Reliability and Quality of Service Issues in Wireless Body Area Networks: A Survey

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***Abstract*—In the modern living era, changing peoples' life style and aging have subjected human kind into many health risks. It is therefore necessary to monitor individual health status for timely preventive and emergency health care services. Advances in micro fabricated electromechanical devices (MEMs) and related technologies, envisaged development of miniaturized wireless devices for remote health monitoring and diagnosis. Today, proper functioning of the vital organs of the human body such as; kidneys, lungs, heart and brain activity can be monitored through measuring related parameters using biological sensors. Wireless Body Area Network (WBAN) technology use IEEE 802.15.6 standard for Health monitoring based on RF or non-RF communication schemes. Using this standard, miniaturized MEMs can measure, aggregate and communicate vital body organs' health information. Ensuring healthy organs guarantees for extended biological life time, however monitored information may be hindered by many factors over a wireless link. In fact, efficient data communication depends on the network infrastructure model and link management. Extreme network or device failures constraints data packet communication due to irregularities in frame structure and link reliability. In broad aspect, WBAN are mainly challenged by link reliability and overall quality of service. The major contribution of this paper is provision of overall survey on current development, network reliability and QoS challenges as well as some open issues in WBAN.**

***Index Terms*—electromechanical devices (MEM), remote health monitoring, wireless body area networks (WBAN), reliability, quality of service (QoS)**

I. Introduction

Apart from biological reasons, aging and changing human life styles are contributed by many factors including; long work hours, unhealthy eating, genetics, heredity, smoking, and other health endangering habits. Changing life styles or aging increases risks of exposure to degenerative chronic diseases like; cardiovascular diseases, cancer, diabetes mellitus, parkinson's and leprosy to both elders and youth.

Modernization in health sector leverages for efficient provision of health care services and timely delivery of medical attention to sports-persons, prenatal and premature babies, elders and the sick. Previously, health monitoring systems to hospitalized patients, emergency rooms and in the Intensive Care Units (ICU) were completely wired and therefore limited mobility of both patients and care takers.

Prolonged bed rests and hospitalization is costlier and most likely subjects the sick to the risk of other communicable diseases. Wireless based monitoring alternative have been advantageous to patients as it leverages for bed rest costs. It also allows health recovery through monitored physical training for the sick within or away from the health care premises.

Wireless body area networks are such that, miniaturized biological sensors and transducers are attached near the monitored vital body organs. Biological sensors measure various body parameters and transmit sensed data packets to the coordinators, sometimes known as motes. Motes are WBAN devices which relays data packets between monitored vital organs and central health information management unit for automated decision support.

Biological sensors can be positioned as surgical implants such as Radio Frequency Identifiers (RFID) or body surface sensors and sometimes as wearable devices. While surgical implants are placed under the skin or near respective body organs, surface sensors are attached on the skin surface near or around the monitored body organs. Wearable sensors are worn by the body in the form of wrist watch like device or as textile attached with a number of sensors.

WBAN are such that, at a specified time interval sensed data are stored in the coordinators before forwarding to the health care information management units. Based on the originality, sensitivity and priority setup of the wireless channel, data streams in the communication channel forms big data sets characterized by non uniformity, varying data rate and frame size over a limited bandwidth.

Like in Big data, WBAN data streams suffer from interference, packet dropout, data error rate, packet collisions and shorter link lifetime. These factors questions for network throughput, energy efficiency and therefore network reliability and quality of service.

II. System Architecture of WBAN

Wireless body area networks can be presented in four different system layers over a wireless link. System layers are sometimes known as tiers as depicted in "Fig. 1" [1], [2]. The layers are such that; layer one is composed of the

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coordinator and sensor nodes attached into the body as surface contact transducers, wearable devices or implants. It includes MEM devices for measuring various body parameters such as; temperature, heart rate, SPO2, blood sugar, ECG and EEG. Mote aggregates biological sensor information.

The second layer consists of the personal data acquisition devices linked to sensors and transducers through a wireless network. It acts as a local data acquisition and temporary storage device using smart phones or PDA. Collected health information in the coordinators are forwarded to the central processing units in a random or delay based fashion through WiFi, GPRS or other RF technologies.

The third layer consists of the data storage, processing and management units for assessment, analysis and decision support to emergency service units and experts. Through this layer, acquired data from body vital organs are processed using various digital signal processing techniques such as data compression, pattern matching, segmentation and other recognition techniques.

