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An Energy Efficient Routing Protocol for Wireless Body Area Sensor Networks

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Abstract In this paper a reliable, efficient in terms of power consumption and high stable network is proposed for Wireless Body Area Sensor Networks. Eight sensor nodes are used from which two are recording critical data. These two sensors are not apart of multi-hopping but send data direct to the sink. Remaining six sensors are computed to become a forwarder node. Forwarder nodes gathers data from sensors and after aggregating sends ti the sink. Two parameters are set for cost function so that a forwarder node is selected. If a sensor is having minimum distance and maximum energy as compared to the entire nodes then it will be selected as forwarder node. Multi-hopping is used to reduce the distance of data communication and to save energy consumption. Simulation is carried out and shows stable results.

Keywords Energy · Sensors · Routing protocol · Health · Sink

1 Introduction

Advancement in electronics have resulted in developing micro-electro-mechanical systems (MEMS) technology. MEMS have enabled the development of sensors which are smart. MEMS sensors are small in size but are able to sense or gather the data and measure it as well. Development in wireless communication have enabled these sensors to be able to communicate using wireless technologies in an untethered manner. These sensors have the

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capability that they can observe/sense the parameters of the surroundings, process that data and then transmit it wirelessly [1, 2]. These developments have created a platform for wireless sensor networks (WSNs). WSNs allow these sensors to communicate with a base station in an ad-hoc technique. The base station is a device which gathers data from the sensors [3]. A wireless body area sensor network (WBASN) is a subfield of WSN in which continuous monitoring of health parameters in daily life routine. WBASN consists of small sized sensors which are placed on different parts of the human body for the purpose of observing physiological parameters [4]. Each sensor has the capability to process the recorded data and then to transfer it to base station known as sink. WBASN is also known as wireless body area network (WBAN) simply body area networks (BAN) [5, 6]. In recent years the researchers have become interested in WBASNs. The reason of this is every year people in millions die due to diseases like asthma, diabetes, cardiovascular disease and many more [7]. The realization of WBASNs have become possible developments of communication technique's and miniaturization of components leading to Micro-Electro-Mechanical Systems (MEMS) [8]. Table 1 lists invasive and non-invasive sensors.

There are various places on human body on which physiological parameters which can be measured as shown in Fig. 1.

The old aged people are very tough to be taken care of. According to a prediction by The Department of Economic and Social Affairs of the United Nation has given a number of 1198 million will be old aged people in the year 2025 which was 759 million in the year 2010 [5, 6]. WBASN's significant application is health monitoring. Sensors are placed on human body or can be implanted in the body for the purpose of monitoring vital signs like heart rate, blood pressure, glucose level, body temperature, and others. WBANS to monitor health parameters is helpful significantly in reducing patient expenditures in hospital. It is not necessary for a patient to stay at hospital but can be monitored at home. The sensors record the physiological parameters to the base station or the sink. The sink then transmits this data to outside world for further process [9]. Sensor nodes used in WBASNs are operated on batteries. These sensor nodes being small in size have limited battery resources [10].

The communication architecture of WBASN is shown in Fig. 2. The circular dots are the sensors that are located at different places for monitoring purpose. It can be observed that the sensors are connected with a rectangular box known as base station or sink. This connection can be wired or wireless. The sink computes and processes this data and sends this data to the outside world. The sink is connected to the personal digital assistant (PDA)

Table 1 Invasive and noninvasive sensors

Non-invasive/wearable sensors	Invasive/implantable sensors
Electrocardiogram (ECG)	Pacemaker
Glucose sensor	Cochlear implants
Electromyography (EMG)	Implantable defibrillators
Electroencephalogram (EEG)	Wireless capsule endoscope (Electronic Pill)
Temperature	Electronic pill for drug delivery
Pulse oximeter	Deep brain stimulator
Blood pressure	Retina implants
Oxygen, pH value	

