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Traffic Control Thermal-Aware Routing in Body Area Networks

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Abstract

Due to increasing developments of medical science, early detection and receiving exact information in treatment of diseases and even preventing them are very important. Body Area Networks (BANs), a subset of Wireless Sensor Networks (WSNs), can deliver vital signs of patients to physician by collecting and analysis of patients' data and with applying different types of medical sensors. Since in-vivo sensors nodes transfer biomedical data to the neighboring nodes, produced temperature will be appeared from processing and communications in the human body. Routing protocols can have important role in balancing the temperature of sensors. In this paper, a thermal-aware routing protocol is proposed which uses two thresholds. The first threshold is used for preventing the increase of more temperature and the second threshold is used for decreasing sensor temperature. We evaluate the performance of the protocol using extensive simulations. The results of simulation show that the proposed protocol improves average temperature rise, packet delivery ratio and packet delay compared to the similar routing protocols.

Keywords: Body Area Network, Thermal-aware, Routing, Hop by Hop

1. Introduction

Body Area Networks (BANs) as special type of Wireless Sensor Networks (WSNs) are applied in different fields especially in medical science for supervision on the human body. Traditional health supervision system in addition to false issue of information involves the issue of cost increasing of healthcare (Latré et al., 2011; Chen et al., 2011). Small and smart sensor can connect to the human body as a result of the development of microelectronic and microelectromechanical systems. This device collects vital signs of patient and sends it to medical personnel such as pharmacists and nurses for more experiment and analysis.

Implanting biomedical sensors inside the human body causes damages on environmental tissues. Since the sensors inside the body transfers biomedical data to the neighboring node, produced heat of processing and communications inside the human body will be appeared. The operation on node produces heat and causes increasing the temperature in its surrounding. When the power consumption of node is very low or node practically does not send data, it may not produce considerable heat. But when node always sends and receives data in considerable time, produced heat with node could not be ignored (Oey and Moh, 2013).

One of the methods for dealing with this problem is thermal-aware routing. In the existing thermal-aware routing protocols in BANs, traffic is redirected to avoid hot spot areas in the network. Traffic redirection causes unbalanced traffic in the network, leading to more packet delay and more energy consumption of the nodes. Therefore, a thermal-aware routing protocol not only should decrease the temperature rise of the nodes, but also needs to balance traffic in the network.

Proposed protocol is a thermal-aware routing protocol that manages the temperature of sensors with traffic control through two stages. In the first stage, if the temperature of a sensor will be upper than the first threshold, the rate of traffic sending to that sensor will be controlled by previous nodes. In the second stage, if controlling traffic rate is not effective and the temperature of sensor will be beyond the second threshold, the traffic which sent to this sensor redirects and will be sent toward other sensors until this sensor will be cool. Node with the lowest hop counts to the sink is selected as next alternative node. If several nodes have the equal hop counts to the sink, node is selected with the least temperature. In normal conditions of network means the state in which the temperature of sensors are lower than the first threshold, the node of next hop of each node will be selected based on criteria of the number of hop and remaining energy and packets will be sent to them.

Furthermore, we point out a brief review of related works on thermal-aware routing protocols in Section 2 and in Section 3, we discuss our proposed protocol. Section 4 shows details of our simulations and evaluates the performance of the proposed model. Lastly, Section 5 reveals the conclusion.

2. Related work

Different thermal-aware routing protocols are designed in body area networks (Jiang et al., 2017; Bangash et al., 2014). Because Quality of Service (QoS) requirements in BANs are very important, most of the routing protocols in these networks provide QoS parameters (Razzaque et al., 2017, Bhanumathi and Sangeetha, 2017).

TARA (Thermal-Aware Routing Algorithm) (Tang et al., 2005) attempts to avoid the entrance to hot areas by observing the temperature of neighboring nodes and diverts the packet by using retreat strategy from the route. This strategy causes high delay and low life span of the network but it balances the pressure in the network.

HPR (Hotspot Preventing Routing) protocol (Bag et al., 2007) does not pass packets from random long routes in the network. Instead, it tries to pass packets from the shortest route from the source to destination only with recurring very hot areas which may be in the route. Also it dynamically adjusts the route based on traffic situation of network. Hence HPR prevents the formation of hot points that have very high temperature and also delivers packets with very low delay to destination.

LTR (Least Temperature Routing) (Bag et al., 2006) is developed based on TARA protocol. Each node connects to the node of its neighbor and collects data about their temperature or observation of their activity. Each node tries to transfer packet to the coolest neighbor. Also a parameter of maximum mutation (MAX HOPS) is defined and if counting of receiving hop of packet exceeds from this parameter, the packet will be deleted. Comparative routing protocol with the minimum temperature (ALTR), another type of LTR protocol is comparative routing protocol with the minimum temperature. As we see based on the name of comparative routing with the minimum temperature, ALTR can match itself with special topologies. Since in some topologies of network as ring topology, the sequence of packet inevitably follows the same route and the temperature of sensor nodes on special routes will be increased and a forehand delay mechanism is used by ALTR.

