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AN ENHANCED-SIMPLE PROTOCOL FOR WIRELESS BODY AREA NETWORKS

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Abstract

A Wireless Body Sensor Network (WBSN) characterizes an independent system that is used for the purpose of monitoring the daily routine activities of an individual. It comprises of smart sensor nodes which do not have any kind of adverse effect on the daily routine activities and are quite effective in the detection of chronic health problems such as diabetes, heart attack, asthma etc., and to caution the person suffering from diseases in the case of an emergency conditions. In this work, a wireless body area network routing protocol is designed where distance of the sink from various nodes and residual energy of the nodes decides the forwarding nodes to maximize the throughput. In this work, all the sensors on the body will transfer data to sink node and sink node will transmit data to base station or to the server. The simulation results will be evaluated in terms of remaining energy, throughput and number of dead nodes. The obtained results are also compared with recent published protocols and it has been found that in comparison to SIMPLE and iM-SIMPLE, the proposed protocol E2 (nomenclature used in the paper) has throughput higher than 12.46% and 6.7% respectively.

Keywords: Body area networks, Forwarding function, Radio model, Residual energy and throughput

1. Introduction

A Wireless Body Sensor Network (WBSN) characterizes an independent system that is used for the purpose of monitoring the daily routine activities of an individual [1-3]. It comprises of smart sensor nodes which do not have any kind of adverse effect on the daily routine activities and are quite effective in the detection

Nomenclatures

CF	Cost function
D	Distance, m
E_{amp}	Amplifier energy, pJ/bit/m^4
E_0	Initial energy, J
E_{RX}	energy consumed during reception, nJ/bit
$E_{RX\text{-}elec}$	energy consumed at the time of reception, nJ/bit
E_{TX}	Transmission Energy, nJ/bit
$E_{TX\text{-}elec}$	energy consumed at the time of transmission, nJ/bit
FF	Forwarding function
N	Index
P	Index

Abbreviations

ANYBODY	A Self-Organization Protocol for Body Area Networks
ATTEMPT	A ware Energy efficient Multi-hop Protocol
M- ATTEMPT	Mobility-supporting Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop ProTocol
QoS	Quality of Services
SIMPLE	Stable. Increased Throughput Multi-hop Protocol for Link Efficiency
TDMA	World Health Organization
TPA	Transmit Power Adaption
TPC	Transmission Power Control
WBAN	Wireless Body Area Networks
WBSN	Wireless Body Sensor Networks

detection of chronic health problems such as diabetes, heart attack, asthma, etc., and to caution the person suffering from diseases in the case of an emergency condition.

The WBAN propose encouraging services in many different areas like research, industries, defence, and business [4]. A very nominal measure of power is consumed by the sensor nodes in WBSN. These sensor nodes are very useful and effective in the applications such as military, entertainment, sports training, bomb diffusers, etc. It is now quite easy with the help of WBSNs, even from a remote position, to monitor movements, activities, and important signals of a human body with the help of internet [5].

In this manner, it is quite helpful in saving money. Due to all these facts, the need of these devices is expanding with the time and a number of elements such as fault assurance, reliability, Quality of Service (QoS) and assurance of security required to be fulfilled. WBSNs have not been capable of fulfilling each one of the above discussed specifications because of the limited resources like power of battery memory, changing topology and fluctuating bandwidth.

WBSN nodes have numerous characteristics that turn them perfect for applications in a great number of developing systems. The WBSN technology is a simple and cost effective technology. It is also an energy efficient scheme and it also supports heterogeneity [1-3].

2. Related Work

In WBAN, the single hop communication is presented in [5], to deal with the issue of the single hop communication. As far as multi-hop communication is concerned, it is proposed by Seo et al. [6]. A secure low-delay protocol was proposed by Latre et al. [7] for multi-hop wireless body area networks. The structure of this routing protocol is like a spanning tree. Parent nodes drain out their energy at a much rapid pace because of the additional traffic load of children nodes.

