Energy-Efficient Mobility-Aware Clustering Protocol in WBASN for eHealth Applications

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Abstract. Wireless body area sensor networks (WBASN) becomes an emerge network which is now implemented for eHealth applications. The WBASN consists of multiple embedded biosensors and the coordinator. The biosensors collect vital data of human body, which will be transmitted to the coordinator; then, the coordinator forwards the vital data to doctor via the Internet. Because many sensors may select the same routing path to the coordinator, the collision of transmission may occur which leads to degrade network performance. In this paper, we proposed an energy-efficient mobility-aware clustering protocol (EMAC) which allows the sensors to form into clusters, then only cluster heads forward data to the coordinator. The results show that network performance has been improved in terms of high residual energy at the sensor nodes and high received packets at the coordinator.

Keywords: Wireless body area sensor network · Energy-efficient · Clustering · eHealth applications

1 Introduction

Wireless body area sensor networks (WBASN) are implemented for eHealth applications which will monitor the vital data of human for medical treatment at the hospital or at home [1–3]. The wireless biosensors can be attached or deployed on-in the human body to collect vital signals, such as heart rate, blood pressure, or temperature [3]. These biosensors can transmit data via the wireless link, the human can move freely at home or the hospital which is very convenient and helpful to the elderly. The typical network for eHealth applications can be described as in Fig. 1 [1,3]. In Fig. 1 the WBASN topology consists of one coordinator at the center of network, and many biosensors which can be deployed at the arm, leg, or shoulder of human body. The vital data from the human body can be transmitted to the gateway which forwards data to the medical

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server or the doctor through Internet for eHealth applications. In the situation where many biosensor nodes transmit data to the coordinator at the same time, many nodes may select the same routing path to transmit data to the coordination. Therefore, collision may occur which cause re-transmission packets. As a consequence, the energy consumption at node may increase while transmitting data [4].

Many routing protocols have been developed to reduce the energy consumption at node by selecting the forwarder or forming into a cluster [5]. In [6], the Mobility-supporting Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop ProTocol (M-ATTEMPT) has been investigated which results in low energy consumption at nodes while considering the mobility and the rise of temperature at node. The node will select the neighbors to forward data to the sink, the node may have more than one route to the sink. In M-ATTEMPT, node selects the routing path to the sink node according to the path with less hop-counts or less energy consumption. In [7], the author applie multi-hop routing protocol in WBASNs which called the Stable Increased-throughput Multi-hop Protocol for Link Efficiency (SIMPLE). The SIMPLE protocol ensures the network efficiency in terms of high throughput, reliable and power efficient protocol in which the node selects the forwarder according to a cost function of distance to the sink and the residual energy of node. The clustering protocol has shown the benefits of preserving the energy consumption and increasing the throughput of the network.

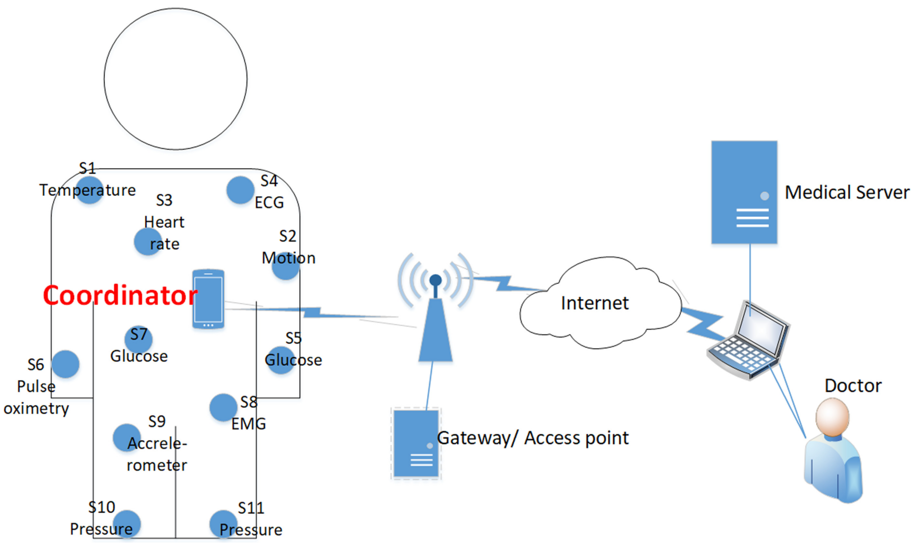

Fig. 1. WBASN topology for e-Health application.