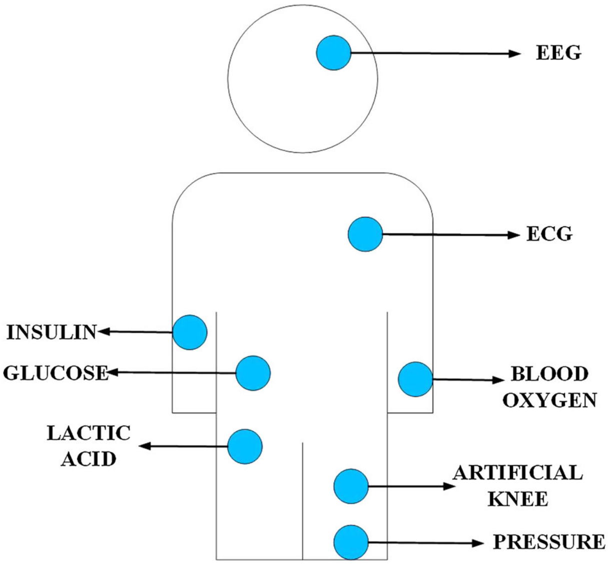

Fig. 1 Sensor placement for monitoring

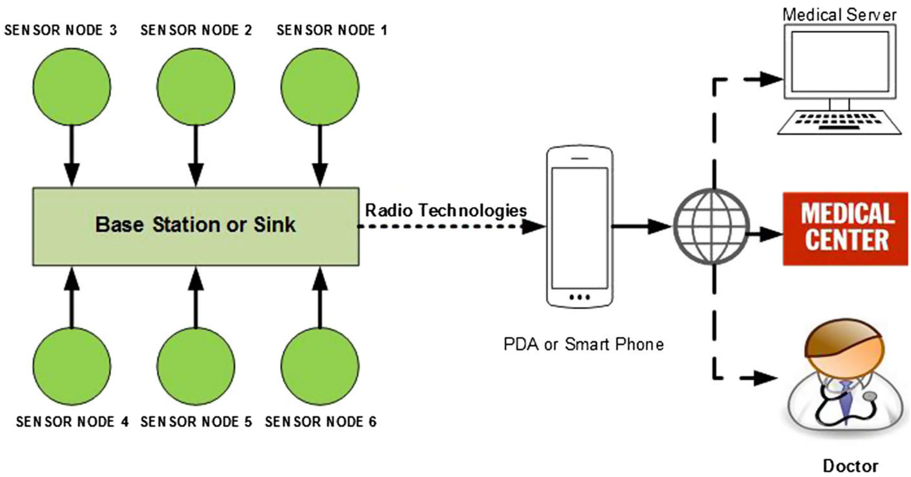

Fig. 2 Wireless body area sensor network communication architecture

that can be a smart phone using low power radio technologies. From PDA the data can be sent to medical world for record keeping, medical center or a doctor for any necessary action.

The sensor nodes used in these types of networks being small in size have the limitation of having small amount of power.

2 Related Work

The authors in [11] have proposed a protocol which is based on Time Division Multiple Access (TDMA) used for the purpose of adjusting transmission and its duration. The allocation of the slots has been optimized by minimization in the energy consumption. The research carried out by [9] is based on the optimized place for the placement of sensors on human body. In this research the number of sensors used is eight (08) and the base station has been place on the center of body. The Euclidean model was used for the purpose of sensor placement for getting accurate but minimum distance from the base station. This resulted in achieving lesser path loss as compared to one of the existing schemes. A new routing protocol named as ZEQoS has been proposed in [12]. This protocol develops a mechanism by coordinating with three algorithms for performing operations like end to end delays of path, end to end reliability of each path of the entire available paths so that the best path may be selected and calculating the communication costs. The algorithms used are routing table path selector algorithm, constructor algorithm and neighbor table constructor algorithm.

An energy aware routing protocol [13] is designed for hospitals. In this research they found that change in topology causes the batteries to drain quickly which in return destroys performance of the network. They propose energy aware and stable routing (ESR) which is able to derive benefit from the residual energy and stability of nodes. This is performed for the purpose of selecting the best route to transmit data packets. An energy efficient healthcare system of monitoring system which is based on ZigBee in [14]. Simulation was conducted on OPNET. For the purpose of achieving adaptive duty cycle the authors have tried to make ZigBee to work in a beacon enable mode. They achieved extended network time and energy consumption of sensors by avoiding idle mode energy utilization. In [15] two protocols have been combined (1) Priority-based Cross Layer Routing Protocol (PCLRP) and (2) Priority Cross Layer Medium Access Channel protocol (PCLMAC). This combination provides consistent propagation of traffic. To determine shortest path for the purpose of sending emergency or critical data to a medical representative or a doctor ant colony optimization (ACO) and also travelling salesman approach is applied. This simulation was varied on using OMNET++. To enhance network life the Bayesian game formulation has been used. In their proposed system if there is any urgent or critical data then that is routed to the destination which could be medical representative or doctor [16].