Quwaider et al. [8] suggested a routing protocol which endures to variations in network. Store and forward mechanism is used by them to improve the probability of a data packet to achieve effectively to sink node. All sensor nodes are capable to make storage of a data packet. In source to goal course, every node makes storage of the data packet and transmission to following node. With the storage of a data packet and after this retransmission results more consumption of energy and extend end to end delay.

Watteyne et al. [9] proposed a Self-Organization Protocol for Body Area Networks (AnyBody). The purpose of this protocol is to limit the transmission of sensor nodes directly to sink. It upgrades the effectiveness of network by varying the selection grounds of CHs.

Nabi et al. [10] proposed a protocol which is more or less similar to store and forward system. They incorporate this store and forward plan with transmit power adaption (TPA). In order to have control on the consumption of transmission power, each node is aware of its neighbours. Nodes make the transmission of data with least power and with a steady quality of link.

Transmission power control (TPC) method as proposed by Nabi et al. is applied by Guo et al. [11]. At the point when link quality of a node diminished, an automatic repeat request (ARR) is generated and sent back thus it enables the re-retransmission of drop packet. Retransmission of lost packet enhances the network throughput with the cost of consumption of energy.

Tsouri et al. [12] and Sapio and Tsouri [13] applied creeping waves to relay data packet. This protocol was proposed by them to reduce the energy consumption of nodes while maintaining the reliability.

Javaid et al. [14, 15] made the analysis of the delay in WBANs and various medium access methods for WBAN. A delay tolerant protocol is proposed by Muhannad et al. [16]. They made the comparison of their protocol with various other protocols.

Later part of this article explains the two recently proposed protocols; ATTEMPT and SIMPLE for WBSN in detail.

2.1. Attempt protocol

An opportunistic, mobility-supporting adaptive threshold-based thermal-aware energy-efficient multi-hop protocol (M-ATTEMPT) is proposed and studied by Javaid et al. [17]. This scheme provides mobility of some of the nodes at the expense of low throughput and an extra expense of relay node. At any time, sink node moves far from nodes' range of transmission (due to movement of body parts), it relies on a relay node which is applied for making the collection of data from sensor nodes.

2.1.1. Initial phase

In the initialization phase, all nodes transmit HELLO messages. These HELLO messages contain information regarding distance from sink nodes in terms of hops count, and neighbours information. This information is updated in each count.

2.1. 2. Routing phase

In the routing phase, information is transmitted to sink with fewer number of hops, thus shortest path in terms of hops is selected. If two routes have same number of minimum hops count, then path with lesser energy consumption is selected. This protocol support both single and multi-hop communication.

2.1.3. Scheduling

Once route is selected, sink node creates time division multiple access (TDMA) for scheduling between sink and root nodes.

2.1.4. Mobility Support in attempt

Mobility support in ATTEMPT is introduced. Nodes with higher data rates placed at lesser mobile places. These nodes are known as parent nodes and are directly connected to sink. Nodes directly connected to parent nodes are known as level -1,child nodes, and nodes connected directly below to child nodes are known as level-2, child nodes and so on [17].

In the protocol sink node is deployed at waist in place of wrist. Due to the fact that hands move now and then, sink becomes mobile for a major part of the time and lie far from the sensors for a long duration. This will result in the more power consumption of relay and sensor nodes. A greater number of packets will be dropped because of the mobility of the sink on hands that in turn results into the loss of important and critical data. Further discussion on M-ATTEMPT protocol can be found in [17].

2.2. Simple protocol

In WBANs, the constant quantities of nodes offers chance to loosen up limitations in the case of routing protocols. With the inspiration of routing constrains, SIMPLE protocol enhance the period of stability and throughput of the network. Following paragraphs throws a light on the features of the framework model along with the characteristics of SIMPLE protocol [18].

2.2.1. System model

Figure 1 illustrates that eight nodes are placed on the body of the person. Each sensor node consists of same power and computation capabilities. The Sink node is placed at chest. ECG and Glucose sensors nodes are Node 1 and Node 2 respectively. Data is transmitted directly to sink by these two nodes. The typical sensor node parameters are detailed in Table 1.