In this paper, we proposed an Energy-efficient Mobility-Aware Clustering protocol (EMAC) protocol for WBASN. We assume that the topology of

WBASN is divided into multiple-hop communication. The algorithm aims to find the cluster in which the nodes can forward data to the coordinator with the lowest energy consumption. Our contribution can be explained as follows. Sensor nodes will form into the cluster by considering the residual energy and the network topology. The sensor node can elect to become the cluster head, then, the cluster head sends the HELLO message to its neighbors. The other nodes request to join the cluster by sending the REPLY messages. The cluster is updated after some rounds because the network topology changes according to the human mobility. We evaluate our proposed algorithm by comparing to other clustering protocols in terms of received packets at the coordinator, the number of dead nodes, and residual energy at node. The rest of paper is organized as follows. In Sect. 2, the energy-efficient mobility-aware clustering protocol (EMAC) protocol for WBASN is introduced. In the next section, the network performance is evaluated. Finally, the paper is concluded in Sect. 4.

2 Energy-Efficient Mobility-Aware Clustering Protocol in WBASN

2.1 Network Model

The network of WBASN is considered as in [6,7] in which a WBASN consists of a coordinator and M biosensor nodes in e-Health application. The network topology is shown as in Fig. 1. Biosensor node can transmit vital data to the coordinator via either one-hop communication or multi-hop communication. The sensor node is denoted as s_i. We assume that several sensor nodes can form a cluster in which the cluster head collects data packets of its cluster members then forwarding to the coordinator. The biosensor nodes can be categorized into cluster head (CH) or cluster members (CM). The network can be divided into C clusters in which each cluster has one CH and K CMs. The cluster head will be selected according to the residual energy and bandwidth of node. We define the bandwidth of cluster head as the total number of successfully received packets at the cluster head which cluster head will forward to the coordinator. Because of the limitation of the battery, the node will change the role of cluster head after some rounds.

In WBASN, each sensor node collects data according to the type of sensors such as heart rate, blood pressure. Data can be categorized into emergency data or periodic data which have different requirements of throughput, latency, and data rate. In our work, some reasonable assumptions can be adopted as follows:

- Nodes are dynamic with the same initial energy 0.5J and are deployed in or on the human body.
- The network consists of only one coordinator node and the location of coordinator node is known by all the sensor nodes. The distance between coordinator node to the sensor may change by time because of the movement of human body.

- The sensor nodes have a certain limitation as energy, storage, radio communication capabilities, and bandwidth.
- The depth of node is defined as the number of hops to reach to the sink node.
- After the cluster is formed, the sensor node will transmit data to the cluster head and, then, the cluster head forward aggregated data to the sink.

2.2 Energy Consumption Model

In WBASN, if nodes transmit data to the coordinator via one-hop transmission, the model of energy consumption for transmitting b-bits messages is calculated as in [6,7]. The energy expended to transmit the b-bits message (Etx) and to receive this message (Erx) are respectively given as follows:

$$E_{tx} = b * (E_{tx-elec} + E_{amp} * d^2) \tag{1}$$

where $E_{tx-elec}$ is the electronics energy dissipated per bit, d denotes the distance between transmitter and receiver, E_{amp} is the energy required for the amplified circuit.

$$E_{rx} = b * E_{rx-elec} \tag{2}$$

where $E_{rx-elec}$ is the electronics energy dissipated per bit.