3 Power Consumption Analysis

In WBASNs the sensors used are of small size and in their module they contain radio and the battery also. When the transmission takes place then the sensors deplete energy and drain fast. Sensors have to sense, process this sensed data and then transmit this processed data to the base station. Out of these three functions the sensors consume more energy in data transmission. The mathematical demonstration of energy consumed during transmission is represented in Eq. 1.

$$E_{TX} = \left(E_{amp} + E_{elec}\right) * s * d^2 \quad (1)$$

In Eq. 1 the parameter d represents the distance. Increase in distance will increase the transmission energy making sensor to consume more energy. The amount of energy which is consumed by a sensor node in WBASN for transmitting data is given by Eq. 2.

$$E_{node} = E_{tx} + E_{retx} + E_{ack} + E_{acc} \tag{2}$$

E_{node}: total energy, E_{tx}: transmission energy, E_{retx}: retransmit energy, E_{ack}: energy consumed while transmitting acknowledge (ACK) packet, E_{acc}: energy used up by the channel access procedures.

4 Radio Transceiver

In order to extend the life network the sensors must be provided with energy efficient radio transceiver so that it may consume less energy for its functions. The transceiver used in this research is the Nordic nRF2401A[1] because of its ultra-low power (ULP) consumption. It operates at 2.4 GHz Industrial, Scientific and Medical (ISM) band. If it is operated on AA sized or AAA sized batteries then even it can enable battery life to work for several months to years. Some of the parameters are mentioned in Table 2.

5 Proposed Scheme

The proposed scheme uses eight sensors. Table 3 shows the coordinates of entire sensor nodes of the proposed scheme.

The sensor deployment on human body is shown in Fig. 3. The circular dots represent the sensors and the rectangular box is the base station.

The sensor nodes have equal power and computation capabilities. The initial energy of nodes is 0.5 J. Threshold energy level is set as 0.1 J. If a sensor has less than threshold energy level is considered to be dead node. Sink node is placed at center of the body. The multi hopping scheme is used for the purpose of saving energy as the distance of the far nodes becomes less and the forwarder node now sends the data to the sink. There is a forwarder node which gain data from other sensors and forwards that to the sink. In proposed scheme the forwarder is selected whenever one round ends. The sink has the information that what is the identity, energy status of the sensor nodes. The selection of the forwarder node is important and needs to be selected on the basis of cost function. This is to find out the next hop in the route. The cost function [17] is calculated for finding that any of the sensor can be acted like a forwarder or not. Selection of forwarder node is based on least distance from the sink and energy greater than threshold energy.

The mathematical representation of cost function is given by:

$$CF_i = \frac{d_i}{RE_i} \tag{3}$$

where d is the distance of a sensor from sink and RE is the residual energy of sensor and i is the number of a sensor. The sensor node having minimum distance from the sink and maximum residual energy out of all will be selected as a forwarder node. The communication of the sensor nodes to the forwarder node is based on Time Division Multiple Access (TDMA) so that the nodes send observed data in given time slots.

The life of the nodes has an impact on (1) network life time and (2) network stability. Network stability is the time span for which the first node dies and network lifetime is when all the sensor nodes die.

[1] https://www.nordicsemi.com/.

Table 2 Nordic nRF2401A parameters [17]

Parameters	Values
T_x DC current	10.5 mA
R_x. DC current	18 mA
Minimum voltage supply	1.9 V
$E_{tx\text{-}elec}$	16.7 nJ/bit
$E_{rx\text{-}elec}$	36.1 nJ/bit
E_{amp}	1.97e-9 j/b

Table 3 Sensors' coordinates

Sensor	X coordinate (m)	Y coordinate (m)
Sensor 1	0.25	0.1
Sensor 2	0.5	0.2
Sensor 3	0.25	0.3
Sensor 4	0.5	0.4
Sensor 5	0.35	0.65
Sensor 6	0.45	0.8
Sensor 7	0.6	0.65
Sensor 8	0.1	0.65

