An Efficient QoS and Thermal-aware Routing For BAN-IOT applications

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***Abstract*—Body Area Networks (BANs) are sets of sensors on the human body that can be used in IOT applications. They transfer information obtained from the body to the sink node wirelessly. In BAN-IOT applications, given the restricted battery power of sensors, energy has been seen as a challenge.**

With the energy limitation of sensors, hop-by-hop routing can reduce energy consumption. In routing, delivering information on sensors should be accomplished regarding the quality of service. On the contrary, a temperature rise in the body sensors can damage the patient's tissues. In this paper, the next hop node in the network is selected by using hop-by-hop routing. The results of the simulation show that the proposed method significantly improves the network lifetime and energy consumption of network sensors compared with the base protocol.

***Index Terms*—Wireless Body Area Sensor Networks (WBASN), Routing, IOT, Hop by hop**

I. INTRODUCTION

Wireless body area sensor networks (WBASN) is an example of special wireless sensor network, which measures patient's physiological parameters such as blood pressure, body temperature, heartbeat, and brain signs and make it feasible to monitor his health from a distance by using wireless sensor nodes within his body area [1]. In wireless body area sensor networks (WBASN) on Internet of Things (IOT) applications, because sensor nodes are always placed inside the body, it is not feasible to charge the battery. Therefore, optimal energy consumption is one of the biggest challenges facing these kinds of networks [2]. WBASN technology is essential to the IoT in the healthcare system because it allows for the use of low-power, lightweight wireless sensor nodes to monitor patients.

Routing in wireless sensor networks is undertaken in two forms: fixed routing based on route selection from source to destination and hop-by-hop routing. In routing, whose foundation is the choice of a fixed path from source to destination, each node should pick a route until it reaches the destination (sink node) and steer its packets along this path. In hop-by-hop routing, each node picks one node from neighboring nodes as the next hop node and sends packets to the node, leaving the task of packet delivery to the following nodes unaffected. In hop-by-hop routing, energy consumption is more efficient than routing based on route selection, because sensor nodes may fail at any time due to battery depletion, causing the route to fail. Secondly, due to the traffic generated on a fixed path, it is likely that packets reach the destination with a delay and run out of time. Thirdly, the choice of a fixed path from source to destination needs additional energy. Thus, in wireless body sensor networks, it is advisable to use hop-by-hop routing. Fixed-based routing is suitable for a network where sensors have high energy resources and can use this energy for routing with a high communication range. Body area sensor networks in IOT applications face needs such as delay, energy, temperature, and reliability, which require appropriate protocols. Since routing protocols play an important role in system performance, such as delay, energy, temperature, etc., it is necessary to study existing routing protocols for body area networks. Moreover, challenges specific to body area networks call for the design of new routing protocols for body area networks [3-7].

In the proposed method, the next hop node is selected that meets the needs of various data. To this end, data should be classified in the first place, and a separate next-hop node is chosen for each class. Data is classified into four types: normal, delay-sensitive, reliability-sensitive, and critical. For normal data, the next hop node is chosen with regard to the number of steps to sink and the temperature of neighboring sensors.

In the second section of the present article, we offer a research background and review of the literature. Next, in the third part, the thermal-aware routing methods are presented. In the fourth part, the proposed method is analyzed and evaluated. In the end, a conclusion of all discussions is presented.

II. RELATED WORK

In the past decade, researchers and engineers strived to solve the problem of temperature rise. The aim of all thermal-aware routing protocols for wireless body area sensor networks is to decrease the temperature of biomedical sensor nodes. Thermal-aware routing protocols in wireless body sensor networks are explained in what follows.

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The Thermal-Aware Routing Algorithm (TARA) protocol [8] aims to avoid getting into a hot area by observing the temperature of neighboring nodes and deterring packets by using a retreat strategy. This strategy causes long delays and a short lifetime of a network, but it balances the pressure on the network. TARA attempts to forward data packets from paths where hot spots are not included by using an avoidance mechanism. In other words, each node that is a hot spot within its reach range sends back data packets to the sender so that they are sent to the destination using other paths.