In our algorithm, after sending data to the cluster head, the cluster member turn off the radio then enters the idle state in order to save energy. If the sensor node si transmits data to the coordinator; the energy consumption for one-hop transmission is calculated as follows

$$E_{tx}(i, S) = D_i * (E_{tx}) = D_i * b * (E_{tx-elec} + E_{amp} * d^2) \tag{3}$$

where D_i is the depth of node s_i, b is the total bits of data.

If node s_j is the cluster head; the depth of cluster j is denoted as D_j . The number of cluster member of cluster j is denoted as K; b denotes the total bits of data. The total energy consumption for receiving data from K cluster members is calculated as follows:

$$E_{rx}(CH_j) = D_j * K * E_{rx} = D_j * K * (b * E_{rx-elec}) \tag{4}$$

Energy consumption for transmitting b-bits data from cluster head to the sink is calculated as follows:

$$E_{tx}(CH_j, S) = D_j * K * E_{tx} = D_j * K * b * (E_{tx-elec} + E_{amp} * d^2) \tag{5}$$

The total energy consumption for transmitting and receiving at the cluster head is denoted as follows

$$E_{consump}(CH_j, S) = E_{tx}(CH_j, S) + E_{rx}(CH_j) \tag{6}$$

2.3 Energy-Efficient Mobility-Aware Clustering Protocol

In our proposed protocol, each node stores information of the sensor ID, distance to the coordinator, list of neighbors, residual energy, number of generated packets, and the current bandwidth. Let assume that bandwidth at node s_j is calculated as total of all packet data needed to send to the cluster head or the coordinator node. The maximum bandwidth in the network is defined as $BW_{threshold}$. If node s_j is the cluster head and the total number of cluster members is K; each member node s_j generates packet with length of b_{ij}. Total bandwidth at node s_j is calculated as follows:

$$BW_j = \sum_{i=1}^{K} b_{ij} \tag{7}$$

In order to balance the energy consumption at node and maximize the total bandwidth, the sensor nodes use the value of energy consumption and the total bandwidth in the history to calculate the probability to elect cluster head as follows

$$P(CH_i(t)) = \alpha \frac{E_{consump}(t-1)}{E_{res}} + \beta \frac{BW_i(t-1)}{BW_{threshold}} \tag{8}$$

where α and β are the coefficient in which $\alpha + \beta = 1$; $E_{consump}(t\text{-}1)$ is the energy consumption at round (t-1) which is calculated as (9); $BW_i(t\text{-}1)$ is the bandwidth at round (t-1).

Our main contribution aims to select the cluster head according to the energy consumption and the total received packet in the past. Assume that node si is currently a cluster head, then node may become cluster head or cluster member at the next round. If energy consumption of node $E_{consump}$ increases ΔE and $BW_i(t)$ increases ΔBW, then $P(CH_i)$ increases. In this case, due to the rise of energy consumption may lead to the short lifetime at node s_i, node s_i will become a cluster member in the next round.

The sensor nodes select the cluster head to join according to the distance to the cluster head. Each node creates the list of cluster head nearby as $N_{HELLO} = \{s_i \mid d(m,i) \leq TRx,\ P(CH_i) \leq P_{th}\}$, in which $d(m,i)$ is the distance between node s_m and cluster head s_i, TRx is the transmission range of node s_m, P_{th} is the threshold value to elect to cluster head. After receiving the HELLO messages of the neighbors, the sensor node select the cluster head with the shortest distance to join in order to reduce the energy consumption in trasmitting packets. The sensor s_m will select the cluster head amongst the list of N_{HELLO} as follows:

$$min_{dist-to-CH} = min\{d(m,i) \mid s_i \in N_{HELLO}\} \tag{9}$$

The cluster formation algorithm is shown in The Algorithm 1. Each sensor node calculates the probability to elect the cluster head, shown from line 1 to line 8. If the $P(CH_i)$ is smaller than the threshold value, node elects to become cluster head and broadcast the *HELLO* message. We assume that the number of cluster heads in the network can be selected as in [8]. For all nodes do not send

