A Forwarder Based Temperature Aware Routing Protocol in Wireless Body Area Networks

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Abstract

A Wireless Body Area Network (WBAN) allows the seamless integration of miniaturized sensor nodes in or around a human body, which may cause damage to the surrounding body issue due to high temperature. Although various temperature aware routing protocols have been proposed to prevent temperature rise of sensor nodes, most of them accommodate single traffic transmission with no mobility support. We propose a Forwarder based Temperature Aware Routing Protocol (FTAR) that supports multiple traffic transmission for normal and critical data. Normal data is forwarded directly to the sink through forwarding nodes which are selected among mobile nodes attached to the arms and legs, while critical data is forwarded to the sink through static nodes attached to fixed body parts with no mobility. We conduct extensive simulations of FTAR, and conclude that FTAR has good performance in terms of hot spot generation ratio, hot spot duration time, and packet delivery ratio.

Keywords: Temperature aware routing, Wireless body area networks, Multiple traffic transmission

1 Introduction

A Wireless Body Area Network (WBAN) collects vital signs of patients using low-power and miniaturized sensor nodes, which are forwarded to physicians for real-time diagnosis and remote health monitoring [1]. As these sensor nodes are deployed on, or inserted inside, the human body, they have limited resources in terms of size, battery energy, memory and transmission range [2]. Another most important issue is the temperature rise of these sensor nodes. When the traffic is concentrated on one particular node, the temperature of that node rises sharply which leads to damage of the surrounding body tissues [3]. Although various temperature aware routing protocol have been proposed to prevent the temperature rise of the nodes, most of them support only single traffic transmission which results in delay or loss of critical data [4-7].

M-ATTEMPT [8] has been proposed to support multiple traffic transmission. In M-ATTEMPT, each node transmits critical data to the sink directly through single-hop communication, while normal data is forwarded to a node having large residual energy. However, single-hop communication is not suitable for WBAN because the transmission power increases according to the distance between the source node and the sink. TLQoS [9] has been proposed to overcome the drawbacks of single-hop communication of M-ATTEMPT. TLQoS is a multi-hop based routing protocol that forwards critical data to the node with low latency and high reliability. On the other hand, normal data is forwarded to the node with the lowest temperature. However, since the number of nodes constituting the network is very small in the WBAN, it is difficult to prevent the temperature rise of intermediate nodes through multi-hop communication. However, the authors have not provided a mechanism to utilize mobile nodes which may overcome the limitations of multi-hop communication. Unlike previous studies, the routing protocols proposed in [10-11] use a mobile node as a forwarder. Each node stores the packet in its buffer until it is connected to the sink, or forwards the packet to the node that is most likely to be connected to the sink. This mechanism has an advantage of preventing the temperature rise of intermediate nodes, however it increases end-to-end delay and loss of critical data. In addition, since these protocols do not consider the temperature rise of nodes, the temperature of a specific node may rise sharply.

To solve the above-mentioned problems, we propose a Forwarder based Temperature Aware Routing Protocol (FTAR) that supports multiple traffic transmission and utilizes a mobile node as a forwarder. To support multiple traffic transmission, FTAR categorizes the data into normal and critical data. Nodes select the mobile node that is most likely to be

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DOI: 10.3966/160792642019072004015

connected to the sink as a forwarder in order to transmit normal data to the sink directly. However, if there is no mobile node, normal data is transmitted to the node with the lowest temperature. In contrast, critical data is transmitted to the node with the smallest number of hop count in order to reduce the end-to-end delay.

The rest of paper is organized as follows. Section 2 describes the related work. Section 3 presents the system description and assumption. In Section 4, we describe the proposed protocol. A performance evaluation is conducted in Section 5. Finally, Section 6 concludes our work.

2 Related Work

TARA [4] is the first proposed temperature-aware routing protocol. In TARA, each node selects the node with the lowest temperature as next hop until the packet arrives at the sink. However, if all of the neighboring nodes are hot spots, a node resends the packet to the node from which the packet is received. Since the information that there is no available next hop is sent together, the previous node no longer forwards the packet to itself. The greedy based routing algorithm that selects the node with the lowest temperature as the next hop do have an advantage of avoiding the temperature rise of nodes but to achieve this, a packet might have to go through many intermediate nodes until it arrives at the destination, which may result in the overall network temperature rise and increased end-to-end delay. LTR [5] has been proposed to solve the overall network temperature rise problem of TARA. In the LTR, each node selects the node with the lowest temperature as the next hop until the packet arrives at the destination. However, if the hop count field of the packet header exceeds MAX_HOPS, the packet is dropped immediately. On the other hand, a new problem arises that, intentional dropping of packets in WBAN may result in the loss of critical data. ALTR [5] has been proposed to overcome the packet loss problem of LTR. In ALTR, each node uses MAX_HOP_ADAPTIVE as the hop count threshold. If the hop count field of the packet header exceeds MAX_HOPS_ADAPTIVE, Shortest Hop Routing(SHR) algorithm is applied instead of dropping the packet. In contrast to ALTR, HPR [6] selects the node with the smallest number of hops as the next hop. However, if the temperature of the node with the smallest number of hops is larger than threshold, the node with the lowest temperature is selected as the next hop.