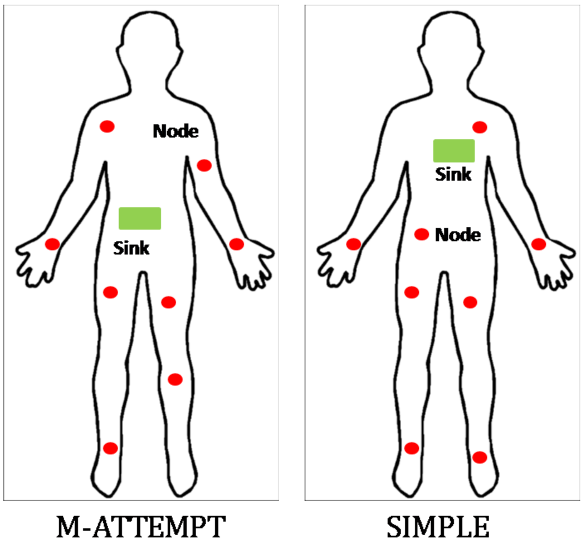

Fig. 1. Body area network with eight nodes.

Table 1.Radio parameters [18].

Parameters	nRF 2401A	CC2420
$E_{TX\text{-}elec}$	16.6 nJ/bit	96.89 nJ/bit
$E_{RX\text{-}elec}$	36.2 nJ/bit	172.78 nJ/bit
E_{amp}	1.96 nJ/bit	270.9 nJ/bit

2.2.2. Initial phase

A small measure of information packet is broadcasted by sink in this phase which comprises the sink's position on the person's body. Each sensor node, after getting the control packet, makes the storage of the sink's position. An information packet is broadcasted by each sensor node which has the following information: position of node on the human body, node ID and the status of the energy. Thus, each sensor node is updated with the information about the location of neighbours and sinks.

2.2.3. Selection of next hop

With the end purpose of saving energy along with the improvement in the network throughput, a multi hop procedure is considered in this protocol. This section of the paper details about the grounds of selection for a node to turn out to be a parent node or forwarder. The main objective is of creating the balance of the energy consumption among sensor nodes of network. In SIMPLE protocol in each round new forwarder is chosen. Sink node is aware of the information of the nodes such as distance, ID and residual energy status. Sink processes each node's cost function and transmission of this cost function is done to all nodes by sink.

Each node makes the decision on the grounds of the below discussed cost function whether to be a forwarder node or not. Considering '*i*' which represents the node number than the evaluation of cost function of node '*i*' is done as follows:

$$CF(i) = \frac{d(i)}{RE(i)} \tag{1}$$

In the above equation, the distance between the sink and node '*i*' is represented by $d(i)$ and $RE(i)$ is the residual energy of node '*i*'. We prefer a node with least cost function to be as a forwarder. Each one of the neighbour node get affixed along with the forwarder node and transfer the data possessed by them to forwarder. This data is collected and forwarded to sink by the forwarder. This (forwarder) node contains highest residual energy and least distance to sink; hence, minimum energy is consumed by it in the process of forwarding data to sink. Nodes for Glucose and ECG monitoring establish straightforward communication with sink and do not get indulge in the process of forwarding data.

2.2.4. Scheduling

As far as this phase is concerned, a time division multiple access (TDMA) is assigned by forwarder node to its children nodes on the basis of the time slots. Each one of these children nodes transmit the data which is sensed by them to forwarder node in its particular predefined time slot. In the case of the event that a node does not contain any data to be sent, it switches to idle state. Nodes wake up just at the time of its transmission. The dissipation of energy of particular sensor node could be minimized by scheduling of sensor nodes.

3. Radio Model

Radio model (Fig. 2) is used to consider the behaviour of the wireless medium. In past various radio model is proposed for WSN. In general first order radio is found suitable for WBAN as detailed in [18-20].