Algorithm 1. Energy-efficient mobility-aware clustering protocol

Input: Input: N nodes, node ID, neighbors of node
Output: Output: list of cluster head $LstCH$ and cluster members of each cluster head
1: Assign $LstCH = \emptyset$; $LstCM = \emptyset$
2: **for all** $s_i \in N$ **do**
3: Calculate the probability to elect cluster head $P(CH_i)$ as in (8)
4: **if** $P(CH_i) \leq P_{th}$ **then**
5: Node s_i broadcast HELLO message
6: Update $LstCH = LstCH \cup s_i$
7: **else**
8: Wait for HELLO message
9: Update $LstCM = LstCM \cup s_i$
10: **end if**
11: **end for**
12: **for all** $s_m \in LstCM$ **do**
13: **if** node s_m receives HELLO message **then**
14: Node s_m waits for HELLO message from neighbors, create a list N_{HELLO}
15: Node s_m finds the CH with $min_{dist-to-CH}$ as in (9)
16: Node s_m sends REPLY message to node s_i
17: Node s_i updates its cluster member $LstCM(s_i) = LstCM(s_i) \cup s_m$
18: **else**
19: Node s_m directly send data to the coordinator
20: **end if**
21: **end for**

the *HELLO* message, nodes will wait for the *HELLO* message then select the cluster to join, shown from line 10 to line 17. The node may receive more than one *HELLO* messages from its neighbors as in line 11. Node selects the cluster head with the least distance comparing to others as in line 12. After selecting cluster head, node sends the REPLY message to the cluster head as in line 13. By receiving the *REPLY* from the other neighbors, the cluster head updates the cluster members as in line 14. Because of the mobility, some nodes may out of the transmission range of the cluster head; then they does not receive any *HELLO* message. These nodes will directly send data to the sink node.

3 Performance Evaluation

In this section, the energy-efficient mobility-aware clustering protocol (EMAC) protocol is evaluated and compared to the ATTEMP and SIMPLE algorithm [7] by using Matlab. The ATTEMP and SIMPLE also deploy the clustering protocols which select the cluster head based on the distance to the sink and the residual energy of node.

3.1 Simulation Environment

In our simulations, nodes are uniformly deployed at random body as in [7]. The sink node is fixed at the center of the network area. We also deploy the energy consumption model for transmitting and receiving data as in [7]. The detailed simulation parameters are listed in Table 1. We assume that the network deployment is changed after 1000 rounds in order to evaluate the network mobility. Each sensor node randomly generates packets to send to the coordinator.

Table 1. Simulation environment.

Parameter	Value
Network size	2 m * 2 m
Number of nodes	20
Data rate	250 kbps
Initial energy	0.5 J
$E_{tx-elec}$	16.7 nJ/b
$E_{rx-elec}$	36.1 nJ/b
E_{amp}	1.97e−9 nJ/b
α	0.5
β	0.5
Pth	0.2

3.2 Simulation Results and Discussion

The network performance is evaluated with respect to total received packets at the sink, number of dead nodes, and the residual energy of node [7]. In order to evaluate the stability of network performance in the dynamic environment, we evaluate the EMAC in three difference scenarios of mobility. The network deployment changes after 1000 rounds, the nodes mobility follows the Random waypoint mobility model with different velocity as in [5–7]. Three values of velocity are selected as 0.1 m/s, 0.2 m/s, and 0.3 m/s for low mobility, average mobility, and high mobility, respectively. The number of dead nodes is shown in Fig. 2. In the worst scenario, the nodes start to die at round 2500th, but half of the nodes die at round 8000th.