Unlike the previous studies, LTRT [7] establishes an end-to-end path that has the lowest temperature. In order to generate an end-to-end path, nodes create a graph that sets the temperature of each node as a weight, and applies the dijkstra's algorithm to the graph. However, the problem of additional overhead for maintaining the entire path and scalability due to increased number of nodes occurs. In addition, a common problem with previous studies is that end-to-end delay or loss of critical data may increase, since multiple traffic transmission is not supported. M-ATTEMPT [8] has been proposed to support multiple traffic transmission. But since critical data is transmitted to the sink through single-hop communication, power consumption for transmission may increase depending on the distance between the source node and the sink. TLQoS [9] has been proposed to overcome the disadvantages of single-hop transmission of M-ATTEMPT. However, since TLQoS performs complicated operations using cross layer framework for three metrics calculation and does not prevent temperature rise of intermediate nodes, it is not suitable for WBANs. Another protocol called PRPLC [10] is a store and carry based routing protocol that aims to reduce end-to-end delays caused by topology change. To achieve this, the neighboring node with a higher Link Likelihood Factor (LLF) indicating the possibility of connection between itself and the sink is selected as a next hop. If the source node is connected to the sink, it immediately transmits the packet to the sink. On the other hand, if the source node is not connected to the sink and there is no neighboring node with a higher LLF than itself, the packet is stored in the buffer. DVRPLC [11] creates the path with the highest end-to-end path cost based on the LLF. If the source node is connected to the sink, it immediately transmits the packet to the sink directly. Otherwise, it selects the path that consists of the node with the highest LLF or store the packet in the buffer. The existing store and carry based routing protocol uses the mobile node as a forwarder to reduce end-to-end delay caused by topology change. However, since it does not support multiple traffic transmission, end-to-end delay or loss of critical data may increase. In addition, since the temperature of nodes is not considered in the routing process, the temperature of the node can rise sharply.

By summarizing the above-mentioned work, it is observed that the temperature aware routing protocols transmit critical data through single-hop communication to support multiple traffic transmission. However, single hop communication is not suitable in WBAN due to limited energy resources. Multi-hop based temperature aware routing protocol, on the other hand, supports multiple traffic transmission. Since the number of nodes in WBANs is very small, it is difficult to prevent the temperature rise of intermediate nodes through multi-hop communication. The conventional store and carry based routing protocols have high end-to-end delay and loss of critical data, and do not consider temperature of a specific node. The proposed FTAR protocol addresses the afore-mentioned limitations by supporting multiple traffic transmission using the mobile node as a forwarder.

3 System Description and Assumption

3.1 System Environment

We construct a network with k sensor nodes and one sink node. As shown in Figure 1, nodes attached to the arms and legs are defined as mobile nodes whereas nodes attached to the center of the body are defined as static nodes. The sink node collects the data and transmits them to the medical center via the external network. We construct a network topology in a three-dimensional graph as shown in Figure 2, and express it as $G = (N, E)$. N is the set of vertices, and E is the set of edges.

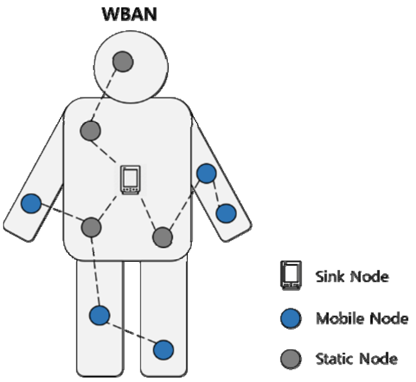

Figure 1. Example of node types

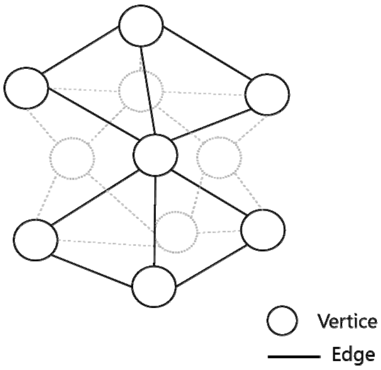

Figure 2. Three-dimensional topology graph

The entire network consists of homogeneous nodes with the same energy level. The maximum radio range of each node is assumed to be r, and the maximum transmit power of the nodes cannot exceed the range of r considering the limited transmission range and battery capacity of the WBAN nodes. The physical data measured by the sensor node is organized into fixed-sized data units and classified into critical and normal data.

