In order to ensure uninterrupted continuous monitoring, factors such as are listed below are usually considered:

- Nodes battery life-time
- Device reliability
- Security of architecture

#### *3) Network Considerations*

Most Sensor Networks operate via wireless connectivity (Wireless Sensor Networks). In order to ensure optimal performance of the wireless transmission of data and also make sure other physical and continuous monitoring requirements/considerations are not violated, careful considerations in the following areas are made:

- Maximum range per node
- Network protocols used

- Data transmission rates of network protocol used
- Provision against interference

Figure 4 below shows a graphical representation of power consumption in relation to various wireless network standards and their output transmission data rates. It succinctly depicts how much the network considerations affect other continuous monitoring considerations (such as node's battery life) as highlighted above.

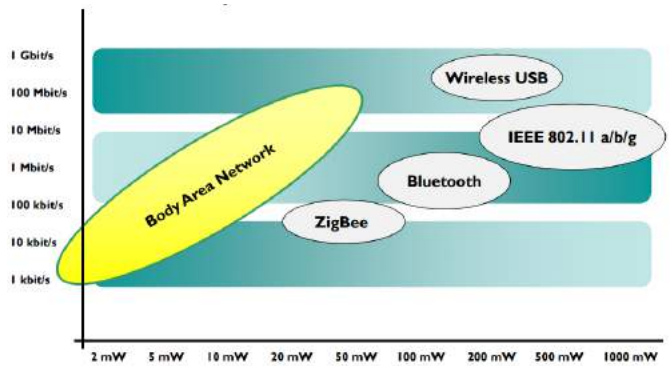


Figure 4. Figure Showing Power Consumption vs Data Rates for Different Wireless Networking Standards [7]

### C. *General Application of Sensor Networks*

In recent times, Sensor Networks have found applications in various spheres of life, few of which include:

- Healthcare
- Environmental monitoring
- Asset tracking
- Sophisticated structural monitoring

## III. Sensor Networks and Electronic Medicine

Electronic Medicine which is defined by the World Health Organization (WHO) to be the use of Information and Communication Technologies (ICT) for healthcare deliveries such as treating patients, conducting medical research, educating the health workforce, tracking diseases and monitoring public health [8] has become a prevalent method of medical practice in modern countries. It mostly involves the transfer of health resources and administration of healthcare by electronic means.

Considering the fact that SNs are distributed and self-organized network of tiny and extremely constrained nodes with sensing, processing and communication capabilities that interact with each other to carry out specific tasks [9], this model has now found many suiting applications in areas such as consumer/industrial machine monitoring, asset tracking, environmental, process and structural monitoring, electric smart grid supervision and less invasive electronic health monitoring and treatment. The power, range and memory constraint characteristic of the SN nodes poses a major challenge to the industrial and research community, especially regarding efficient deployment.

This notwithstanding, it is interesting to know that today, many healthcare devices and systems are now operated based on the SN model in forms called Biomedical Wireless Sensor Network (BWSN). These are primarily small-size Wireless Enabled Sensor Networks designed for medical applications or healthcare services [10]. BWSNs work by interfacing wireless enabled SN nodes (usually devices with biosensors on them) with patients in order to measure, monitor and transmit real-time health condition through the gateway to central data processing points which could help trigger healthcare attention from an actual medical professional or through other automated processes.

### A. *A Critical Part of Wireless Sensor Networks (Sensors)*

The nodes of SNs usually consists of one form of sensor or the other which aids in data acquisition. In Electronic Medicine, these sensors are called bio-sensors. Bio-sensors are simply sensors with the ability to detect biological molecules and communicate its gleaned information through a variety of output signals. As such, devices like this have been employed for the in-vitro diagnosis of a number of diseases and conditions. The blood sugar test devices and pregnancy test strips are evident examples. The model behind implantable biosensors is made up of:

- The Bio-recognition layer (bioreceptors and transducers)
- Transceivers
- BAN gateway/Processor
- Monitoring server/ Communicators

The biorecognition layer usually have in place a suitable enzyme or biological molecule with affinity for the target molecule, which when binding occurs in turn creates an effect for detection by the transducer. These transducers are usually able to convert biological changes to electrically interpretable forms. Transducers come in various forms based on the transduction principle being applied. The most common method is the electrochemical sensors, which apply electrochemical principles and involves techniques such as amperometry, conductimetry, potentiometry, impedance, and electro chemiluminescence, a current strategy being used in the biosensor field.

