SMART: An Improved Wireless Body Area Network

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Abstract- Wireless Body Area Network (WBAN) has added a new dimension to modern technology. Research works related to WBAN has gained much popularity. This paper focuses on implementing a new WBAN model based on M-attempt and SIMPLE. Our proposed model is reliable, energy-efficient with higher throughput which improves the routing protocol for WBAN. This model deploys more sensors and positions them in a suitable place to perform better than the previous models. Our protocol shows a decrement in path loss and an increment in residual energy, which in turn improves the network lifetime. As a result, the number of data packets sending to the sink increases. Therefore, SMART shows better performance than M-attempt and SIMPLE. Body sensors that can easily be placed on the surface of the body or clothes are used in this protocol and the simulation is done in MATLAB. The unavailability and cost of the sensors are the limitations of this model. But this model will be a user-friendly system for distant health caring services. The proposed scheme would allow the system to use an effective cost function to select an appropriate route to sink.

Keywords- Wireless Body Area Network, Residual Energy, Cost Function, Path Loss.

I. INTRODUCTION

In this advanced era, technology plays a vital role in every sphere of our life. To make our life easier and simpler, it has given us creations beyond imagination. Out of all the aspects technology has landed its hand, healthcare is crucial and undoubtedly the most important sector of it. Wireless Body Area Network (WBAN) is such a technology in the field of medical science which has emerged to improvise the ambulatory healthcare service and also our lives.

WBAN is like a distant health caring service. In WBAN different types of wearable sensors are used inside and outside of the human body. These sensors collect various types of data (temperature, blood sugar, blood pressure, etc.) from the human body [1]. These devices can be implanted inside or outside the human body. These are the type of body sensors that are mainly used for medical and healthcare systems. A WBAN can operate independently for the connection of various medical sensors and devices which are located inside or outside the human body.

WBAN offers valuable contributions at monitoring, diagnostic, or therapeutic application. It makes the service among patients and doctors or hospitals a lot easier. Patients can be treated at their homes with the help of this technology. In this paper different network topologies, protocols, and ideas of WBAN, WSN, etc. have been introduced. An improved result of the WBAN system has been found by changing different parameters which include throughput, network lifetime, path loss, and residual energy. The proposed WBAN model named "SMART" has a higher stability rate, increased lifespan of the sensors, increased residual energy, and increased throughput as the sensors are active for a longer time, keeping the cost as minimum as possible. The most important thing is, the sensors which are used in this work are all in-body sensors. No injection procedure or minor wounds is needed for the sensors to take the reading from the body. The main target was to make this technology more automated.

The rest of the paper is arranged in the following order. We review the related works in section 2, while section 3 discusses the motivation of this work. In section 4 the equations for different models have been discussed. Section 5 describes the simulation model of the proposed protocol. In section 6 and section 7, the performance metrics and result analysis have been presented. Finally, section 8 gives the conclusion of the work and discusses future work.

II. RELATED WORKS

Different researches and works have been done on WBAN technology. Here, some of these works are going to be discussed. A mobility supportive and thermal aware routing protocol (M-ATTEMPT) had been described in [2] which is more energy-efficient and reliable than Multi-hop communication. For extracting the data direct communication and linear programming were used which ensures maximum efficiency of the system.

The author proposed a reliable and energy-efficient routing protocol for WBAN in [3]. It was termed as Stable Increased-throughput Multi-hop Protocol for Link Efficiency (SIMPLE) for WBANs which achieved minimum energy consumption and longer network lifetime.

Reference [4] discussed a cross-layer communication protocol for WBANs: CICADA or Cascading Information retrieval by Controlling Access with Distributed slot Assignment. A tree network was established here which guaranteed a collision-free system between medium and sink.

In [5] a new energy-efficient routing protocol was introduced. Three kinds of nodes were used here- sink, body sensors, and relay nodes. This set of relay networks ensured a single-hop transmission system which lessened the energy consumption of the body sensors. Although an additional number of nodes increased the cost of the system, it served the purpose of energy efficiency thoroughly.

In [6] the author presented a store and forward based routing algorithm for WBAN. A prototype model was constructed to experiment with different factors like- the presence of ultra-short-range radio links, unpredictable RF attenuation, and mobility of the human body and later compared to a general probabilistic routing protocol. While securing the node location, the experiment revealed that the proposed model showed better routing performance than the existing protocols in the literature.