LTR (Least Temperature Routing) [9] was built on the TARA algorithm. Each node communicates with its neighboring node and collects information on their temperature or observes their activity. Each node attempts to carry the packet to the coolest neighbor. Moreover, a Max Hop parameter is defined, in that if the number of packet reception steps exceeds the parameter, the packet is discarded. The Adaptive Least Temperature Routing (ALTR) algorithm is another routing suggestion. ALTR can adapt to particular topologies. Since in certain topologies of a network, such as ring topology packet sequence unavoidably follows the same path, making the temperature of sensor nodes go up quickly on certain paths, a proactive delay mechanism is used by ALTR.

The Least Total-Route Temperature (LTRT) protocol [10] suggests a path with the least temperature in that node temperatures are turned into graphic weights, and minimum thermal routes are achieved. LTRT is a combination of SHR and LTR. Since LTRT attempts to deliver packets in the shortest number of steps, it prevents temperature from rising suddenly in the entire network. Moreover, since LTRT takes account of the total temperature of select routes, the paths with high temperatures are bypassed, and packets cease to approach the paths.

The Hotspot Preventing Routing (HPR) algorithm [11] does not forward packets from stochastic long paths. Instead, it always aims to forward packets in the shortest route from the source to a destination, only by bypassing extremely hot spots that may come along the way. Moreover, it adapts to the route dynamically based on network traffic conditions. For this reason, HPR prevents the formation of hotspots with high temperature and forward packets toward the destination with very little delay.

RAIN [12] is a routing protocol that aims to reduce the average temperature rise and average power consumption of bio-medical sensor nodes. The three phases of RAIN are: setup phase, routing phase, and status update phase.

Thermal-Aware Shortest Hop Routing (TSHR) [13] was designed where there is a high priority on delivering packets to the destination. In this algorithm, if one packet is discarded, it is transferred again. TSHR has two phases: phase one and phase two. In the first phase, which is the setup phase, each node builds its routing table and obtains information about neighboring nodes. In the second phase, which is the routing phase, nodes attempting to route packets to the destination use the shortest path algorithm and determine their path to the destination.

Data-centric Multiobjective Quality of Service routing (DMQoS) protocol was proposed by Razagh et al. The most important features of DMQoS protocols are the use of separate routing functions for a variety of packets based on quality of service and modular architecture parameters. In DMQoS, by hop-by-hop routing method is used, which allows a data packet to make several choices to reach the destination. In addition to this, DMQoS is an algorithm based on the situation.

M-ATTEMPT [15] is an energy-efficient and thermal-aware routing protocol for WBSNs to reduce the nodes' temperature as well as to decrease the delay for the critical data using heterogeneous bio-medical sensor nodes. In the network architecture of this scheme, the sink node (base station) is placed at the center, while nodes with high data rates are placed at less mobile places of the human body.

Thermal-aware Multiconstrained Intrabody QoS Routing (TMQoS) algorithm [16] takes account of delay and reliability, which are requirements for the human body. Moreover, in this algorithm, the temperature of the nodes is kept to an acceptable level. Furthermore, the algorithm proposes a cross-layer routing based on the routing table, which ensures diverse requirements of QoS.

Critical Data Routing (CDR) [17] is used to route critical data in wireless intrabody sensor networks, where a connection graph can be generated for various models on the body with a replaceable power supply.

Thermal-Aware Localized QoS Routing (TLQOS) [18] aims to deliver quality of services for diverse traffic based on their requirements. A body synchronizer is attached to the body, which serves as a central data sink for wireless intra-sensor networks.

Data Centric Routing (DCR) [19] was designed for wireless body area sensor networks, which rests on service quality assurance routing. In this algorithm, a specific route is extracted for critical data obtained from critical human body sensors. The specified path takes into account of parameters of service quality and chooses the best path to ensure them. However, the algorithm fails to regard node priorities in the network, and it comes with greater overhead charges compared with other algorithms.