The transceivers which are usually paired with the biosensors help to receive, amplify and transmit the signals using low-consumption network to the processor. The processor in turn processes data collected into a readable form, saves it on the monitoring server (if available) and sends it to the display monitors/communicators (if also available).

The ability of biosensors to bind to in-vivo molecules (bio-receptors) is known to be an harness-able tool in drug discovery and pharmacokinetics. This tool pledges to advance on the methods by which drug-binding modes are demonstrated, hence facilitating superior predicting potential modifications and improvements on lead compounds.

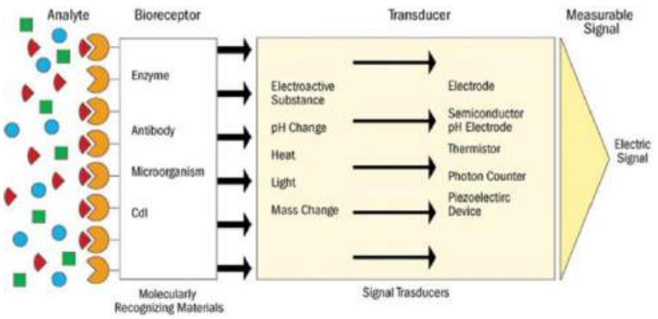


Figure 5. Figure Showing Granular Biosensor Activity [11]

### B. *Application of Sensor Networks in Electronic Medicine*

Biomedical Wireless Enabled Sensor Networks have been tipped to possess tremendous potential in improving the quality of healthcare delivery in areas of patient monitoring and emergency response. The availability of these SN model has fostered the development of new applications and services primed towards improving the quality and spontaneity of medical care administered to patients, providing even better, seamless and faster services. In summary, the major applications of SN in electronic health/medicine are highlighted in the subsections below.

#### 1) *Real-Time Continuous Patient Monitoring*

Patients with critical health conditions often need lots of monitoring, primarily monitoring of vital signs (heart rate, blood glucose level, temperature etc.). Ordinarily, this will result in the attachment of multiple monitoring devices to the patient's body which is mostly wired [12]. For this application, BWSN-based Electronic Medicine devices are built to help monitor (multiple) patient's vital signs without having to jumble them up with loads of wires. BWSN-based devices in this area basically serve as replacements for wired medical monitoring devices.

#### 2) *Home Monitoring For Chronic Diseases and Elderly Patients*

In many countries today, many aged and elderly people are not chronically ill, but however, require healthcare in one way or the other. Rather than filling up hospital beds with non-critically ill people who need less help, BWSN-based medical devices have been created which can help with the routine collection of patient's health status data to help track condition and also allow for the possibility of carrying out long-term trend analysis of patient's health conditions. A typical example of this is the SENSIMED-Triggerfish BWSN-based device which provides an automated recording of continuous ocular dimensional changes over 24 hours. It uses a soft disposable silicon contact lens which has an embedded microsensor in it used to capture spontaneous circumferential changes at the corneoscleral area (around the eyes). An adhesive antenna which is placed around the eye receives wirelessly the information from the contact lens and transmits it to a recorder and other ad-hoc devices for further processing [13].

#### 3) *Collecting of Long-Term Database of Clinical Data*

Since Sensor Network-Based devices communicate most times with a central processing server used for data processing, storage and recommendation generation, meaningful data related to a patient's health can be seamlessly accumulated over time, and correlation can be made between the patient's data to other patients within the same class (e.g. age range, economic status, race etc.). In essence, longitudinal studies across populations can be carried.

#### 4) *Assistance With Motor and Sensory Decline*

New Sensor Network-based devices such as the smart spoon in [14] and the soft robotic gloves designed by Wyss Institute for Biologically Inspired Engineering and the Harvard School of Engineering now exist. For example, the soft robotic gloves help people suffering from loss of hand motor control to regain some of their independence by making use of information about the patient's physiological and physical state (gleaned through streams of attached sensors) to provide adaptive medical assistance to the patient [15]. Increasingly, typical assistive devices such as walkers, wheel chairs, and crutches are now built to fuse in sensors and other artificially intelligent components which can use information from built-in and external sensors to provide the users with continual personalized feedback and guidance towards the correct usage of the devices [16].