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A Self-Organizing Protocol for Body Area Network (ANYBODY) was introduced in [7] which uses cluster-based routing protocol. According to the author, a cluster-based protocol is more efficient for WBANs than other protocols. In this model, first, a node identifies a node with whom it can communicate directly. Then the nodes are formed in a cluster with one cluster head in each group and interconnecting among themselves the routing path to the sink is set up.

Nabi et al. proposed a multi-hop routing protocol for WBANs in [8]. The system is very vigorous against the frequent change in human posture, wireless links, etc. In order to ensure a reliable outgoing link and avoid network disconnection, a technique was implied to adapt the transmitting power of nodes.

Reference [9] emphasized the problem of energy consumptions of the batteries of WBAN and hence, proposed a protocol which is the Minimum Energy Packet Forwarding Protocol (MEPF). Without adjusting the power of forwarding transmission this protocol can guarantee high packet reception which allows the packet to minimize the use of transmission power. Here, a machine learning algorithm was used to judge the performance of the system. In [10] the delay of each link in WBAN channels was calculated and represented graphically. Three types of network paths (WLAN, WiMAX, UMTS) were used in this protocol interconnecting with ZigBee. In [11] the author discussed a platform for ECG which operates in the band region of unlicensed 2.4-2.4835 GHz. This protocol uses creeping waves which reduces the transmission power of the sensors. Maintaining reliable performance, a point to point link budget is proposed which increases the battery life drastically.

III. MOTIVATION

Improvisation and advancement of the healthcare system have always been on the top priority list of our world. According to a survey done by the researchers, Cardiovascular diseases are the most formidable cause of death in Europe and the United States (US) since 1900 [12]. It also says that the number of affected people is more than ten million in Europe [13], one million in the US, and twenty million people around the world. Furthermore, this number is predicted to be triple by the end of the year 2020 [12]. On the other hand, the ratio, in this case, is 17% in South Korea and 39% in the US [14] [15]. These huge numbers have caused a great impact on the minds of researchers and economists. So, the importance of WBAN technology is beyond questionable. To make health care service easier and more accessible to everyone successful transmission of WBAN is necessary. Less energy consumption and a cost-effective system should be ensured for this. The main goal of this work is to make the system faster, simpler, and more user-friendly than the existing one. The contribution of the proposed protocol includes-

- higher stability than the previous works.
- increase in the life span of the sensors.
- increase in the residual energy which causes the sensors to be operable in the system for a longer amount of time.
- increase in the throughput of the system.

IV. EQUATION MODEL

Reference [16] discusses that in order to make this protocol efficient and cost effective, first order radio model has been used. Here, a cost function determines which node should be used for becoming the forwarder node. The equations that can be found in this work are:

$$E_{Tx}(k, d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k, d) \quad (1)$$

$$E_{Tx}(k, d) = E_{Tx\text{-}elec} \times k + E_{amp} \times k \times d\text{^}2 \quad (2)$$

$$E_{Rx}(k) = E_{Rx\text{-}elec}(k)\ E_{Rx}(k) = E_{Rx\text{-}elec} \times k \quad (3)$$

$$E_{Rx}(k) = E_{Rx\text{-}elec} \times k \quad (4)$$

$$E_{Tx}(k, d) = E_{elec} \times k + E_{amp} \times n \times k \times d^n \quad (5)$$

Here, E_{Tx} is the energy needed for the transmission and E_{Rx} is the energy consumed in the receiver's end. $E_{Tx\text{-}elec}$ and $E_{Rx\text{-}elec}$ are the energies required to run the transmitter and receiver electrical circuit. Therefore, d can be signified as the distance between transmitter and receiver and due to transmission channel, d^n is the loss of energy. On the other hand, k is the packet size, n is the path loss co-efficient and E_{amp} is the energy needed for the amplifier circuit in (5).

If i is the number of nodes then cost function is as follows:

$$C.F(i) = d(i)/R.E(i) \quad (6)$$

Where d(i) can be termed as the distance between node i and sink and R.E(i) is the residual energy of the corresponding node.

The path loss model has also been described in [17].

Now, the relation between path loss and distance can be written as:

$$PL(f,d) = PL_0 + 10n\log10(d/d_0) + X\sigma \quad (7)$$

Where PL is the received power, d is the distance between transmitter and receiver, d_0 is the reference distance, n is the path loss coefficient, X is the Gaussian random variable and σ is the standard deviation [18].