LTRT (Least Total-Route Temperature) protocol (Takahashi et al., 2007) proposes the route with the least temperature in which the temperature of nodes converts to graphic weights and the minimum temperature routes are achieved. LTRT is a combination between SHR and LTR. Because LTRT wants to send packets with the shortest number of hop, it prevents sudden increasing in the whole network. Also since LTRT considers whole temperature of selecting routes, the routes which have high temperature is recurred and the packets will not approach to those routes.

TSHR (Thermal-Aware Shortest Hop Routing) (Tabandeh et al., 2009) is designed for applying where there is high priority for delivering packet to destination. In this protocol if a packet is deleted, it will be transferred again. TSHR protocol has two phases: First phase and second phase. In the first phase which is the phase of setting up, each node makes its routing table and achieves the data of neighboring nodes. The second phase which is the phase of routing, nodes which try to direct packets toward destination use the protocol of the shortest route and the route recognizes itself toward destination.

Other thermal-aware routing protocols (Kamal et al., 2010; Movassaghi et al., 2012; Javaid et al., 2013) were designed which by focusing on main parameter of temperature try to lower temperature of sensors in network. In those protocols, a threshold is defined for preventing increasing temperature not to pass the traffic of hot points of network.

TMQoS (Thermal-aware Multiconstrained Intrabody QoS Routing) protocol (Monowar et al., 2014) considers delay and reliability which is a significant need for the types of different programs. Also in this protocol, the temperature of nodes is kept in acceptable level. Furthermore this protocol presents a cross layer routing based on the table of routing that guarantees different needs of QoS.

TLQoS (Thermal-Aware Localized QoS Routing) (Monowar et al., 2015) is a local approach in selecting route with the purpose of pleasing and satisfying QoS situation about the improvement of delay and reliability for the types of traffic in different nodes in the body and also it prevents the formation of nodes with high temperature that is known as hot point. TLQoS recognizes a routing power based on QoS criteria and the temperature of nodes.

CDR (Critical Data Routing) protocol (Bangash et al., 2015a) was presented that its purpose is routing of critical data. This protocol classifies data to critical and noncritical data and manages high temperature. The results show that CDR protocol manages critical data in special limited time and with high reliability.

DCR (Data Centric Routing) (Bangash et al., 2015b) is designed for body wireless sensor networks which is based on routing with the guarantee of services quality. In this protocol, a special route for critical data which achieved from vital sensors of human body is extracted. Recognized route considers quality parameters of services and selects the best route for their guarantee. But this protocol does not consider the priority of nodes in network and it has more overhead cost towards other protocols.

3. Proposed protocol

The components of proposed protocol including the hello packet, neighboring table, estimating the temperature of node and proposed algorithm which are explained in the following sections.

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3.1 *Hello packet*

A node for better decision making should update data of its neighboring node. For this purpose hello packet is periodically transferred in special interval among nodes. The structure of a hello packet is based on Fig. 1.

Sequence Number	Source Node	Residual Energy	Temperature	Hop Count

Fig. 1. The structure of hello packet

The sequence number is the number of all unique packets and it is for recognizing each node was sent. Source node is the node of source sender related to packet. Residual energy is the remaining energy of source node in this field. Temperature is a temperature that node has now and its computation will be noted in next part. The hop count is the least number of hops of each node to the sink.

3.2 *Neighbor table*

Data which hello packet sends to its neighboring node is placed in neighbor table. The structure of neighbor table of a node is shown on Fig. 2.

Neighbor Node	Residual Energy	Temperature	Hop Count

Fig. 2. The structure of neighbor table

Neighbor node is the neighboring node identification of the node. Residual energy is the remaining energy of source node in this field. Temperature is a temperature that node has now and its computation will be noted in next part. The hop count is the least number of hops of each node to the sink.

3.3 *Temperature estimation*

The rate of increasing temperature of a node is computed by Eq. (1) (Tang et al., 2005).

$$T^t(x,y) = \left(1 - \frac{\Delta_t b}{\rho C_p} - \frac{4\Delta_t K}{\rho C_p \Delta^2}\right) T^{t-1}(x,y) + \frac{\Delta_t}{C_p} SAR + \frac{\Delta_t b}{\rho C_p} T_b + \frac{\Delta}{\rho C_p} P_c + \frac{\Delta_t K}{\rho C_p \Delta^2}\left(T^{t-1}(x+1,y) + T^{t-1}(x,y+1) + T^{t-1}(x-1,y) + T^{t-1}(x,y-1)\right) \quad (1)$$

In this equation, Δ_t is the discretized time step, b is the blood pressure, ρ is the mass density, C_p is the specific heat of the tissue, k is the thermal conductivity of tissue, x is the horizontal coordinate of point in time t, y is the vertical coordinate of point in time t, SAR is the attraction rate of body tissue, T_b is the fixed blood temperature, and P_C is the consumed power by nodes.