Node i stores its routing information in the following form: $N_i = \{ID_i, Ntype_i, Ptype_i, H_i, T_i, TCT_i\}$. ID_i is a unique ID assigned to node i, $Type_i$ is type of node i, $Ptype_i$ is packet type stored in the buffer of node i, H_i is the hop count from node i to a sink, T_i is the temperature of node i, TCT_i indicates the time that node i was connected to the sink. A detailed description of each value follows.

- ID_i: ID_i is a unique number that identifies node i. This value is pre-programmed before the node runs.
- $Ntype_i$: $Ntype_i$ is a value for identifying the type of node i, which is assigned as zero for a mobile node and one for a static node. This value is pre-programmed before the node runs.
- $Ptype_i$: $Ptype_i$ is a value for identifying the type of data packet to be forwarded at a node i. It is classified into critical and normal data depending on the importance of the data.
- H_i: H_i is the number of hops between node i and a sink. This value is initialized and updated through the hello message exchange with the neighbor node.
- T_i: T_i represents the temperature of node i. To estimate the temperature of the node, FTAR uses the temperature estimation method proposed by TARA [4]: The main reasons of the temperature rise of the node defined by TARA are electromagnetic field and power dissipation. Pennis Bio Heat Equation [12] is used to estimate the temperature of the node.
- TCT_i: TCT_i stands for Total Connected Time, which represents the duration time that node i was connected to the sink. This value is used to select the mobile node as a forwarder. A detailed description is given in Section 4.3.

Additional assumptions and system descriptions are described in the following sub sections.

3.2 Traffic Classification

The data collected by sensor nodes is divided into critical data and normal data.

- Critical data (Critical traffic): We define important body data such as EMG, EEG, ECG as critical data [13]. Also, even if the measured data value exceeds predefined threshold, it is classified as critical data regardless of the importance of the data. For example, in the case of data measured by a heart rate sensor, if the measured value is within a normal range, it is classified as normal data. However, if the measured value exceeds the threshold, it is classified as critical data.
- Normal data (Normal traffic): Normal data is relatively less important body data. We define the body data collected periodically as normal data. For example, data collected in the temperature or motion sensors can be classified as normal data.

3.3 Mobility Model

The direction and range of movement of the nodes in the WBAN depends on the position of the nodes attached to the body and the movement pattern of the body. Considering these factors, we propose a mobility model that reflects the actual movement patterns of the body. In the proposed mobility model, body movement is divided into global movements and local movements. Global movement refers to body movement patterns, which are defined as stand, walk, and run. Each node has three-dimensional coordinates and speed, and moves to a predetermined position depending on each movement pattern. This predetermined position is called a reference point, and each node forms a radius of a sphere based on a reference point.

For example, since the body does not move in the stand pattern, the position of nodes does not change at the initial reference point. On the other hand, in the walk pattern, the mobile node attached to the arms and legs repeatedly move forward and backward. Considering this movement pattern, the mobile nodes move to a predetermined reference point at regular intervals. After that, they move with a random direction and velocity within a radius of a sphere. Note that static nodes attached to the fixed body parts cannot move, and only mobile nodes attached to the arms and legs move depending on the movement pattern. In the run pattern, mobile nodes move to the same reference point as the walk pattern, but mobility speed is set to maximum.

4 Proposed Protocol: FTAR

FTAR consists of an initialization phase and a routing phase.

4.1 Initialization Phase

In the initialization phase, all nodes periodically broadcast hello messages to neighboring nodes. Hello messages are used not only to recognize the existence of neighboring nodes but also to exchange routing information between each other. A node generates a neighbor table to store the exchanged information through a hello message, and each entry in the routing table consists of the following fields: $neighbor\ table_j = \{ID_j, Ntype_j, H_j, T_j, TCT_j\}$. ID_j is a unique ID of neighboring node j, $Ntype_j$ is type of neighboring node j, H_j is hop count from neighboring node j to a sink, T_j is the temperature of neighboring node j, TCT_j represents the time that neighboring node j was connected to the sink.

4.2 Routing Phase

The purpose of the proposed routing protocol is to support multiple traffic transmission and to prevent temperature rise of nodes. To achieve this, FTAR provides a multiple traffic forwarding algorithm.