In [20], a protocol called "mobTHE" was designed to handle and balance traffic on the network. The protocol selects the nearest to the destination with regard to some parameters such as temperature, node mobility, and energy.

III. PROPOSED PROTOCOL

A. Hello Packet

For a node to make a better decision, data from its neighbors should be updated. To do so, the hello packet is exchanged between nodes in certain time spans periodically. Hello packet consists of fields of packet number, source node number, setup time, node temperature, and number of steps to sink.

B. Neighbor table

Information that the hello packet sends to the neighbor node is put in the neighbor table. The neighbor table consists of fields of neighbor node number, node temperature, delay reliability, and number of steps to sink.

C. Temperature Estimation

The temperature of a node is obtained inside the body as equation 1 suggests [16].

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

(1)

In this formula, Δt is the discretized time step, b is the blood pressure, ρ is the mass density, Cp is the specific heat of the tissue, K is the thermal conductivity of the tissue, Δ is the discretized space step, X is horizontal coordinates of a grid point at time t, y is the vertical coordinates of a grid point at time t, SAR stands for Specific absorption rate of body tissue, Tb is the fixed blood temperature, and Pc is the power consumed by nodes. Equation 1 is used in the next algorithms for temperature calculation.

D. Delay Estimation

A node-to-neighboring node delay is obtained by equation 2 and is put in the neighbor table.

$$DL_{neighbor} = T_{current} - T_{creation} \qquad (2)$$

Where Tcurrent is the current time of simulation, and Tcreation is the time of creation of the hello packet. The total delay includes propagation delay, queuing delay, and processing delay, all of which are explicitly considered in the estimation.

E. Reliability Estimation

Link reliability (LinkR) is obtained by and placed in the neighbor table.

$$LinkR = \mu\ Nsucc/Ntotal + (1-\mu)\ LinkR \qquad (3)$$

In this formula, the weighted average factor (μ) is assumed to be 0.4 in the proposed algorithm. The parameter Nsucc represents the number of packets that are successfully delivered to the neighbor node, and Ntotal is the total number of packets that are delivered to the neighbor node. These values are calculated during the window. LinkR is the previous value that indicates the effects of before reliability in the equation. Because (1-μ) is 0.6, the previous LinkR is the most effective in the reliability.

F. Next Hop Node Selection

The selection of the next hop node is performed based on packet classes. How the next hop node for normal, delay-sensitive, reliability-sensitive, and critical packets is determined is described in the following algorithms. How the next hop node is selected for normal packets is presented in Algorithm 1. NH set is the set of neighbor nodes for normal packets with elements with the minimum number of hops to the sink. If the NH set is empty, no valid next hop exists, preventing further transmission.

Algorithm 1 : Next hop selection for ordinary packets

```
INPUT : N
NH = { $n \in N$ | n is the neighbor with minimum hop counts to sink }
if ( $NH == NULL$ ) then
        $NH_o = Null$
else if ( $NH == 1$ ) then
        $NH_o = n$
else if ( $NH > 1$ ) then
        $NH_o = \{ m \in NH \mid m$ has minimum temperature $\}$
end if
```

How the next hop node is selected for delay-sensitive packets is presented in Algorithm 2. NH set is the set of neighbor nodes for delay-sensitive packets with elements with the minimum number of hops to the sink. If NH is empty in value, the set of next hop sets becomes empty, and if the NH set has one element, the element is chosen as the next hop, and if NH has more than one element, the neighbor node is selected as next hop, which has the minimum delay.

Algorithm 2 : Next hop selection for delay-sensitive packets

```
INPUT : N
NH ={ $n \in N$ | n is the neighbor with minimum hop counts to sink }
if ( $NH == NULL$ ) then
        $NH_D = Null$
else if ( $NH == 1$ ) then
        $NH_D = n$
else if ( $NH > 1$ ) then
        $NH_D = \{ m \in NH \mid m$ has minimum $DL_{neighbor} \}$
end if
```

How the next hop node is selected for reliability-sensitive packets is presented in Algorithm 3. NH set is the set of neighbor nodes for reliability-sensitive packets with elements with the minimum number of hops, one and two, to the sink. If NH is empty in value, the set of next hop sets becomes empty, and if the NH set has one element, the element is chosen as the next hop, and if NH has more than one element, the neighbor node is selected as next hop, which has the maximum reliability.