### C. *Biomedical Wireless-Enabled Sensor Network (BWSN) Peculiarity*

It is important to note that the Sensor Networks have been adapted in electronics medicine, primarily making use of sensors around the body operating within a Body Area Networks (BAN). This BAN is interfaced with a mobile phone/technology which serves as the immediate personal server for data processing as well as a gateway for the BAN sensors to other BANs and the central computing server which processes, interprets the data received, and forwards the extracted information to the medical service provider for appropriate medical actions. At times, E-Health devices working within the BAN are able to receive feedback information remotely and also take some required first aid action in the case of critical health conditions. Figure 5 below shows a typical BWSN architecture designed to work outwards from within a BAN while Figure 6 shows the implementation of the three major Sensor Network topologies on a human body.

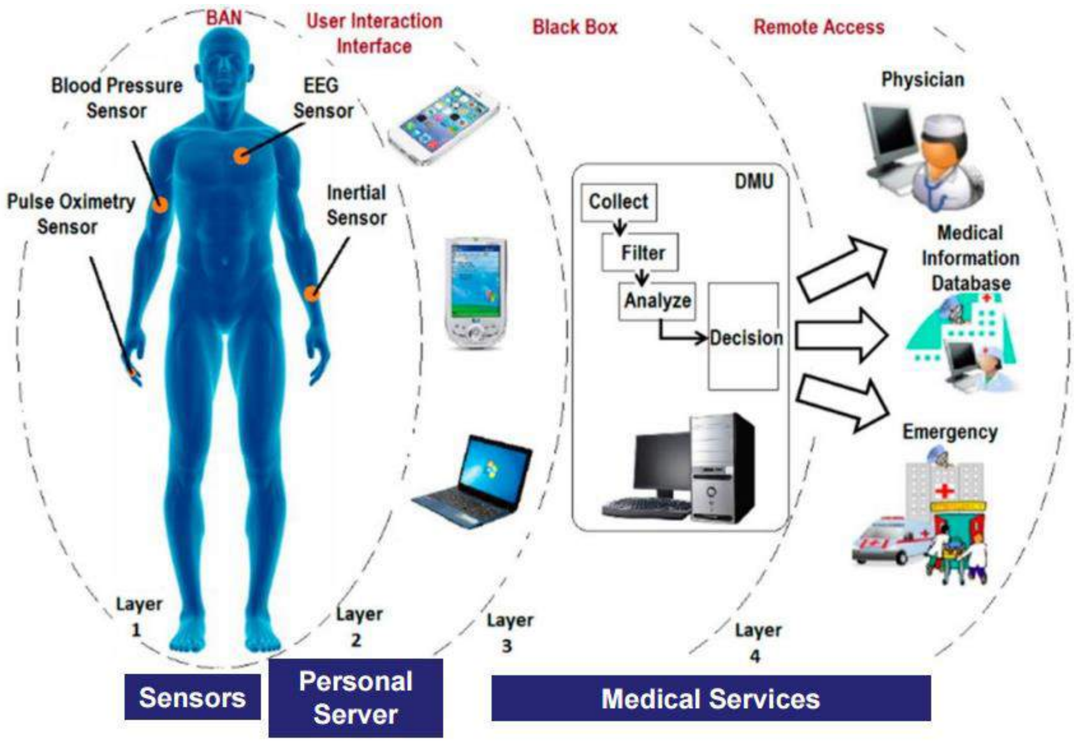


Figure 6. A Typical BWSN Architecture Designed to Work Outwards from Within A BAN [7]

Table 1 below shows in a tabular form the main differences between a regular Wireless Sensor Network implemented for an outdoor or industrial application against an adapted version (BWSN) which is usually implemented for medical purposes.