4.2.1 Normal Data Forwarding Process

The main objective of the normal data forwarding is to prevent temperature rise of nodes. The simplest way to achieve this is to transmit the data to the node with the lowest temperature. However, since the number of nodes constituting the WBAN is very small, the temperature of the entire network increases even if the temperature of a node is set as the routing metric. In order to solve the performance degradation caused by the limited number of nodes, FTAR selects the mobile node that has the highest possibility of connection with a sink as a forwarder. If a mobile node is used as a forwarder, it is more likely that normal data can be transmitted to the sink directly. As a result, the number of hops to the destination can be reduced hence it is possible to prevent the temperature rise of the entire network.

Algorithm 1 shows the data forwarding process based on the type of a source node. If the type of a source node is mobile, the packet is stored in the buffer until the source node is connected to the sink in order to transmit the normal data directly. On the other hand, if the type of a source node is static, normal data is forwarded through multi-hop communication. Algorithm 2 shows the forwarding process based on the data type. In algorithm 2, the mobile node with the highest *TCT* value is selected as a forwarder in order to transmit normal data directly. However, if there are not any mobile nodes, the static node with the lowest *T* value is selected as a next hop to prevent the temperature rise of nodes.

Algorithm 1. Forwarding process based on the type of a source

```
Q.: a priority queue
p.: a packet to send
p.Dest: destination of a packet p
p.Ptype: type of a packet p
Ntype: type of a node forwarding a packet p
NH: next hop of a source node
while p ← Q.dequeue do
    if p.Dest is one of the neighboring node then
        forward the packet p to the destination
  else
    if Ntype = MOBILE then
        if p.Ptype = NORMAL then
            Q.inqueue(p)
        end if
        if p.Ptype = CRITICAL then
            NH ← Next Hop Selection(p)
        end if
    end if
    if Ntype = STATIC then
        NH ← Next Hop Selection(p)
    end if
  end if
end while
```

Algorithm 2. Forwarding process based on the data type

```
$H_i$: hop count from node $i$ to destination
$T_i$: temperature of node $i$
$TCT_i$: Total Connected Time of node $i$
p: a packet to send
p.Ptype: type of a packet p
NH: next hop of a source node
```

```
static_set: a set of static nodes whose temperature is below the threshold
mobile_set: a set of mobile nodes whose temperature is below the threshold
 function NEXT HOP SELECTION(p)
   for all $i \in$ N do
     if p.Ptype = CRITICAL then
       if static_set is not empty then
         $NH \leftarrow \arg\min_{i \in static\_set} (H_i)$
         return NH
       else
         $NH \leftarrow \arg\max_{i \in mobile\_set} (TCT_i)$
         return NH
       end if
     end if
     if p.Ptype = NORMAL then
       if mobile_set is not empty then
         $NH \leftarrow \arg\max_{i \in mobile\_set} (TCT_i)$
         return NH
       else
         $NH \leftarrow \arg\min_{i \in static\_set} (T_i)$
         return NH
       end if
     end if
   end for
end function
```

4.2.2 Critical Data Forwarding Process

The main objective of critical data forwarding is to minimize the end-to-end delay and maximize the packet delivery ratio. The best way to minimize the end-to-end delay of critical data is to perform single hop transmission. However, since nodes constituting WBAN have limited battery and transmission power, single hop transmission is not suitable in WBAN. Of course, it is possible to transmit critical data faster using a mobile node, but the end-to-end delay may increase depending on the movement pattern of the body. Considering these characteristics, critical data is forwarded to the node with the smallest number of hop count among static nodes. However, if there are not any static nodes or they are all hot spots, critical data is forwarded to the mobile node with the highest *TCT* value to detour the hot spot area.

In Algorithm 1, critical data is forwarded through multi-hop communication and the detailed procedure is described in algorithm 2. In Algorithm 2, critical data is forwarded to the static node with the least *H* value. However, if there are not any static nodes or they are all hot spots, the mobile node with the highest *TCT* value is selected as a forwarder to leave the hot spot area.