Algorithm 3 : Next hop selection for reliability-sensitive packets

```
INPUT : N
NH ={ $n \in N$ | n is the neighbor with first and second minimum hop counts to sink}
if ($NH$= =NULL) then
    $NH_R$= Null
else if (NH = = 1) then
    $NH_R$= $n$
else if ( NH > 1) then
    $NH_R$ = { $m \in NH$ | $m$ has maximum $Link_R$}
end if
```

How the next hop node is selected for critical packets is presented in Algorithm 4. NH set is the set of neighbor nodes for critical packets with elements with the minimum number of hops, one and two to the sink. If NH is empty in value, the set of next hop sets becomes empty, and if the NH set has one element, the first and the second maximum value for reliability are chosen, and the node with the lowest delay is chosen as the next hop.

Algorithm 4 : Next hop selection for critical packets

```
INPUT : N
NH ={ $n \in N$ | Neighbors with first and second minimum hop counts to sink }
if ( $NH$ = = NULL) then
    $NH_C$ = Null
else if (NH = = 1) then
    $NH_C$ = $n$
else if ( NH > 1) then
    NH = { $n \in NH$ | $n$ has first and second maximum $Link_R$}
    $NH_C$ = { $m \in NH$ | $m$ has minimum $DL_{neighbor}$ }
end if
```

Algorithm 5 deals with the requirements of data packets. If the requirements are not met at the time of receiving packets, the packet is discarded. If the packet is delay-sensitive or critical and fails to reach the destination within the specified deadline, it is discarded. If the packet is reliability-sensitive or critical and the next hop node's reliability is below the required threshold, the packet is discarded.

At this point, an example of the proposed method is presented. Suppose that part of the network topology is shown in Fig. 1. We assume that data delivered by sensors is of four kinds: critical, delay sensitive, reliability sensitive, and normal. In this example, node 11 is regarded as the current node. The nodes 2,3,8,10,15, and 6 are neighbors of node 11. By using the proposed algorithm, we want to obtain the next hop node for critical, delay-sensitive, reliability-sensitive, and normal data.

Algorithm 5 : Packet Requirements

```
INPUT: P
if ( ( P. $type$ is DSP) || ( P. $type$ is CP) ) then    // delay-sensitive or critical packet
    if (P.delay > $D_{req}$) then
        Drop the packet
endif
if ( ( P. $type$ is RSP) || (P. $type$ is CP) ) then    // reliability-sensitive or critical packe
    if ($NH_R$.Reliability < $R_{req}$) then
        Drop the packet
endif
```

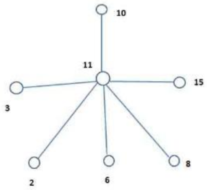

Fig. 1. An example of the proposed method

The neighbor table of node 11 is by Fig. 2. The information in this table is obtained based on information from hello packets.

Neighbor node	Reliability	Delay	Temperature	Hop counts
2	0.98	0.7	37.2	6
3	0.99	0.5	37.3	4
8	0.96	0.3	37.1	4
10	0.98	0.3	37.4	3
15	0.97	0.2	37.9	3
6	0.94	0.4	37.7	5

Fig. 2. Neighbor table of node 11

Given the neighbor table of node 11 and the proposed algorithms of the next hop node, the selection of next hop nodes is undertaken for each class of packets. For normal packets, from nodes 10 and 15, which have the least hop to sink, node 10 is selected because it has the least temperature. For delay-sensitive packets, from nodes 10 and 15, node 15 is selected because it has less delay. For reliability-sensitive packets, from nodes 3,8,10, and 15 with the minimum first and second number of hops, node 3 is selected, because it has more reliability than the other nodes. For critical packets, from these four nodes, nodes 3 and 10 are selected in the first place, and from the two nodes, node 10 with the least delay is selected as the next hop.