TABLE I. TABLE JUXTAPOSING BWSN ARCHITECTURE SPECIFIC REQUIREMENTS AGAINST NORMAL SENSOR NETWORK'S

| *S/N* | *Sensor Network* | *Biomedical Wireless Enabled Sensor Network* |
|---|---|---|
| 1 | Mostly covers the environment | Covers the human body |
| 2 | Large number of nodes | Fewer sensor nodes |
| 3 | Multiple dedicated sensors | Single multitasking processor |
| 4 | Low accuracy | Robust and accurate |
| 5 | Medium security needed | High level of security needed (patient's data involved) |
| 6 | Data loss, less of an issue | Sensitive to data loss (every data is critical) |

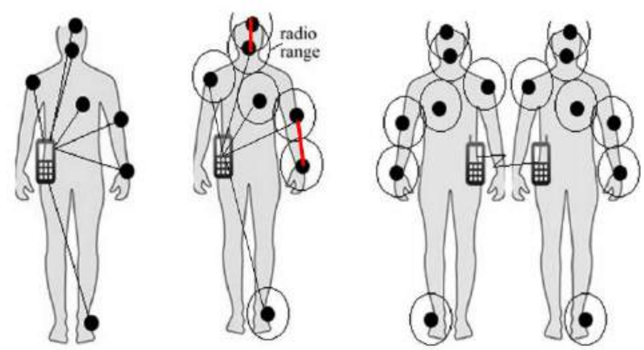


Figure 7. Figure Showing Different Sensor Network Topologies on a Human Body [7]

### D. *Case Study (Google Smart Contact Lens)*

Google's smart contact lens monitors and tracks user's glucose level and send the gleaned information to a mini server (e.g. a mobile phone) device wirelessly for processing and feedback, making the task of monitoring sugar levels far easier. This Biomedical Wireless Enabled Sensor Network-Based Medical Electronic device is believed to be a seeding element for many more such similar BWSN devices that will spring up in the coming years.

Figure 7 below shows components which make up the smart contact lens.

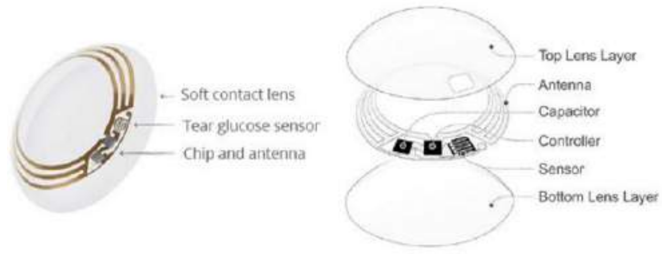


Figure 8. Figure Showing Google's Recently Launched Smart Contact Lens [17]

### *E. Drivers of Sensor Network Application in Healthcare, Challenges and Ethical Issues*

Factors such as aging population, chronic diseases with the need for early diagnosis and prompt medical actions remain the key drivers of the tremendous level of growth the Electronic Medicine industry has witnessed in recent years. However, challenges still exist in areas such as data heterogeneity and energy limitations in implantable nodes which most times result in the need for frequent replacements. The importance of the kind of data BWSNs carry dictates the need for a high level of Quality of Service (QoS) in order to maintain patient's data privacy. However, considering the fact that internetworked devices can easily be hacked, this level of data integrity and authentication cannot be guaranteed. In a nutshell, the main ethical issues resulting from the use of Sensor Networks in Medical Service delivery include:

- Patient-to-Doctor Gap
- Data Privacy Issue
- Hacking and Manipulation

Patients now increasingly rely on the recommendations of this devices on many occasions as against thorough consultation with the doctor. Data stored and transmitted by the SN nodes are expected to remain private, however, there is no guarantee that these transferred data have/will not be breached. Sensor Networks-Based devices can be and manipulated to provide wrong recommendations to patients [18]. For cases like this, it remains an ethical issue as to who it is to blame for resulting mishaps.

Despite the recent advances observed with BWSNs, notable risks still remain which cannot be overlooked and for which precautionary measures must be taken by system architecture designers as stated by European group on Ethics in Science and New Technologies. A few of these risk areas include.

- Incompatibility and adverse tissue reaction
- Migration of implanted device
- Electromagnetic interference
- Failure of the system and need for replacement surgery

In dealing with the current risk, advancement in research for more miniaturized devices which still need to be powered has prompted the research and development of alternative power sources, as power supplies such as batteries are difficult to miniaturize and need a design that factors in easy replacement or recharging. Hence BWSN devices are being re-evaluated to factor in proposed self-powering mechanisms based on chemical-to-electrochemical energy transformations in biofuel cell (BFC) elements [19]. Self-powered bio-sensing have three proposed classes based on the basis of biocatalyst such as microbial fuel cells, enzymatic BFCs and mitochondrial BFCs. Successful development of such BFCs would greatly reduce risks associated with implantable devices such as implant failure, replacement due to dead power supply, electric hazards and the need for an external power source.