4.3 Total Connected Time Formulation

In order to select the mobile node as a forwarder, it is necessary to judge whether the mobile node is likely to be connected to the sink or not. The simplest way to calculate the possibility of a connection with the sink is to calculate the duration time in which node *i* was connected to the sink as below.

$$CT_i^{t-1,t} = DT_i^{t-1,t} \ / \ Twindow \qquad \textbf{(1)}$$

$CT_i^{t-1,t}$ stands for Connected Time and $DT_i^{t-1,t}$ represents the Duration Time in which node *i* is actually connected to the sink from previous time-slot (t-1) to current time-slot (t). *Twindow* represents the sum of each time-slot. However, the node with the highest $CT^{t-1,t}$ is not a good forwarder. First, even though $CT_i^{t-1,t}$ is higher than $CT_j^{t-1,t}$ on current time-slot (t), the $CT_j^{t-1,t}$ may appear higher in near future. Secondly, it is difficult to determine which of node *i* temporarily connected to the sink and node *j* periodically connected to the sink is a good forwarder. In order to overcome the limitation of the $CT^{t-1,t}$, we calculate the possibility of a connection between node *i* and the sink as follow.

$$TCT_i^t = (1-w) * TCT_i^{t-1} + w * CT_i^{t-1,t} \qquad \textbf{(2)}$$

The TCT_i^t stands for Total Connected Time and TCT_i^t utilizes the previously calculated $CT_i^{t-1,t}$ to overcome the limitations of $CT_i^{t-1,t}$. W is weighted factor and we give a higher value to the recently calculated $CT_i^{t-1,t}$.

4.4 Case Study

In this sub section, we provide an example of how the proposed routing algorithm works in the proposed system model. Through the initialization procedure, we can construct Table 1 ~ 4 with hop count, temperature and connection time as for nodes in Figure 3. As shown in Table 1 to Table 4, TCT value is computed for only mobile nodes.

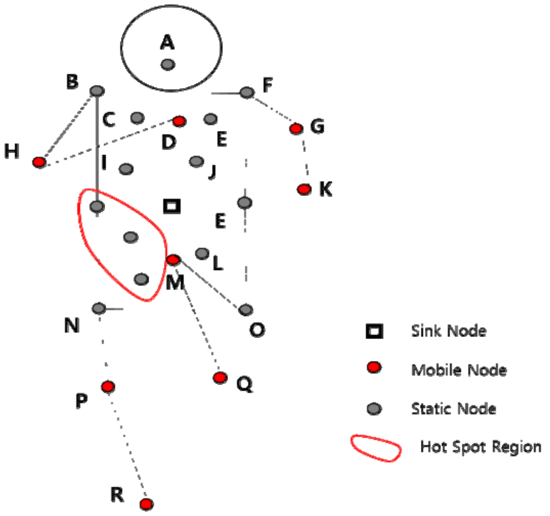

Figure 3. An Example of a Network Topology in Proposed Mobility Model

Table 1. Routing Table of Node A

ID	Ntype	H	T	TCT
B	STATIC	4	13.3	-
C	STATIC	3	23.5	-
D	MOBILE	3	20.7	0.7
E	STATIC	3	24.6	-
F	STATIC	4	14.0	-

Table 2. Routing Table of Node N

ID	Ntype	H	T	TCT
M	MOBILE	2	24.3	0.8
P	MOBILE	3	13.0	0.2

Table 3. Routing Table of Node K

ID	Ntype	H	T	TCT
G	MOBILE	5	15.3	0.3
E	STATIC	2	25.6	-

Table 4. Routing Table of Node M

ID	Ntype	H	T	TCT
SINK	SINK	1	-	-
L	STATIC	2	20.7	-
N	STATIC	3	24.6	-
O	STATIC	3	14.0	-

Forwarding critical data in static node. Static nodes select the static node with the smallest number of hop count as a next hop to forward critical data. In Figure 3, node ***A*** selects static node ***C*** with the smallest number of hop count among static nodes (***B, C, D, E, F***) as a next hop for critical data transmission. On the other hand, node ***N*** cannot perform multi-hop transmission since neighboring nodes are hot spot. To overcome this situation, node ***N*** selects the mobile node with the highest *TCT* value among mobile nodes (***M, P***). As a result, mobile node ***M*** is selected as a next hop.

Forwarding critical data in mobile node. Mobile nodes select the static node with the smallest number of hop count as a next hop in order to decrease the end-to-end delay of critical data. In Figure 3, node ***K*** forwards critical data to static node ***E*** with the smallest number of hop count.

Forwarding normal data in static node. Static nodes try to select the mobile node with the highest *TCT* value as a forwarder for normal data transmission. In Figure 3, node ***N*** tries to forward normal data to sink directly by selecting the next mobile node ***M***, which has the highest *TCT* value among mobile nodes (***M, P***). On the other hand, node ***A*** selects static node ***B*** with the lowest temperature as a next hop because there are not any mobile nodes.

Forwarding normal data in mobile node. Mobile nodes forward normal data to the sink directly when the sink is adjacent to itself. Otherwise, it stores the packet in the buffer until the next time-slot. In Figure 3, since node ***M*** is connected to the sink, packets in the buffer are forwarded to the sink directly. On the other hand, since node ***K*** is not connected to the sink, packets are stored in the buffer.