IV. PERFORMANCE EVALUATION

In this stage, we analyze the simulation results of the proposed method. Therefore, we address the most critical performance evaluation metrics for routing critical, delay-sensitive, reliability-sensitive, and normal data in body sensor networks.

All simulations are carried out via the simulation software NS2 edition 2.35 [21] under the Linux operating system.

A. Simulation Parameters

In Table 1, the simulation parameters used in the performance evaluation of the proposed method are shown. The parameters are used in different scenarios.

Table 1. Simulation parameters

Parameter	***Value***
P_c	0.002
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)
Initial energy	50 (J)
Transmit power	8.5872e^{-4} (W)
Radio range	40 (Cm)
Area	2*3 (m^2)
Buffer size	60
Number of odes	10-30

B. Metrics

Energy consumption: average energy consumption of sensor battery (in Joules) in the network. In the routing of body sensor networks, due to battery power constraints, the energy consumed at a node and the amount of remaining energy of nodes in a path take on great importance.

Delay: delay is the time that elapses until a packet reaches the destination. The duration consists of propagation time, queuing time, and processing time. In the routing of delay-sensitive data, the data packet should reach the destination as soon as possible. If the time of packet delivery takes longer than the allowable limit, they may run out of time. The parameter is the average delay of all packets.

Average temperature rise: it is the average temperature rise of nodes (in per Celsius). This measure is obtained by using the node temperature change at the time of simulation.

Network lifetime: Network lifetime (in seconds) is the time when the first node of the sensor runs out of energy in the network.

Packet delivery ratio: The packet delivery ratio is the ratio of the number of packets that successfully reach the destination (sink node) to all packets.

C. Simulation Results

In this section, the results of the simulation are analyzed. The average result of 10 simulation runs is calculated.

Impact of Data Rate

Energy consumption: The following figure is the comparative diagram of energy consumption in the DCR protocol and shows the proposed method with packet delivery rate change.

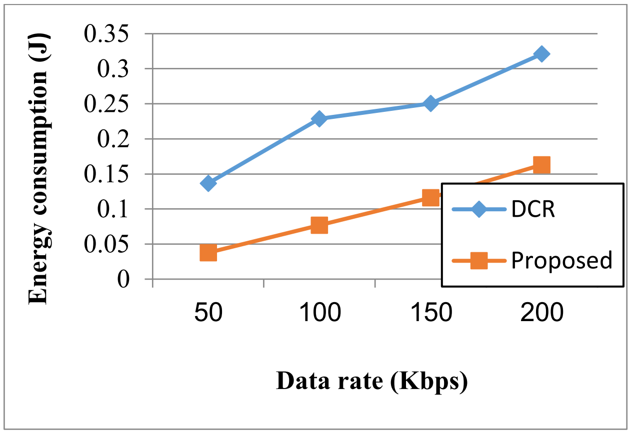

Fig. 3. Impact of delivery ratio on energy consumption

Network lifetime: The following figure shows the network lifetime about the data delivery rate change. In this figure, it is evident that the lifetime of the proposed method is longer than DCR protocol.

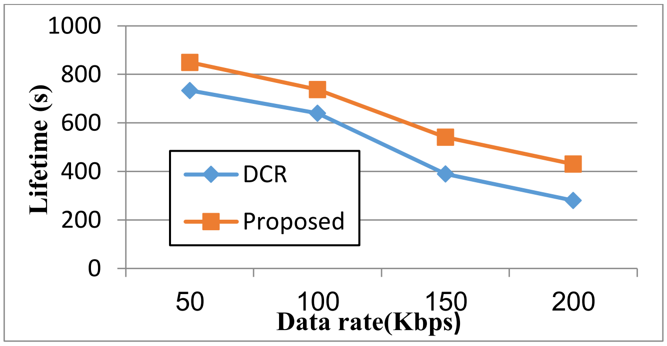

Fig. 4. Impact of delivery ratio on network lifetime

Impact of the Number of Nodes

The following figure represents the effect of the number of network nodes on the energy consumption of the proposed method as well as DCR. As the figure suggests, as the number of nodes increases, so does energy consumption.