Here, at reference distance d0, PL_0 is the received power which can be described as follows:

$$PL_0 = 10\log10(4\pi \times d \times f)^2/c \quad (8)$$

Where f is frequency, c is the speed of light and d is the distance between transmitter and receiver.

V. PROPOSED MODEL: SMART

In this section, a novel routing protocol for WBANs is presented. As the sensors used in Wireless Body Area Networks (WBANs) are heterogeneous, their placement on the human body is an issue. By using the concept of single-hop and multi-hop network this issue is resolved. Fig 1. shows that the sink is placed in the middle of the human body which is around the waist or lower abdominal area and ten sensor nodes are used on the human body. All sensors that are used here are comprised of the same power and computation capabilities. Here,

1. Node 1 is a temperature sensor that is placed at the left hands underarm. It works the detection of body heat.
2. Node 2 is an ECG sensor that is placed at the chest. It is defined as the test that records the electrical activity of the heart using electrodes attached to the skin. This sensor determines the cause of unexplained chest pain, which could be caused by a heart attack. It also finds the symptoms of heart disease.
3. Node 3 is an EMG sensor that is placed at the right arm. Electrical activity of the muscles is measured by this sensor.
4. Node 4 is the SPO2 sensor which is placed at the right hand's wrist. It figures out the oxygen saturation of the blood. It uses 2 hops to get to the sink.
5. Node 5 is a Blood pressure sensor that is placed at the left hand's wrist. It measures human blood pressure. It measures systolic, diastolic, and mean arterial pressure.

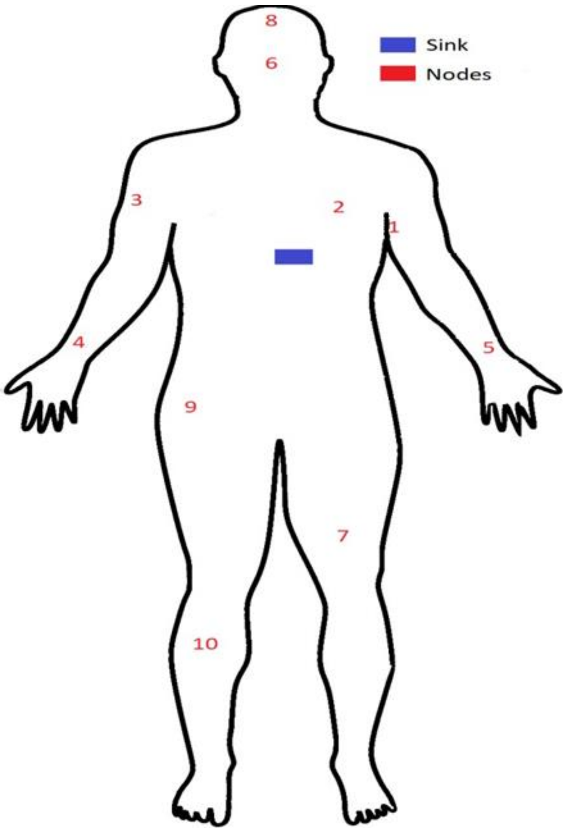

Fig. 1: Node deployment of SMART protocol model

6. Node 6 is a respiratory sensor (RA sensor) that is placed at the nose. This sensor can measure breathing activity and can identify whether a person has breathing problems or not. It also used 2 hops for data transmission.
7. Node 7 is a Lactic Acid sensor that is placed at the thigh. This sensor can measure hormone activity and lactic acid amount of the body.
8. Node 8 is an EEG sensor that is placed at the head. It can measure the electrical activity of the brain and uses 2 hops routing for data transmission.
9. Node 9 is a sensor that is discussed in [19] and placed in the abdominal area. This sensor can measure gastric and other stomach activity.
10. Node 10 is an acceleration sensor that is placed at the knee. This sensor can measure a human's movement speed. It uses 2 hops.