Fourth layer is composed of databases, physicians desk and emergency services infrastructure. It is where final measures and decisions are taken after assessment of the health records. Experienced physician further review complex situations based on experience.

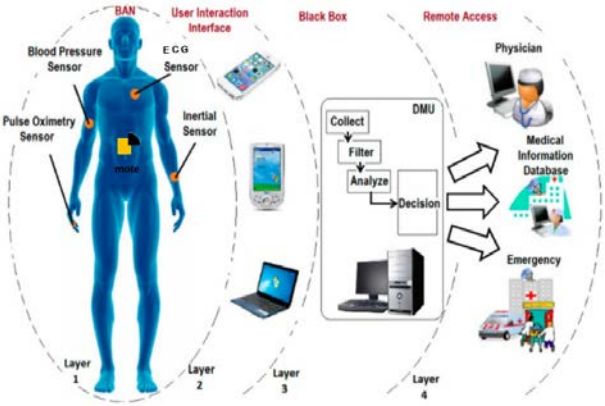

Figure 1. System architecture of WBAN.

III. Applications of WBAN

Recent growth in WBAN research unfolds many application areas in health information monitoring and security. Wireless Body Area Networks have found many applications in different application fields among which are; health monitoring of the proper functioning of the vital organs of the sick and elders. In sports, WBAN are used to monitor athletes' health status during training and rehabilitation after injury; in military, WBAN are used to monitor stress and health status of military troupe in the battle field; wireless personal and body area networks can also be used to monitor hazardous conditions and risks of exposure to radiation over the radiating physical environment, monitoring growth of the prenatal, neonatal and premature babies. In medical imaging wireless sensors are used to take x-ray picture of sensitive parts of the body like the mouth cavity in diagnosing root canal and other related medical problems including cancer diagnosis [3], [4].

WBAN can be used to acquire and aggregate information about various habits of the monitored individuals, this includes smoking, mobility and falling incidences using special bio-kinetic sensors fixed in predetermined parts of the body. Analysis of the collected information penalizes monitored person habits using machine learning classification techniques based on previous normal data.

IV. Reliability and QoS Challenges in WBAN

Health monitoring is life sensitive issue; therefore, matters pertaining real time health information must be processed with freshness and higher accuracy. Despite the recent development, WBAN still faces some challenges. As of this paper, challenges in WBAN are categorized into; data privacy, information processing, transmission channels, energy efficiency, specific absorption and faults.

A. Data Privacy

Security threat is the primary challenge of the WBAN. Handling of the health information of an individual requires observation and compliance to human rights on private matters. Any breach of individual's private health information confronts personal privacy and legal rights. Health information are confidential and must be securely used or stored unless under personal consent on disclosure.

Upon designing WBAN, it is necessary to observe network security against any intrusion, scams or possible data leakage. Network security for WBAN remains an interesting research challenge since deployment of technology in the future health care setups grows with increasing number of users.

Instilled research on secure routing and efficient authentication techniques on data access and transmission would leverage for possibilities in data security threats.

B. Information Processing

WBAN contributes huge volumes of data streams throughout the network and into the repositories of the health information management systems. However data from different motes may have ambiguities due to its incompleteness, varying data rates and jitters.

Remote monitoring is challenging as far as processing of the information requires fresh data for emergency services, higher accuracy of the decision support systems and experienced physicians when data patterns have ambiguous features.

Most of the WBAN research focused on network routing issues with limited attendance to information processing in the wireless channel. Huge volumes of data constraints bandwidth requirement and therefore increases network susceptibility to packet collisions, delays and outlier formation.

Design of efficient coding algorithm, data sampling and low weight data compression software in WBAN will leverage for limited bandwidth and therefore reduce

packet collisions. Outliers in data sets may result into poor medical diagnosis and as a matter of fact, data from different sources may have discordant, therefore effective outlier detection and elimination in WBAN information is necessary.

C. Specific Absorption

As nodes relay data between network layers, they require energy which is also dissipated in the form of heat. Dissipated energy is absorbed by body tissues. Dimitris J Panagopoulos and George L. Carlos defined specific absorption rate (SAR) as "the amount of absorbed non-ionizing radiation power (or rate of absorbed energy) by unit mass of biological tissue". Due to increasing number of users of wearable devices and implants, researchers are highly challenged by users' safety based on expected hike in radiation.

Tissue specific absorption depends on different factors including; tissue geometry, dielectric property and body orientation relative to the signal sources. Minimization of radiation effects requires proper selection of radiating materials with less weight and low radiation for wearable and implants' antenna, since body tissues are easily damaged by prolonged extreme heat from radiating materials.