The average residual energy of each node is shown in Fig. 3. The residual energy declines quickly in case of high mobility. Despite that, the residual energy remains higher than 0.05 Joules at the round 8000th. As a consequence, the network lifetime of nodes remains longer. Because the high mobility scenario cause changes in the network topology, the nodes may out of transmission range of its cluster head then they require more energy consumption for data transmission. However, high mobility requires the cluster to re-establish which the sensors send more HELLO and REPLY messages.

The total received packets at the coordinator are calculated by total packets successfully receiving at the coordinator node. The simulation result in Fig. 4

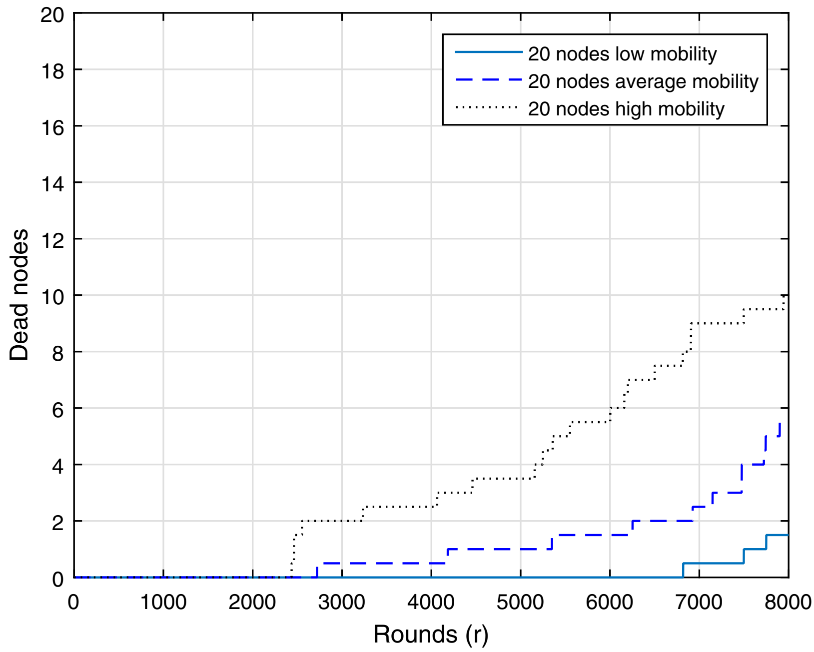

Fig. 2. Number of dead nodes in different network scenarios.

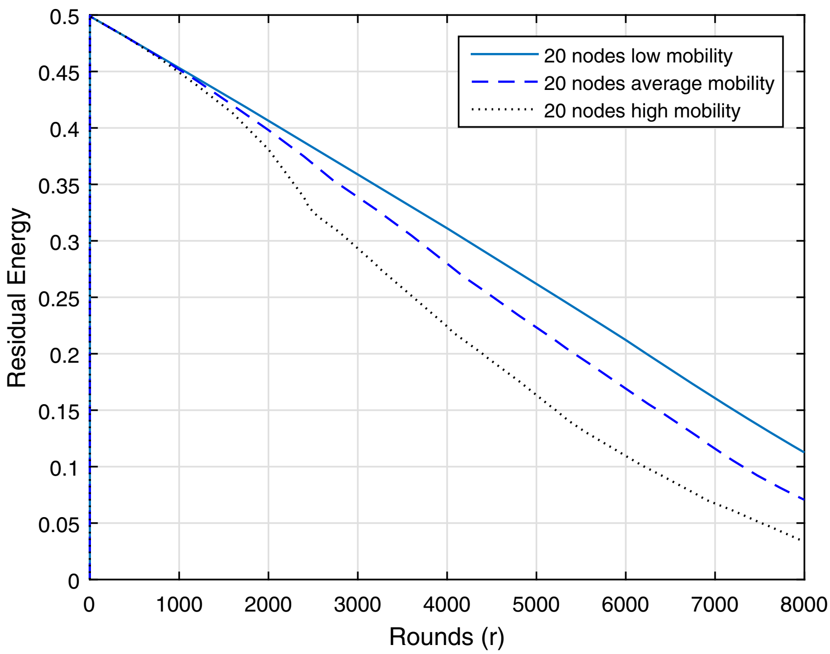

Fig. 3. Residual energy of nodes in different network senarios.