Impact of the Deadline

In this scenario, the number of nodes is considered 20, and the delivery ratio is 100 kb per second. As the deadline of packets changes, the proposed method has less delay compared with DCR. The reason why the delay drops is that not only the fewer numbers of hops used to transmit packets in the proposed method, but the next hop is also used, which has less delay than other nodes for delay-sensitive packets.

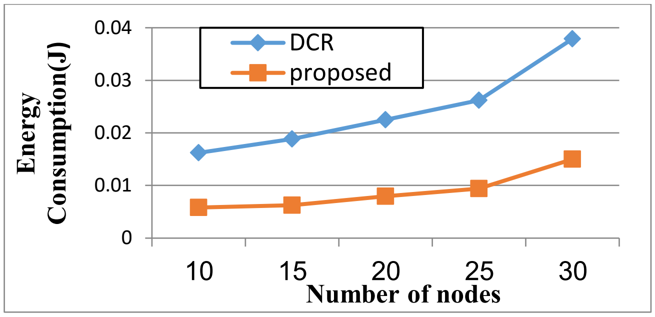

Fig. 5. Impact of the number of nodes on energy consumption

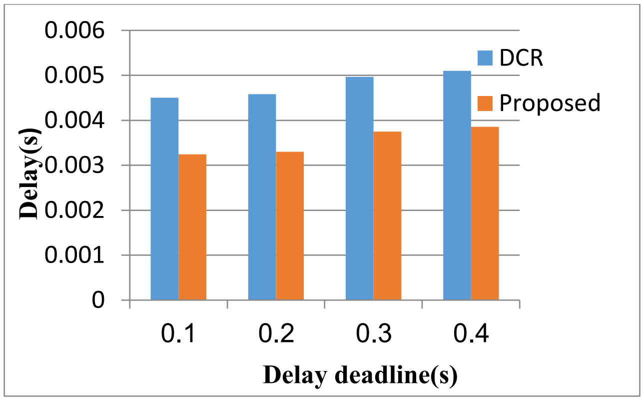

Fig. 6. Impact of deadline on packet delay

Impact of Reliability Requirements

In this scenario, the number of nodes is considered 20, and the delivery ratio is 100 kb per second. Packet delivery ratio is less than DCR in the proposed method, because in the proposed method, it is the next hop node that is seen, and reliability up to the neighbor nodes is taken into consideration.

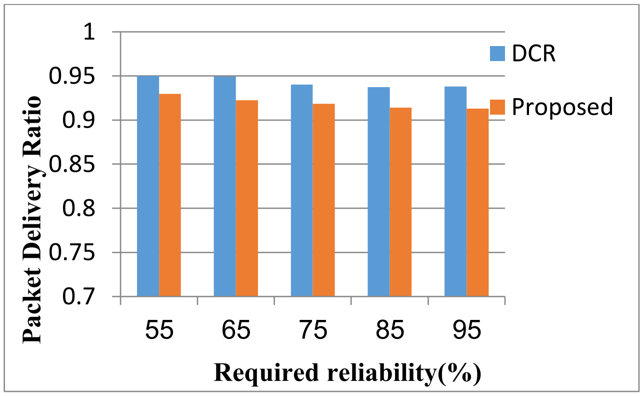

Fig. 7. Impact of reliability requirements

CONCLUSION

In this paper, a method was proposed for choosing the next hop node based on parameters, namely, quality of service and node temperature. In this method, by classifying packets and selecting efficient next-hop nodes, packet requirements are satisfied. The results of the simulation showed that the proposed method significantly improved energy, delay, and lifetime of packets compared to a similar method. Network energy and lifetime are improved in relation to the similar method because routing is undertaken in a hop-by-hop manner in the proposed method.

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