There are other challenges in material selection, design and positioning of light weight antennas with better directivity and radiation patterns while striving for optimized network performance subject to minimizing radiation effects and signal attenuation.

D. Transmission Channel

Data transmission channel for WBAN plays important role to bridge information between source and destination. Upon configuring a wireless channel, factors for security, modulation technique, data packet processing and bandwidth requirements of the transmission channel must be considered. BAN may have one to several wireless sensors (nodes), its transmission bandwidth requirement varies according to the type of monitored body parameter as stipulated in Table I [5].

Data transmission in Medium Access Control (MAC) is mainly governed by two main policies; Time division Multiple access (TDMA), a contention free technique where nodes do not compete for transmission bandwidth instead the bandwidth is equally distributed by assigning time slots to each transmitter; Carrier sense Multiple access with collision avoidance (CSMA/CA), a contention based channel access technique where nodes will compete for the transmission bandwidth in a condition that one node will transmit data only when the transmission channel is free.

In line with the governing policies nodes can be configured with priority for specific information with emergency cases. However TDMA is less tolerant to network dynamics despite its capability to support high traffic compared to CSMA/CA, therefore CSMA/CA is much preferable in handling emergency data regardless of its higher energy requirements.

From table we observe that, modeling a wireless channel to handle varying data rates while maintaining better throughput and delay performance of the WBAN for real time events, is challenging with limited channel resources available.

TABLE I. STANDARD DATA RATES AND DELAY IN WBAN

Application	Data Rate	Delay
ECG (12 leads)	288 kbps	250 ms
ECG (6 leads)	71 kbps	250 ms
EMG	320 kbps	250 ms
EEG (12 leads)	43.2 kbps	250 ms
Blood saturation	16 bps	250 ms
Temperature	120 bps	250 ms
Glucose monitoring	1600 bps	250 ms
Motion sensor	35 kbps	250 ms
Cochlear implant	100 kbps	250 ms
Artificial retina	50–700 kbps	250 ms
Audio	1 Mbps	100 ms
Video	<10 Mbps	100 ms
Voice	50–100 kbps	100 ms
Motion sensor	35 kbps	250 ms

E. Energy Efficiency

Performance of the network is mainly determined by several factors including; its lifetime, delay and throughput. Wireless body sensors are battery powered therefore any power constraints affects their proper functioning. Considering their size and working environment, it is difficult to replace depleting batteries.

Designing light weight durable batteries will help to improve reliability of the network links and therefore overall network performance. Apart from the battery capacities, issues which may cause short life time of the WBAN are; data transmission and reception rates, poor network routing, long distance transmission and network or device faults.

Network devices consume energy at the instant they receive or transmit data, energy consumed is dissipated in form of heat, the frequency with which a network device will transmit or receive data threatens battery life time. Similarly, as the transmission distance increases so does the energy requirement. However, different routing techniques have been proposed by researchers to minimize power consumption as well as network delays using random forests and ant colony algorithms.

Shortest path transmission serves energy consumption in one way but also depletes the battery along the dedicated path very fast.

Depleting energy on the network devices may result into network delays, link drop out, transmission loss and outliers formation in data sets. This affects overall performance and quality of service of the WBAN.

F. Faults

Wireless sensors are usually left unattended for long time and therefore remain prone to failure. A sensor failure result into poor data quality which subsequently affects overall system functions.

Main causes of faults in WBAN are originated from device itself or a network. Device faults can happen due to nature of the working environment such as overheating，aging or technical malfunctioning based on the design model.

Network faults are caused by factors including but not limited to; specific absorption rate, overhearing, power depletion in the node or other network devices. Faults result into link dropout or discordant in data sets which subsequently affects medical diagnosis, predictive analytics for health status of individuals and general network performance.

V. Literature Survey

Based on Moore's law, sensing electronic devices are currently miniaturized and more functional. Therefore, remote health monitoring through WBAN become less complicated due to modern technology. WBAN plays a role in big data as network nodes streams data into health care information management systems.

Measurements of various body vital organs including electroencephalograph, echo cardiograph, blood oxygen saturation (SPO2), blood sugar, body temperature among others is now simplified for predictive and emergency health care services [6].

Emergency health care services make use of the collected information for prognosis and predictive health whose impact are to advise and for emergency health care provision to threatening health conditions before severity [7].