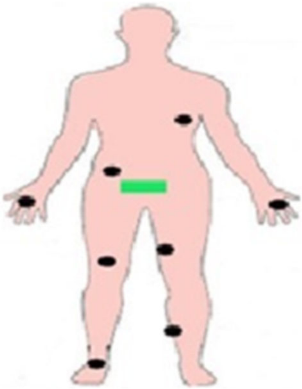

Fig. 3 Sensor deployment

6 Simulation Results

Simulation have been carried on Matlab 2016 and has been compared to the existing routing protocol M-ATTEMPT [18]. The rate of power consumption is based on the selected sensing transceiver parameter. The Nordic nRF2401A consumes energy is Nano joules of energy for a single bit. There are four parameters which are to be compared. As there are eight sensor nodes used in this proposed scheme and also in M-ATTEMPT [18] so the network life time and network stability depends upon the life of these sensors can be observed in Fig. 4. In Fig. 4 the comparison of given between the proposed scheme and M-ATTEMPT [18] in terms of dead nodes and their rounds. It can be observed that the first node of the M-ATTEMPT [18] scheme dies at slightly above 2000 rounds while at proposed scheme the first node dies at approximately near the 5000 rounds. So it can be

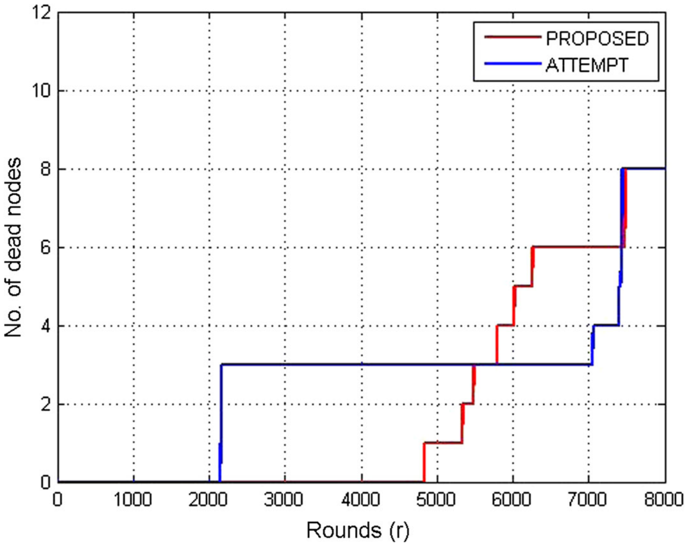

Fig. 4 Comparison of the dead nodes

concluded that the proposed scheme has higher network stability as compared to the M-ATTEMPT [18]. Also it may be observed that first three nodes in M-ATTEMPT [18] die in a very quick session. The entire nodes of M-ATTEMPT [18] die between 7000 and 8000 round while the proposed scheme is able to achieve 8000 rounds.

The data from sensors sent to the sink are in the form of packets. This data is very much sensitive because it is related to the human health so it is important that this data must reach at the destination that is the sink. The successful number of packets received is called

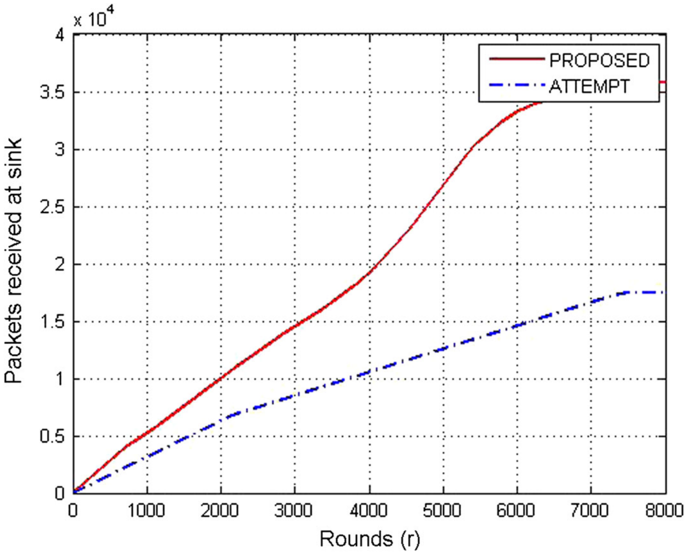

Fig. 5 Comparison of the packets received

throughout. Figure 5 illustrates the comparison of the number of packets which are received by the sink from sensors of both the proposed and M-ATTEMPT [18] scheme. If number of rounds increase, the number of packet received by the sink increase. As observed from Fig. 5 the total number of packets received by M-ATTEMPT [18] is 1.75×10^4 and the packets received by the proposed scheme are 3.25×10^4. This successful result has been achieved by the proposed scheme due to availability of sensor nodes. As the sensor nodes die, the number of packet received decrease. As observed from Fig. 4 the