3.4 *Proposed Algorithm*

The proposed next hop selection algorithm is shown in Algorithm 1. In this algorithm, at first the temperature of next hop node is compared with the first threshold (Line No.1). If the temperature is less than the first threshold, neighboring nodes with the least hop is placed inside set NH and NH always has a next hop and it is never empty (Line No.2). If NH set has only one member (Line No.3) the same member is considered as next hop (Line No.4). Otherwise, node with the maximum remaining energy is selected as next hop (Line No.6). If the temperature of all nodes will be more than the first threshold, next node is selected based on the maximum remaining energy. If node temperature of next hop will be between the first and second threshold (Line No.10), the sending rate of the predecessor node is controlled (Line No.11). If node temperature is more than second threshold (Line No.13), node with the least temperature will be selected as next node (Line No.15).

Algorithm 1: Thermal-aware Next hop Selection

INPUT: T, Th_1 ,Th_2, N
1. if $T_{Nexthop} < Th_1$ then
2. NH = { $n \in N$| hop counts to sink for n is minimum }
3. if (NH=1) then
4. Next hop = NH
5. else
6. NR = { $n \in N$ | n has maximum residual energy }
7. Next hop = first element of NR
8. end if
9. end if
10. if $Th_1 < T_{Nexthop} < Th_2$ then
11. Control sending rate of predecessor node of node n
12. end if
13. if $T_{Nexthop} > Th_2$ then
14. NH={ $n \in N$ | hop counts to sink for n is minimum }
15. if (|NH| ==1) then
16. Next hop = first element of NH
17. else
18. NT={ $n \in N$ | node n with minimum temprature }
19. Nexthop = first element of NT
20. end if
21. end if

4. Performance evaluation

In this section, we compare proposed protocol with present similar protocols to recognize its efficiency toward other protocols. All simulations were performed by network simulator NS-2 version 2.35.

4.1 *Simulation Parameter*

Simulation parameters are shown in Table 1. The simulation parameters are used in different scenarios of network.

Table 1
Simulation Parameters

Parameter	Value
P_c	0.002 J
C_p	3600 J/kg. ^{0}C
B	2700 J/m3.s. ^{0}C
Δ_t	5 s
SAR	0.8 W/kg
T_b	37 ^{0}C
P	1040 kg/m^3
K	0.498 J/m.s. ^{0}C
Δ	1 m

4.2 Performance metric

In evaluating proposed protocol TRATC (Thermal-aware Routing Algorithm based on Traffic Control), different metrics are considered which are explained as follows:

Temperature rise: It is the average of increasing temperature of nodes which is the average of the changes of primary temperature of nodes in interval of simulation.

Energy consumption: It is the average of consumed energy of sensor battery in network. In routing of body sensor networks because of the limitation of battery power, the amount of consumed energy in a node and the rate of remaining energy of the nodes of a route are so important.

Delay: Delay is the time which takes until the packet reaches to destination. In routing of data sensitive to delay, data packets should reach to destination in the least time and if the time of sending packets is more than possible limit, it may be the end of time. This parameter is the average of delay of all packets.

Packet delivery ratio: It is the rate of packet delivery to the number of packets that will be sent successfully to destination (sink node) to all packets.

5. Results

In this part, the results of simulation are analyzed. In all figures, the results of simulation with the results of TLQoS and TSHR protocols are compared as similar mechanisms. The simulation is performed 20 times and there will be an average from results.

Fig. 3 shows the average temperature rise of sensors based on the number of source nodes. As it is observed in the figure, the average temperature rise of TRATC is less than other two protocols. The reason of this declining is that in the proposed protocol, the temperature of sensors will be controlled based on the first and second thresholds.