Proposed self-powered biosensors will be able to produce sufficient energy for signaling and need no external source nor metal catalyst. Other biological molecules could be used to control them as modulators, which will either inhibit or activate the catalyst

## IV. Prospects And Socio-Economic Impact Of The Application Of Sensor Networks To Medicine

Currently, about 8% of the United Kingdom's (UK) Gross Domestic Product (GDP) is spent on healthcare, sharing over £120 billion in the 2016/2017 annual budget [20]. Although we know that no healthcare system anywhere in the world has really achieved levels of spending sufficient enough to meet all its citizen's healthcare needs [21], research has shown that with the huge chunk of the healthcare budget spent on medical research all across the country, the area of Electronic medicine will only continue to grow as an increasing number of citizens now opt for ICT based medical services on a daily basis. Figures 8 and 9 below give more insight into the recent large-scale financial investment made by different countries on healthcare.

The negative effect of the ever-present scarcity of resources (limited time of surgeons, bed spaces, specialized equipment) has in recent times been cushioned by the effectiveness of electronic medicine which has been made possible via the implementation of sensor network based models of healthcare delivery for adequate patient monitoring, education, record keeping and at times first aid administration in emergency cases. Cost-effectiveness analysis has shown improvement in the number of life years saved since the recent massive introduction of e-health devices/medical electronics into the UK medical industry and other countries such as the Netherlands and USA [20].

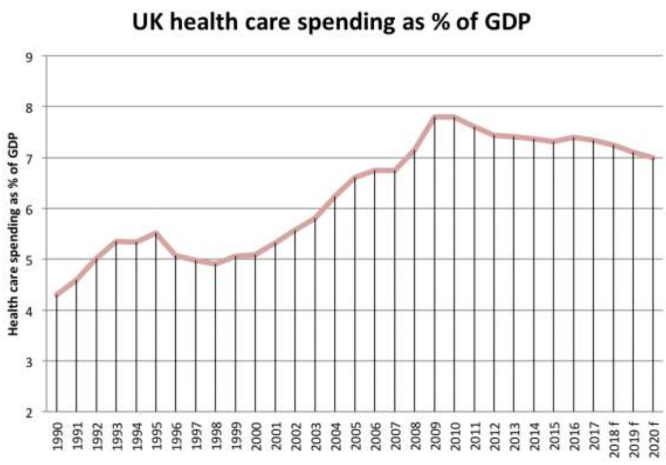


Figure 9. UK Healthcare Spending as a Percentage of GDP (1990 to 2020) [22]

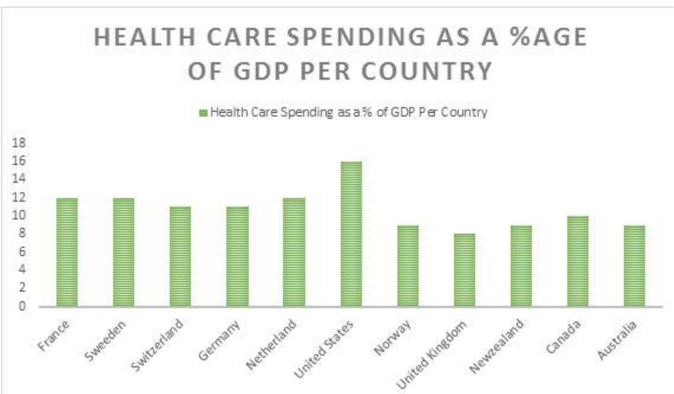


Figure 10. Chart Showing HealthCare Spending as a Percentage of GDP for Different Countries in 2013 [23]

## V. CONCLUSION

It is indeed a fact now that spatiotemporal sampling of physical, physiological, psychological, cognitive, and behavioural processes through the use of networked sensors have now been reengineered and made applicable to the field of Medicine. They have also gained firmness and are increasingly becoming standard options for handling some healthcare procedures. Although both technical and ethical challenges still exist in the efficient and effective deployment of networked sensor nodes for medical activities, it certainly has proven to provide positive cost effectiveness.

Over the years, European, Asian and the American countries have consistently invested billions into their healthcare sectors, much of which has ended up funding researches towards the improvement and standardization of various Sensor Network Based medical models. Indeed, the application of Sensor Networks in Electronic Medicine is now well grounded and is definitely here to stay.

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