shows that our proposed EMAC performs better than SIMPLE and ATTEMP with respect to the higher number of received packets. In EMAC, nodes only transmit data to the cluster head which is already in the transmission range of node. Therefore, the probability of packet transmission is high. As a result, the total received packet at the coordinator is higher comparing to other protocols.

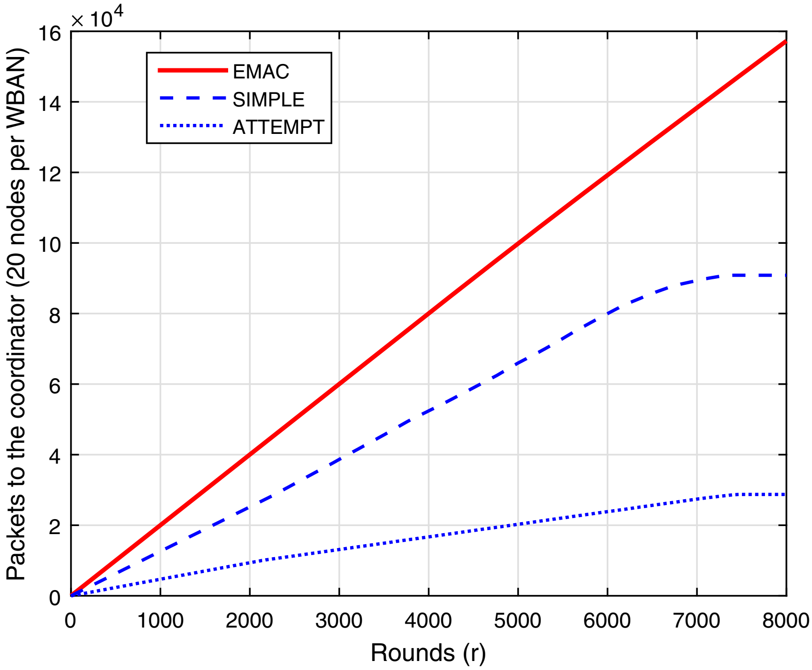

Fig. 4. Number of received packets at the coordinator node.

In Fig. 5, the number of dead nodes is used to evaluate the network lifetime. The dead node is calculated when nodes die due to energy depletion of battery. The simulation result in Fig. 3 shows the number of dead nodes along with the rounds. Our proposed EMAC performs better than ATTEMP and SIMPLE in which the nodes start to die in the 4500th round, while in the nodes dies in the 2000th and 3800th round as in the ATTEMPT and SIMPLE, respectively. In EMAC, the nodes change the role of cluster head after some time according to the history of bandwidth, which allows the nodes reduce the traffic. The non-cluster head will elect to be cluster head in the future, therefore, the traffic is kept balance in the network.

In the EMAC, the cluster head only communicates with only cluster members in each round, the number of overhead packets such as HELLO and REPLY messages are limited within K cluster members. The cluster member only transmits to the cluster head via the assigned time slot, the collision can be reduced.