5 Performance Evaluation

5.1 Simulation Environment

The performance of the proposed protocol was evaluated through simulation. We used the ns-3 network simulator for performance evaluation. We set the network size to 2m x 2m, which is similar to the actual human body size. Static nodes are attached to fixed body parts, mobile nodes are attached to arms and legs, and the sink is attached to the middle of the body.

Table 5. Simulation environment

Parameter	Value (M-ATTEMPT)	Value (FTAR)
Number of Static Nodes	20	20
Number of Mobile Nodes	8	8
Maximum Transmission Range	1m	0.2m
Power Consumption (Tx)	7.5mWatt	1.5mWatt
Power Consumption (Rx)	7.5mWatt	1.5mWatt
Initial Temperature	10°C	10°C
Temperature Threshold	43°C	43°C
Initial Energy	100j	100j
Network Size	2m x 2n	2m x 2m
MAC	802.15.4	802.15.4
Weighted Factor	-	0.7

Table 5 shows the simulation parameters. Considering the short transmission range and limited energy of low-power RF transceivers designed for embedded applications, we set the transmission range of each node to 0.5m. The values of Tx and Rx are set to 1.5 mWatt, where Tx and Rx represent the power consumed in transmit and receive states, respectively. The initial temperature of nodes is set to 10°C, and the temperature threshold is set to 43°C [14]. The mobility model repeats three movement patterns: STAND, WALK, RUN. Each movement pattern lasts for 10 seconds, and it changes to the next movement randomly after the movement finished. The performance of FTAR is compared with M-ATTEMPT. However, since the M-ATTEMPT transmits critical data through single hop communication, we set the transmission range of each node to 1m in M-ATTEMPT. The values of Tx and Rx are dynamically changed to 7.5mWatt. Other simulation environments are the same as FTAR.

We evaluate the packet delivery ratio, end-to-end delay, hot spot generation ratio and hot spot duration time varying packet generation rate and simulation time. The simulation time is set to 1440 seconds in case of measuring the performance varying packet generation rate. On the other hand, data generation rate is set to 10pps in case of measuring the performance varying simulation time.

5.2 Temperature Rise

When a node becomes a hot spot, it cannot perform its function until it is released from the hot spot. So, the temperature rise of nodes also affects the packet delivery ratio. The effect of hot spot generation on the packet delivery ratio is described in the next sub section, and this sub section presents two performance evaluation results related to the temperature rise of nodes. First, the hot spot generation ratio shows the percentage of nodes that became hot spot among all the nodes. Secondly, the hot spot duration time shows the average duration time of each node that became hot spot.

As shown in both Figure 4 and Figure 6, as the packet generation rate increases, the hot spot generation ratio and hot spot duration time gradually increase in M-ATTEMPT and FTAR. Especially, performance of M-ATTEMPT decreases sharply when the data generation rate is set to 20. The reason is that, since M-ATTEMPT transmits normal data to the node with a large remaining energy, it cannot prevent the temperature rise of nodes in advance. As a result, the temperature of nodes increases sharply as the data generation rate increases. Also, both Figure 5 and Figure 7 show the similar result in case of increasing the packet generation rate. Especially, we can see that M-ATTEMPT has the poor performance after 2500 seconds of simulation time. The reason is that, since M-ATTEMPT transmits normal data through multi-hop communication, the more simulation time increases, the more temperature of intermediate nodes rises sharply. On the other hand, since the FTAR uses a mobile node for normal data transmission, the hop count can be reduced according to the movement pattern of the body. This leads to the effect of distributing the traffic concentrated in intermediate nodes. In addition, since the node with the lowest temperature is selected as the next hop, the hot spot generation ratio and hot spot duration time of FTAR are lower than those of M-ATTEMPT.