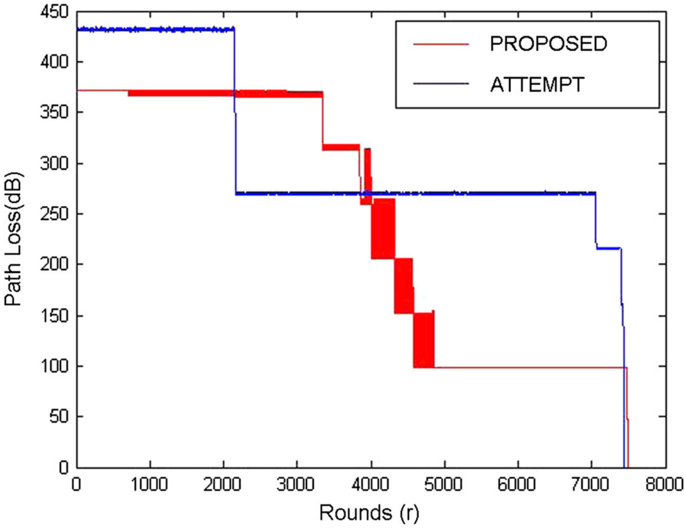

Fig. 6 Comparison of path loss

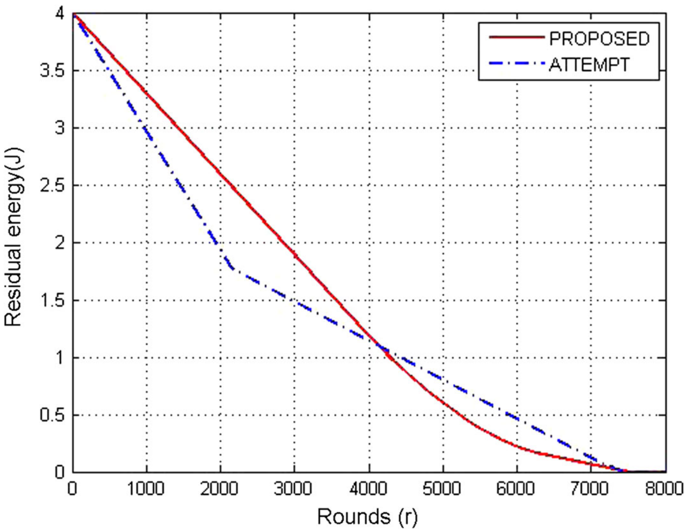

Fig. 7 Comparison of residual energy

nodes in the proposed scheme last longer than the nodes in M-ATTEMPT [18] so it can higher number of packets received.

Path loss comparison of both schemes is provided in Fig. 6. Path loss of the proposed scheme is less than that of M-ATTEMPT [18]. It can be observed that the at just above 2000 rounds the path loss of M-ATTEMPT [18] dropped and became less than the proposed scheme and remain less up to 4000 rounds. This is because the nodes in M-ATTEMPT [18] scheme die quicker as compared to the proposed scheme. From 4000 rounds the proposed scheme is able to reduce its path loss.

The average of the energy consumption between both the schemes is presented in Fig. 7. In Fig. 7 that energy analysis of the M-ATTEMPT [18] denoted by blue colored line and of the proposed scheme denoted by red colored line. The energy consumption of the proposed scheme is stable as compared to M-ATTEMPT [18] in which energy consumption is not that stable making the sensors die in quick session. This was achieved by the proposed scheme with the help of forwarder cost selection in every round making the sensor distance lesser due to multi-hopping through forwarder to the sink.

7 Conclusion

In this paper an energy efficient routing protocol for WBASNs is proposed. This protocol is the combination of single hop for critical data sensors and multi-hop for regular recording data sensors. In this scheme the sensor are first computed for forwarder node. This forwarder node is the one which collects data from other sensors, aggregates this data and then forwards to the sink. After the successful completion of a round a forwarder node is selected on the basis of having least distance from the sink and maximum residual energy as compared to entire sensor nodes. The proposed scheme achieved better network stability and life time as the sensor nodes die slowly making it an efficient routing protocol.

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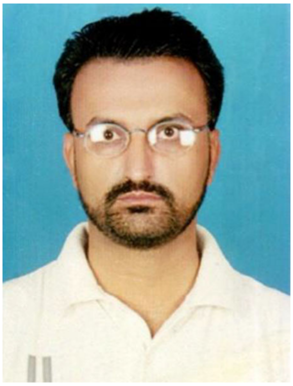

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