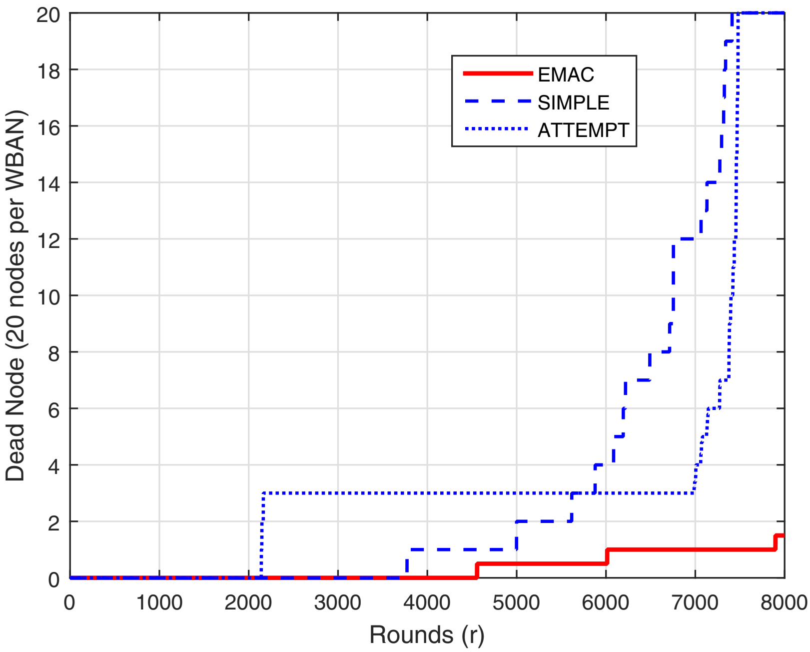

Fig. 5. Number of dead nodes.

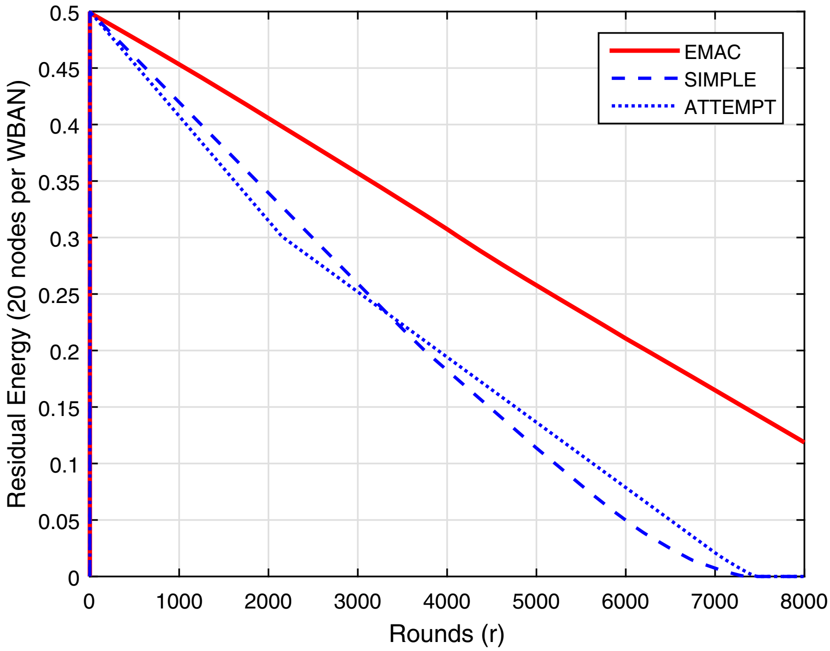

Fig. 6. Residual energy at one node.

Therefore, the consumption energy is reduced at cluster head per round. If the network topology change, the cluster will be re-selected with new cluster head and cluster members. In EMAC, the nodes select its cluster head according the least distance which results in low energy consumption in transmitting. Figure 6, shows that the average residual energy of EMAC is higher than ATTEMPT and SIMPLE.

4 Conclusion

In this paper, we have proposed the EMAC protocol to maintain the cluster with the change of network topology due to mobility. The biosensors nodes offer low dead nodes as well as high energy residual. However, the low dead nodes results in longer network lifetime which guarantees high packets received at the coordinator. The simulation evaluation shows that the EMAC outperforms other protocols in terms of higher residual energy and higher successful received packets at the coordinator node. In our future works, we will improve the cluster head selection based on the temperature rise at nodes in order to balance energy of nodes.

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