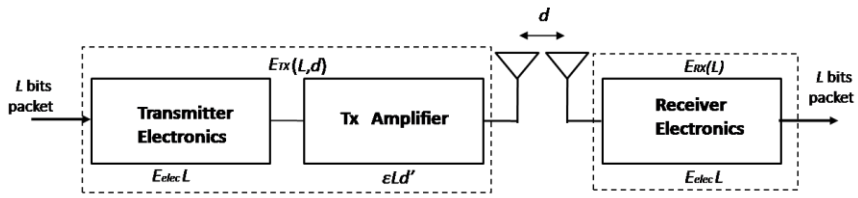

Fig. 2. First order radio model.

The above mentioned radio model assumes that *d*, is the separation between transmitter and receiver. We can define the first order radio model equations as

$$E_{TX}(L,d) = E_{TX-elec}(L) + E_{TX-amp}(L,d) \tag{2}$$

$$E_{TX}(L,d) = E_{TX-elec} \times L + E_{TX-amp} \times L \times d^2 \tag{3}$$

$$E_{RX}(L,d) = E_{RX-elec}(L)E_{RX}(L) = E_{RX-elec}(L) \times L \tag{4}$$

where E_{TX} is the energy consumed at the time of transmission, E_{RX} is the energy consumed during reception, $E_{TX\text{-elec}}$ and $E_{\text{RX-elec}}$ are the energies needed for the operation of the electronic circuit of transmitter and receiver, respectively. E_{amp} is termed as the measure of energy needed for the amplifier circuit. On the other side, L denotes the size of the packet.

The platform that is used for the communication in WBAN is human body which provides its contribution of attenuation to radio signal. Hence, path loss coefficient parameter is added by us in radio model. We can rewrite the equation 3of transmitter as follows

$$E_{TX}(L,d) = E_{elec} \times L + E_{amp} \times L \times d^{n} \tag{5}$$

The parameters of energy provided in equation 5 rely on the hardware. In WBAN technology, two transceivers that are generally used for the analysis are Nordic nRF 2401A is a single chip, low power and Chipcon CC2420 transceivers. Both have the same bandwidth i.e. 2.4GHz. The typical parameters used in equations and in simulation are detailed in Table 2.

Table 2. Simulation parameters.

Parameter	Value
E_0	0.49 Joule
E_{elec}	5.0 nJ/bit
E_{fs}	10.0pJ/bit/m^2
E_{amp}	1.3 fJ/bit/m^4
E_{da}	5.0 pJ/bit
Packet Size	4000 bits

3.1. Performance metrics

The protocol is discussed in terms of the following parameters.

i) Throughput: Throughput is a fractional value and it is the aggregate number of generated packets that are correctly reached at sink. This is also equal to the difference of total generated and lost packets.

ii) Residual Energy: Residual energy represents the energy that is left over with the nodes in each subsequent round. This is helpful in evaluating the energy consumption in the network.

4. Proposed Models

The above discussion is based on the protocol forwarding functions. Still a careful analysis is needed which investigates the effect the distance and energy. In order to achieve the target of enhancing the throughput and reliable communication with more reliability between sensors and sink, this paper proposes novel forwarding functions. The various forwarding functions with their nomenclature are detailed in Table 3.

The CF1 depends on distance and residual energy, CF2 depends on distance only, CF3 depends on residual energy only, CF4 relies on distance and scaled residual energy and CF5 depends on distance and dissipated energy. Form Fig. 3, it is clear that, the performance of CF1 is poorest, and the performance of CF5 is best among the chosen forwarding functions. The performance of CF1 and CF3 is nearly same, and on the other side the performance of CF2, CF4 and CF5 is nearly same.

Thus from CF1 and CF3 it can be concluded that, only with residual energy performance is poorer. The performance of CF2 and CF4 is overlapping and not visible in graph. It clearly concluded that the effect so residual energy will have little or no effect. This is very obvious as each of the node have same initial energy, thus their dissipation will also be nearly uniform. In CF5 we try to minimize the dissipated energy, and the performance of the protocol is best among the chosen one.

Table 3. Forwarding functions comparison.