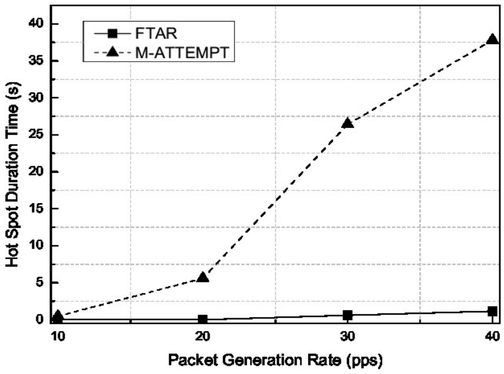

Figure 4. Hot spot duration time varying data generation rate

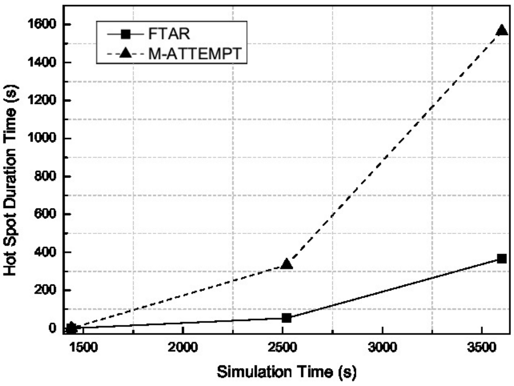

Figure 5. Hot spot duration time varying simulation time

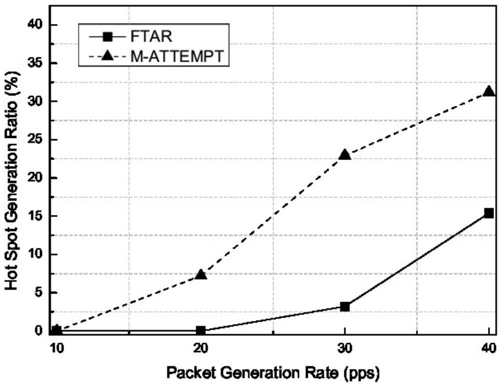

Figure 6. Hot spot generation ratio varying data generation rate

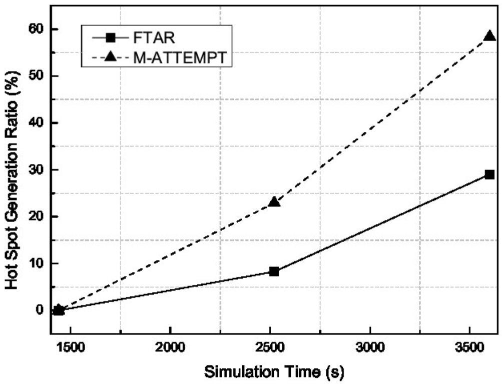

Figure 7. Hot spot generation ratio varying simulation time

5.3 Packet Delivery Ratio

The packet delivery ratio is one of the important metrics in WBAN. Especially, the packet delivery ratio of critical data is the most important criterion for protocol performance evaluation. In the simulation, the packet loss occurs when the node is no longer capable of data sensing and routing due to battery exhaustion or when it becomes a hot spot because of increased data generation rate and simulation time. Here, it is assumed that there is no packet loss due to radio channel environment.

Figure 8 and Figure 9 show that the packet delivery ratio of M-ATTEMPT drops sharply as the data generation rate and simulation time increases. In Figure 8, as the data generation rate increases, the critical data packet delivery ratio of M-ATTEMPT drops sharply. Since M-ATTEMPT performs single-hop communication for critical data transmission, the energy consumption used for transmission increases as the data generation rate increases. If energy required to perform single-hop communication is not enough, critical data transmission cannot be performed, thus dropping packet delivery ratio of critical data. On the other hand, since FTAR transmits critical data through multi-hop communication, packet loss caused by the lack of energy required for transmission is less than M-ATTEMPT. Also, we can see the similar result in Figure 9. M-ATTEMPT uses a hot spot avoidance mechanism that breaks all links with the surrounding nodes when the temperature of a node exceeds the threshold. As a result, the more hot spot region increases, the less the number of available links is reduced, and the packet delivery ratio drops. On the other hand, since the FTAR uses a hot spot prevention mechanism that prevents the temperature rise of nodes in advance. As a result, even if the simulation time increases, the overall packet delivery ratio is higher than M-ATTEMPT.