VI. PERFORMANCE METRICS

There are a number of parameters which are the measurand of a system's performance. In order to determine whether a system is good or bad these performance metrics play the most significant role. Here, the key performance metrics are evaluated for the proposed protocol. These are discussed in detail in the following subsection-

1. *Network Lifetime:* Generally, for a WBAN network lifetime means the time duration between the initialization/restart of a WBAN to the point when the first sensor node in the network dies. Here, for this paper, the network lifetime of a WBAN is denoted as the total operation time of the network until the last node dies.
2. Stability Period: The stability period can be termed as the time of a network operation until the first node dies. In other words, it denotes the period from the starting of operation of the nodes until the end of the operation. On the other hand, the period after the death of the first node can be named as an unstable period.
3. *Throughput:* Throughput can be classified as the total amount or volume of data that can be transmitted through the network at a given amount of time.
4. *Residual Energy:* In this work, residual energy is used as the parameter to analyze the energy consumption of the network. Residual energy refers to the remaining energy left in the nodes/sensors after completing the operation.
5. *Path Loss:* It is the difference between transmitted power and received power. It simply refers to a reduction in the power density of electromagnetic waves. It is measured in decibels (dB).

VII. RESULT ANALYSIS

As previously mentioned, the proposed protocol SMART is formed keeping in mind the idea of both SIMPLE and M-ATTEMPT. This new protocol is compared with both of the previous protocols. The MATLAB platform is used for the simulation process.