Nomenclature	Forwarding Function	Dependency
CF1	$F.F(i)=\frac{d(i)}{R.E(i)}$	Distance and Residual Energy
CF2	$F.F(i)=\frac{1}{d(i)}$	Distance Only
CF3	$F.F(i)=\frac{1}{R.E(i)}$	Residual Energy
CF4	$F.F(i)=\frac{1}{d(i)[R.E(i)]^2}$	Distance and Residual Energy
CF5	$F.F(i)=\frac{1}{d(i)[E-R.E(i)]^2}$	Distance and Dissipated Energy

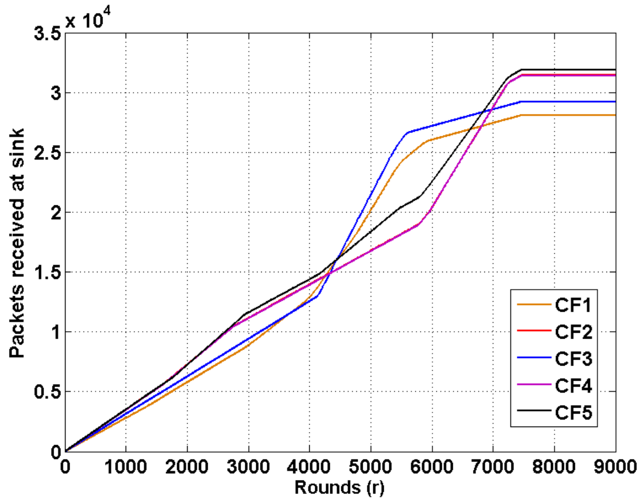

Fig. 3. Throughput comparison of various forwarding functions.

As discussed above, the cost functions CF4 and CF5 have nearly same performance. To generalise the proposed model we modify CF4 and now defined as E1 protocol with forwarding function as:

$$FF(i) = \frac{1}{d(i)\left[R.E(i)\right]^{p}}, \quad p \geq 2 \tag{6a}$$

As it is useless to select a forwarding node which is far away from the data sending node therefore forwarding nodes are selected which are closest to transmitting node.

As a second modification we define forwarding function as

$$FF(i) = \frac{1}{d(i)\left[E - R.E(i)\right]^{p}}, \quad p \geq 2 \tag{6b}$$

We defined this protocol as E2. In this function we consider that the energy lost which is defined as difference in the energy of initial energy and left over energy after each round. Also the nodes with lesser energy should not be considered as forwarding node.

5. Simulation Results and Analysis

In the simulation various values of index *p* are considered. However, same results are found for all values greater than or equal to 2, thus we fix it to 2. The sensor node distribution (network) is shown in Fig. 1. The pseudo code for ATTEMPT and SIMPLE and proposed protocol is detailed below:

Algorithm 1: ATTEMPT	**Algorithm 2: SIMPLE/PROPOSED**
Routing Phase	**Routing Phase**
if (route 1 < route2)	In each round
Route1=selected route	For each node
else	Select forwarder using FF
Route2=selected route	**if** (min FF1 < minFF2)
if (route 2 < route1)	select node1=forwarder node
Route2=selected route	**else**
else	select node2=forwarder node
Route1=selected route	**if** (min FF2 < minFF1)
if (route1=route2)	select node2=forwarder node
$E_{hop\text{-}count}$ ← Energy consumption for a route	**else**
if ($E_{hop\text{-}count1} < E_{hop\text{-}count2}$)	select node1=forwarder node
Route1=selected route	E_{th} ← Threshold Energy
else	**if** FF node Energy > E_{yh}
Route2=selected route	select node as forwarder
endif	**else**
endif	Directly transmit to sink
endif	**endif**
endif	**endif**
	endif

With keeping in mind the end goal of evaluation of the protocols we have carried out an extensive a group of experiments by making use of MATLAB R2010a. In the first set of results we made a detail study of the performance of the SIMPLE protocol by making the comparisons with the present protocol M-ATTEMPT. In the second part SIMPLE protocol is compared with proposed one.