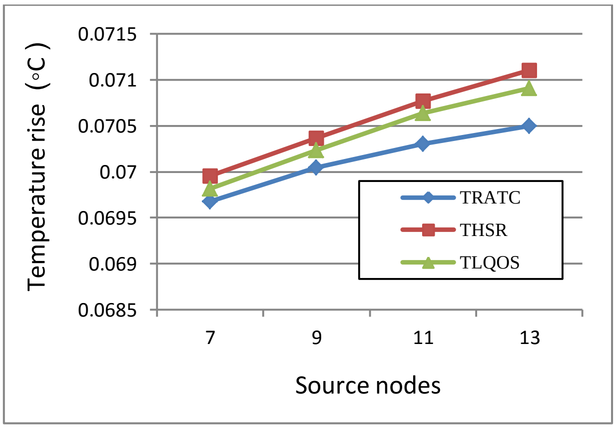

Fig. 3. Average temperature rise

If the temperature of sensors will be more than the first threshold, the sending rate will be controlled and if the temperature of sensor will be more than the second threshold, the traffic redirects to the other nodes until the temperature of that node will be lower. This issue causes declining the average of the temperature of sensor in the whole network because the traffic turned to the side of other node.

Fig. 4 shows the average energy consumption of sensors based on the number of source nodes that explained above and as it is seen in the figure, average energy consumption of the proposed protocol is nearly the same with two other protocols. It means TRATC decreases the temperature of network sensors without it uses more energy.

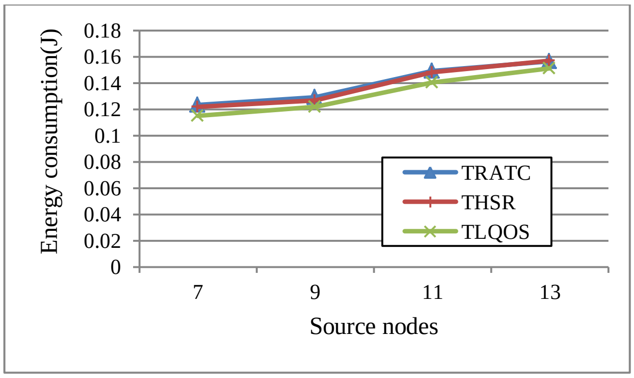

Fig. 4. Average energy consumption

Fig. 5 shows the rate of packet delivery of sensors based on the number of source nodes. As it is seen in the figure, TRATC has higher packet delivery ratio related two other protocols. The reason of this increasing is that in the proposed protocol, for usual state, remaining energy of the neighboring nodes are considered as one criteria for selecting the next hop node which this criterion extends the lifetime of network. By increasing network lifetime, more packets will be delivered to the destination.

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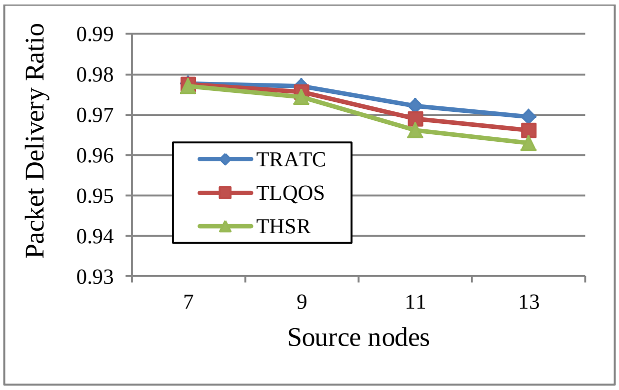

Fig. 5. Packet delivery ratio

Fig. 6 shows the delay of sensors based on the number of source nodes. As it is seen in the figure, TRATC has lower delay toward other two protocols. The reason of this decline is that in the proposed protocol, next hop node selection is performed based on the lowest hop counts to the sink which resulted in less delay of packets.

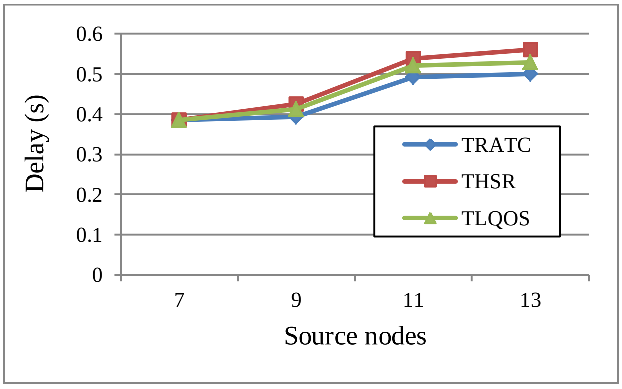

Fig. 6. Average delay

6. Conclusion

The paper has presented a thermal-aware routing protocol for BANs. In the proposed protocol, the temperature of sensors will be controlled based on the first and second thresholds. If the temperature of sensors will be more than the first threshold, the sending rate will be decreased and if the temperature of sensor will be more than the second threshold, the traffic is redirected to the other nodes. Results of simulation indicate that TRATC protocol has lower temperature rise, higher packet delivery ratio and lower packet delay than TLQOS and THSR protocols. However, average energy consumption of TRATC protocol is nearly the same with two other protocols. Ongoing work on this area includes designing a thermal-aware routing protocol considering the body movement and packet prioritization.

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