As a matter of fact, due to varying network link characteristics, data streams may have variations in a reason of; errors in measurement, interference, data loss, collisions and incompleteness [8]. Varying characteristics in data affects network performance and overall quality of service.

Deployment of WBAN is currently very common with predicted gradual growth in the near future. Using normal values of the functioning of respective body organs, experts may asses health status of an individual by comparing measured parameters from their normal operating conditions for example P, Q, R and S tress of an ECG [9], [10], detected discrepancies as a result of the physical condition during measurement penalizes for unhealthy condition.

Network delays are mainly caused by large super frame size requiring higher transmission bandwidth [11]. Channel bandwidth is one of the limited network resource, in fact some of the medical information requires immediate retrospective action towards threatening health condition of the monitored individuals. Minimization of the bandwidth requirements envisages for low latency through deployment of the best data compression techniques, and prepossessing before transmission [12].

Prior to transmission, lightweight software can detect and eliminate anomalies in data, this will avoid erroneous prognosis by the decision support devices. Information processing using machine learning techniques can leverage for efficient usage of the transmission channel, improve data rate and network throughput [13], [14].

Body sensors are very tiny battery powered electronic devices, hence battery replacement is nearly impossible. Rising demands for designing lightweight long life batteries will reduce link dropout and network delays in the future [15], [16]. Similarly, since energy is a scarce resource, properly designed routing policies leverages for energy requirements of WBAN, this may include energy aware, temperature aware and cluster based routing policies [17].

Body implants and wearable sensors suffer from severe data losses due to moisture, dielectric constant of the body tissues as well as of the radiating materials. Body tissues hinder propagation of the radio frequencies due to absorption, however extreme radiation results into tissue damage and therefore affect overall purpose [18].

Varying properties of the radiating materials challenge researchers on the proper design and size of the data transmission antennas with minimum losses [19].

Network link dropout happens when network devices malfunction, this can happen when nodes become inactive because of depleted battery or damaged devices as a result of aging or environmental factors, Faulty network may also result into erroneous data streams [20]. However, fault detection in WBAN can use similar approach as of WSN which includes comparison analysis of sensor data based on past experience although it is difficult to differentiate data from device fault [21].

Data privacy is highly compromised in WBAN since patients' data are confidential unless under mutual consent between patients and service providers. It is necessary to enhance security measures both in the network and in the repositories in order to maintain privacy and integrity of the service providers [22].

Mobility in WBAN hinders signal transmission, when network nodes changes its position it may sometime come closer to other devices. When two neighboring nodes transacts data they may both transmit towards the immediate relay node and hence it overhears. This results into packet dropout [23].

VI. Open Issues in WBAN

WBAN is an interesting research field emerged within wireless sensor networks whose applications mainly focus on health monitoring. Despite its recent advances, WBAN faces many challenges in need of further attention.

Security and privacy concerns for the WBAN remains an open research challenge since health information records requires higher confidentiality for personal data privacy and integrity of the service providers. This includes data security at the moment of data transfer along the communication channel or access to data from the repository by authorized users. Since data can easily be intercepted or jammed, security measures should

carefully focus on scams which may lead into poor diagnostic measures for critical health conditions.

WBAN are networks of very few sensors compared to traditional WSN, data transmission can be of the RF or non-RF nature. For body implants, data transceivers are embedded with light weight radiating metallic elements. Upon data transmission and detection, radiated heat is absorbed by the body tissues. This endangers tissue survival and therefore health of the monitored individuals. Special consideration on the selection of materials and standard design criteria will ensure mobility and safety. This is inline with antenna positioning, body orientation and handover consideration for WBAN.

Long link lifespan ensures extended network operation and better performance. The structure and size of the body sensors limits replacement of the batteries and therefore hinders link stability when batteries depletes. However, there is a need for continued research on energy aware and routing protocols for WBAN.

As lots of recent studies focused on the networking part of the WBAN, a little has been focused on the information processing including data sampling, compression and coding. Machine learning techniques in designing low weight software for data pre-processing and predictive analysis of the health information records in WBAN has not been eyed deeply. Low weight software would leverage for energy consumption and network routing.

VII. Conclusion

In this paper we have summarized some of the application areas of WBAN, Also, we have highlighted key challenges for WBAN in health monitoring and discussed some of the open issues which calls for further research. However, there are other areas where with current advances in technology, issues like interference on the transmission channel, inter BAN interference and data aggregation remains open for future research.

Considering efficient network operation while avoiding or reducing aforementioned constraints will ensure reliable network, better quality of service and performance.

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