5.1. Comparison of simple and attempt protocol

In Fig. 4, number of dead nodes vs. number of rounds is plotted. In ATTEMPT protocol at the round 2161, all of sudden 3 nodes become dead. However, in case of SIMPLE protocol till rounds 4436 number of dead node remains as zero. From rounds 4436 to 5390 rounds the number of dead node is one thereafter, number of dead node rises and crosses the ATTEMPT curve at the round 5546.

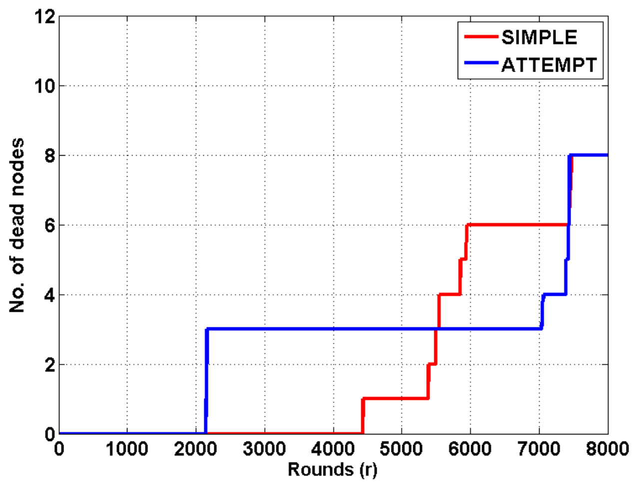

Fig. 4. Number of dead nodes vs. rounds.

For ATTEMPT, number of dead nodes remains two till round 7047 however number of dead nodes enhances and at the round 7445 and the number of dead nodes becomes 8. Thus the stability of period of the SIMPLE protocol is larger in comparison to ATTEMPT protocol. In ATTEMPT protocol for a larger number of rounds which also include earlier rounds number of dead nodes remains as three thus it performance is expected to be poor in terms of throughput.

In Fig. 5, residual energy vs. round is plotted. Over here till 4000 round the residual energy of SIMPLE protocol nodes is higher. Thereafter, residual energy decreases with number of rounds. The number of packets received also depends on number of alive nodes, therefore Figs. 4 and 5 hold direct correspondence. As in ATTEMPT, till rounds 2161, number of dead nodes is zero and thereafter number of dead nodes becomes three. Thus, a shift in residual energy can be expected as shown in graph. The behaviour of all the graphs can be understood as follows: Simple protocol relies on multi-hop topology, therefore node far away from sink node used forwarding nodes to send packets to the sink. Forwarding nodes are elected using forwarding function in Eq. (1).

Selection of proper forwarding nodes in each round saves energy. As in this mechanism in each round most probably different forwarding nodes are selected, therefore this multi-hop method is a kind of load balancing mechanism which restricts the accumulation of load on a particular node. Simulation results reveals that SIMPLE protocol consume lesser energy till 60% of simulation rounds. This clearly state that, more node will have more energy to transmit packets to sink, thus it improve both stability period and throughput. In M-ATTEMPT some nodes exhaust very early due to heavy loading conditions.

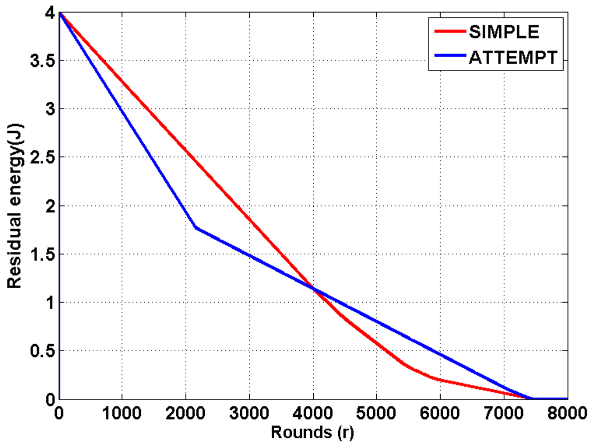

Fig. 5. Residual energy vs. rounds.