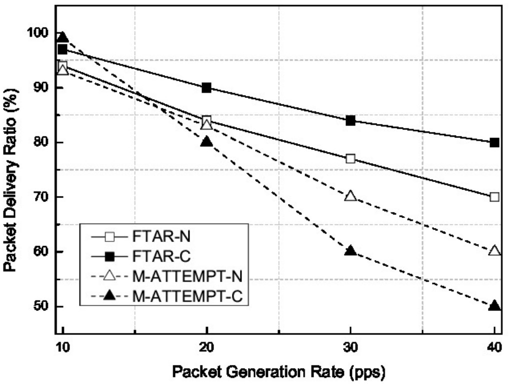

Figure 8. Packet delivery ratio varying data generation rate

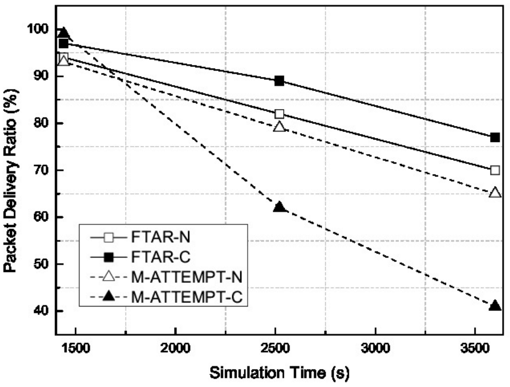

Figure 9. Packet delivery ratio varying simulation time

5.4 End-to-End Delay

The end-to-end delay is heavily influenced by topology change. Considering the fact that body position in the WBAN changes quickly and frequently, it is very difficult to transmit the packet within a given deadline. Considering these characteristics, we believe that, the best result can be achieved when the end-to-end delay of critical data is lower than that of normal data.

Figure 10 shows that FTAR has poor performance than M-ATTEMPT in terms of end-to-end delay of normal data as data generation rate increases. The reason is, the more packet generation rate increases, the more hot spot region increases and the number of available path decreases together. As a result, the packet can be detoured to the destination because FTAR forwards normal data to the node with the lowest temperature. Similarly, Figure 11 shows that FTAR has poor performance in terms of end-to-end delay of normal data. The reason is that, if the mobile node that is likely to be connected to the sink is selected as a forwarder for normal data transmission in FTAR, the end-to-end delay of normal data may increase according to the movement pattern of the body. Since the movement pattern of the body is changed periodically, the end-to-end delay of normal data is also affected by simulation time. On the other hand, since M-ATTEMPT forwards normal data to the node with a large amount of residual energy, the end-to-end delay of normal data is not significantly affected by the movement pattern of the body. On the other hand, both Figure 10 and 11 show that M-ATTEMPT has better performance than FTAR in terms of end-to-end delay of critical data. The reason is that, M-ATTEMPT sends critical data to the sink directly through single hop communication, while FTAR forwards critical data to the sink through multi-hop communication.

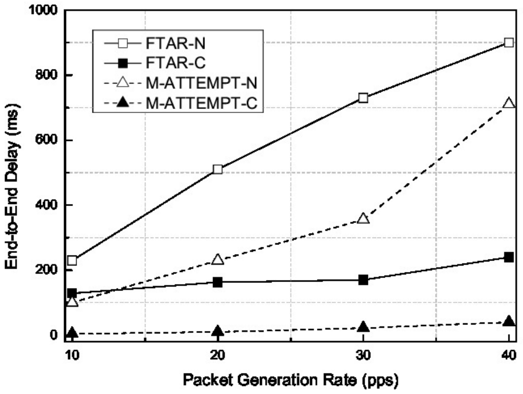

Figure 10. End-to-End delay varying data generation rate

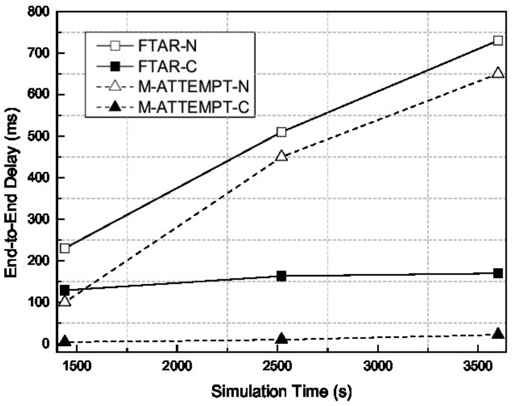

Figure 11. End-to-End delay varying simulation time

As mentioned earlier, M-ATTEMPT sends critical data quickly through single-hop communication, but it requires significant power consumption, so the packet delivery ratio decreases as data generation rate or simulation time increases. In contrast, FTAR has a higher end-to-end delay of critical data than M-ATTEMPT. However, since it can save power consumption for transmission, the packet delivery ratio of critical data is higher than that of M-ATTEMPT.

6 Conclusion

In this paper, we proposed FTAR, a temperature aware routing protocol that supports multiple traffic transmission and utilizes the mobile node as a forwarder. FTAR selects the mobile node that is most likely to be connected to the sink as a forwarder for normal data transmission. If there are no mobile nodes, normal data is forwarded to the static node with the lowest temperature. In contrast, critical data is transmitted to the static node with the smallest number of hop count. To evaluate the performance of FTAR, we performed comparative simulations against M-ATTEMPT. Simulation results show that FTAR has better performance than M-ATTEMPT in terms of hot spot generation ratio, hot spot duration time, and packet delivery ratio of critical data.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Education (2018R1D1A1B07043731). Also, this work was supported by Zayed University Research Office, Research Cluster Project #R18027.

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