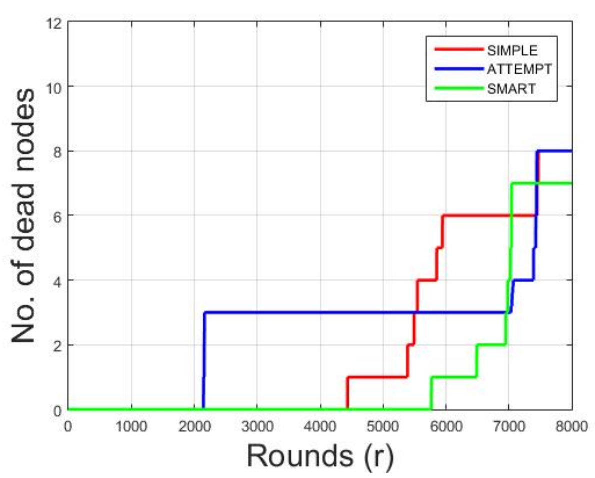

Fig. 2: Analysis of network life time

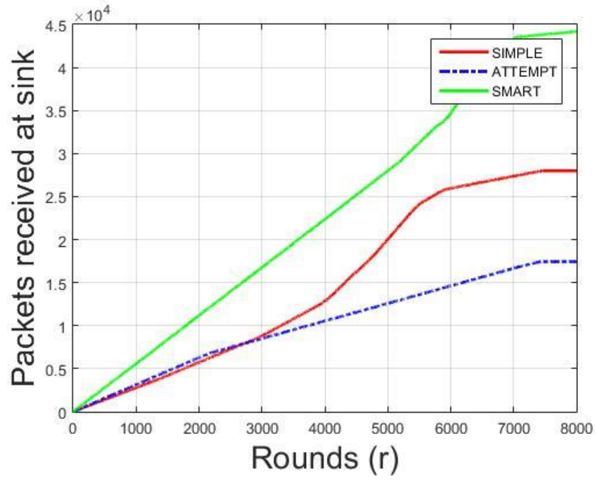

Fig. 3: Analysis of throughput

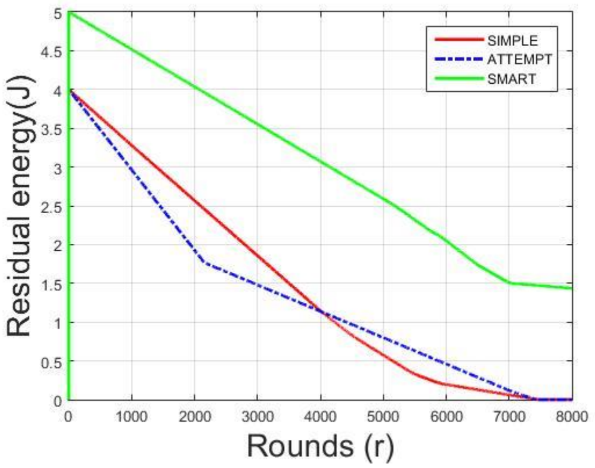

Fig. 4: Analysis of residual energy

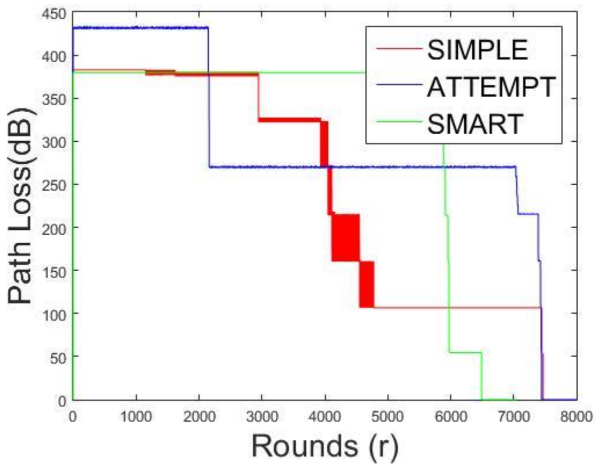

Fig. 5: Analysis of network path loss

A. *Network life*

Fig. 2 shows the average network lifetime of the proposed SMART protocol. According to the previous discussion in [3], the SIMPLE had a longer lifetime of the sensors than ATTEMPT. So, this clearly shows that the proposed protocol is also better than the ATTEMPT. For example, in this figure, it took about 2100 rounds for ATTEMPT for the first node to be dead, and for SIMPLE it took about 4400 rounds. But in the proposed protocol it was operable for about 5800 rounds. This scenario goes for all the other sensors. So, the stability of the proposed protocol is better than the previous two protocols. If there's no malfunction, almost all the nodes consume the same amount of energy and also die almost at the same time. So, the network lifetime is increased in this proposed protocol.

B. *Throughput*

Fig. 3 indicates the total data packets that are received at the sink. In the previous section, it was clearly shown that the proposed protocol has a longer network lifetime. It means in SMART the number of alive nodes with respect to rounds is more than the previous two protocols. From our previous discussion, it can be stated that the stability period of MATTEMPT is shorter than the SIMPLE protocol and that's why the number of data packets sent to the sink is also decreased. On the other hand, due to the longer stability period SMART protocol achieves high throughput. Here, after the end of 8000 rounds, the ATTEMPT was able to send about 17000 packets and the SIMPLE was able to send about 28000 packets. But the proposed SMART protocol can send like 45000 packets.

C. *Residual energy*

Residual energy means the remaining energy in the nodes or sensors after a certain period of time. Fig 4 shows the average energy of the network consumed in each round. According to simulation results, the SIMPLE protocol absorbs minimum energy until 70% of simulation time. It means that more nodes are alive and they can transmit data. On the contrary, for M-ATTEMPT, most of the nodes exhaust pretty early due to heavy traffic load. But for the proposed protocol, it can be observed that even after the end of the 8000 period it still has about 1.5 times more energy remaining in the nodes. This allows the nodes to send more and more data packets to the sink. So, it depicts that the proposed SMART model gives better performance than both of the previous protocols.

D. *Path loss*

Fig. 5 represents the result of the path loss of all three of the protocols. At first, SIMPLE and SMART protocol performs well. But after 2000 rounds, path loss of MATTEMPT dramatically decreases because some nodes of the M-ATTEMPT model die. It is known that the minimum number of alive nodes has a minimum cumulative path loss. From the above discussion, it can be seen that the proposed protocol has a longer stability period and also more alive nodes which result in more cumulative path loss than MATTEMPT but quite equal to SIMPLE. Moreover, the path loss was neutralized after 6000 rounds which took longer in the other two protocol.

VIII. CONCLUSION

In this work, a mechanism named SMART to route data for WBAN has been proposed. A cost function is used in this protocol for selecting the appropriate route to sink. The cost function is calculated from the values of the residual energy of nodes and their corresponding distance from the sink. The parent node collects data from the children nodes, stores them, and sends them to a remote server when necessary. A star protocol is used for this data transmission in this model. In this paper, the results show that the performance is better than most of the other researches that have been done already. The results of the number of dead nodes, residual energy, and packet receiving rate at the sink are much better than the previous ones. Though the path loss while transmission has increased for multi-hopping and longer lifetime of the sensors, it can be avoided or minimized taking necessary steps. The main limitation of this work is that it has no real-time value because it has not been tested or used on any human being. The less availability of these sensors and their high cost has been a major problem in gaining the hardware model testing. In future work, we will try to implement it on hardware projects and test it on the human body to attain more accuracy. It is hoped that this model would help to make the automation process of health care services more improved and simpler.

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