However in case of SIMPLE protocol from rounds 4500 to 6000 numbers of dead nodes increases from 1 to 6 with crossover with ATTEMPT curve at 5390. Thus, residual energy show variations in the curve and it comes down below to ATTEMPT curve due to the larger number of dead nodes, and finally residual energy goes to zero at 7445 rounds.

In Fig. 6 packet received at the sink vs. round is plotted, till 3000 rounds the packets received remain the same for both the protocol. Thereafter a huge difference is observed in the packet received. In case of ATTEMPT protocol the total packet received are 1.745×10^4, while for SIMPLE protocol, the number of received packets are 2.8×10^4. Therefore, a huge rise in the packets received and in terms of percentage it is more than 60%.

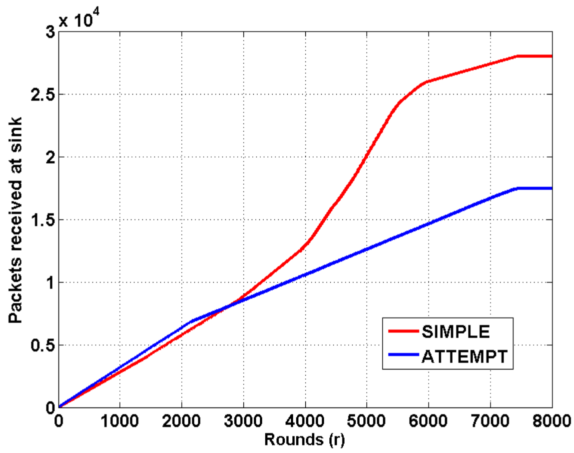

Fig. 6. Packet received at the sink vs. rounds.

5.2. Proposed work and comparison with simple protocol

In this section, results of proposed model are compared with SIMPLE protocol. In Fig. 7, number of dead nodes vs. number of rounds is plotted. In ATTEMPT protocol at the round 2161, all of sudden 3 nodes become dead. However, in case of SIMPLE and E1 till rounds 4436 number of dead node remains as zero. With SIMPLE protocol, the numbers of dead nodes become 6, around the rounds 5917. In E2 till round 2938 number of dead nodes remain zero, and 2939 to 5470 rounds the number of dead node is only one. From rounds 5471 to 7222 numbers of dead nodes are two. There after it catches other protocols.

In Fig. 8, residual energy vs. round is plotted. Here the residual energy curve for SIMPLE and E1 shows similar behaviour and finally residual energy goes to zero at 7445 rounds. Thus in terms of residual energy saving as such no advantage gain with E1. However the E2 protocol has better saving of energy due to lesser number of dead nodes.

In Fig. 9 packet received at the sink vs. Round is plotted, it is clear from the figure that the performance of the proposed protocols is better in comparison to the SIMPLE protocol. After 6000 rounds a significant difference in the packet received at the sink can be observed. In case of E1 protocol the total packets received are 3.06×10^4, while for SIMPLE protocol; the numbers of received packets are 2.8×10^4. Therefore, a rise in the packets received and in terms of percentage it is 9.28%. However, in case of E2, the numbers of received packets are 3.21×10^4 which is 12.46 better than SIMPLE protocol.

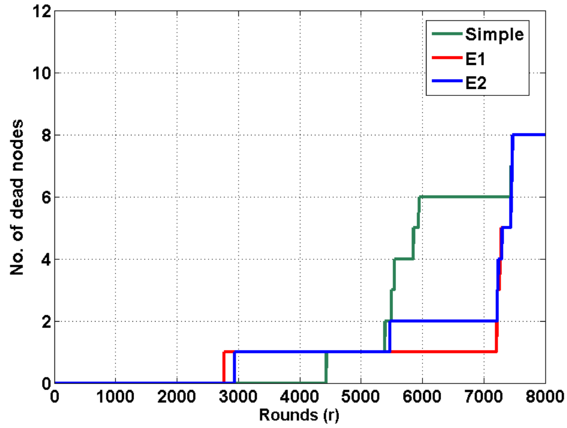

Fig. 7. Number of dead nodes vs. rounds.

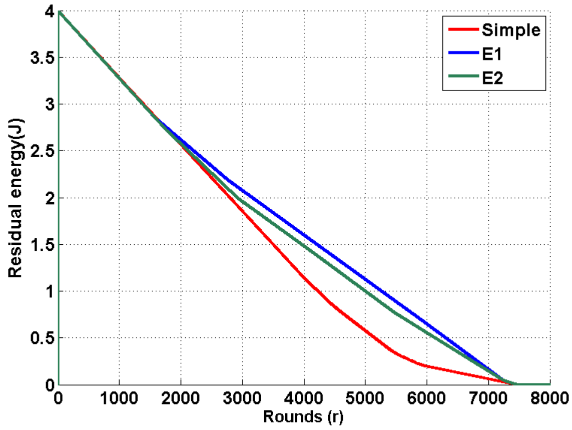

Fig. 8. Residual energy vs. rounds.

From above results it is clear that, the proposed protocols select the forwarding nodes more efficiently in comparison to SIMPLE protocol. This leads to be longer network life time and higher throughput.

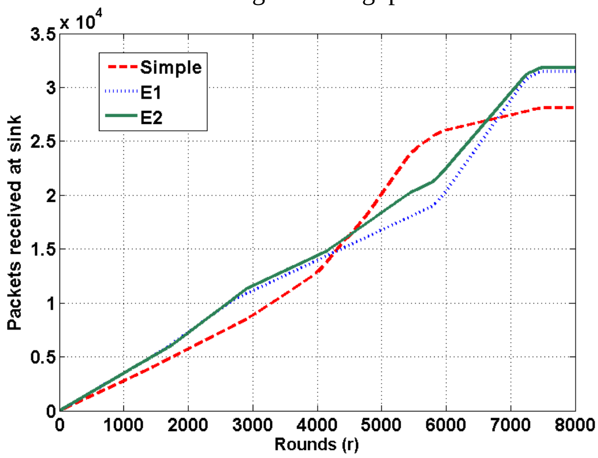

Fig. 9. Packet received at the sink vs. rounds.

6. Comparison with Recent Protocols

The comparison of recently published protocols is shown in Fig. 10. Very recently in iM-SIMPLE protocol is proposed where maximum possible throughput is 3.0×10^4 [21].

Thus, still our protocols E1-performance is 2% better than the iM-SIMPLE, and E2 performance is 6.7% better than the iM-SIMPLE. The performance of E2-SIMPLE is 12.46% better than SIMPLE protocols.

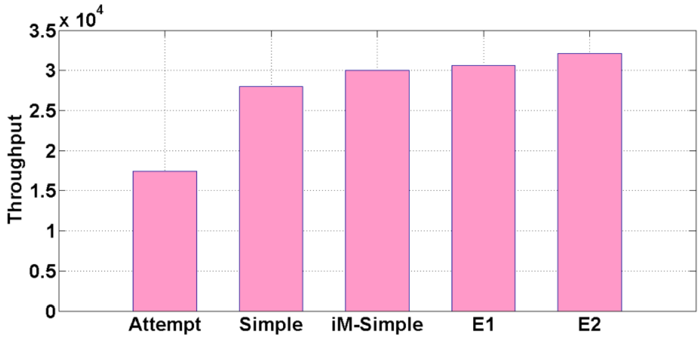

Fig. 10. Throughput comparison of recent protocols.

7. Conclusions

In this work an energy efficient wireless body area network protocol is presented. The selection of forwarding nodes is based on the cost function which is dependent on the distance and energy. The major conclusions can be summarized as follows:

- It is found that the proposed protocol works well in comparison to earlier proposed protocol ATTEMPT, SIMPLE and iM-SIMPLE.
- The throughput of the proposed protocol is nearly 12.46% more than the SIMPLE protocol. However, in comparison to iM-SIMPLE the E2-SIMPLE has 6.7% better throughput.
- In the major conclusions, it is also found that the residual energy have no or little effect on throughput. However, distance has significant effect on the throughput.

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