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RESEARCH ARTICLE

Design of Fuzzy Logic Based-temperature-aware Routing Protocol

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Abstract:

Background:

Rising temperatures in an implanted sensor node is harmful to human tissue; thus, a suitable approach must be considered in designing network protocols.

Objective:

To prevent high node temperatures, we present a new temperature-aware multi-hop routing protocol based on fuzzy logic with a low cost overhead.

Results:

Through comparative simulations, we verify that the proposed scheme can maintain node temperatures to an acceptable and balanced level. This leads to a higher packet delivery ratio than that in existing schemes.

Conclusion:

The fuzzy logic-based temperature routing protocol can contribute to avoiding excessive temperature rises in sensor nodes. In addition, the fuzzy logic input and decision rule are relevant for effectively computing the temperature variation.

Keywords: Wireless body area networks, Fuzzy logic, Temperature-aware routing, Performance evaluation, Quality of service, Network protocol.

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1. INTRODUCTION

Recently, healthcare systems have received considerable attention in terms of the introduction of many technologies for efficiently monitoring patients' health status. Generally, a healthcare system consists of monitoring, networking, and analysis/diagnosis systems. In terms of networking, a wireless body area network (WBAN) has been proposed and developed to obtain information from several implanted sensor nodes in the human body.

Unlike typical sensor networks, a WBAN has specific requirements. One of them is related to the temperature rise of a sensor node. This is because the implantation and attachment of sensor nodes can be harmful to human tissues.

Thus, network protocols must be designed to consider the temperature-aware properties in WBANs.

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To address this, some temperature protocols have been proposed. First, some comprehensive literature reviews have been conducted on temperature-aware routing protocols [1 - 4]. Each survey paper has presented insight on temperature-aware protocols by analyzing their advantages and disadvantages. In addition, some studies address the energy efficient temperature-aware routing protocols [5, 6]. The main contribution of this study is in extending the network lifetime and stability period of hot-spot nodes.

Despite previous work conducted, a new temperature-aware routing protocol with low overhead must be developed. To reduce the overhead, we introduce a fuzzy logic-based temperature-aware routing protocol. Although multiple routing decision metrics [7 - 9] were jointly considered in previous studies, the combination of these parameters may conflict and even result in uncertainly. Also, some other approaches including fuzzy logic have been proposed. But, there are still deployment issues to be addressed.

To defeat mentioned issues, the proposed scheme selects a

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next-hop node using a fuzzy logic-based method that jointly considers the current temperature of the node, buffer occupancy, and link quality. The buffer occupancy and link quality represent the expected temperature rise. By simultaneously considering the current and future temperatures, the suitable next hop can be selected while preventing the temperature from rising in a node. The performance of the proposed scheme is evaluated by simulations, and the superiority of the proposed scheme is demonstrated by the longer lifetime and higher packet delivery ratio compared with existing schemes.

2. LITERATURE REVIEW

For the better understanding for motivation, we describe representative work briefly in this section.

First of all, many routing protocols were proposed to make decision for the next hop with multiple parameters instead of single one. For example, Yu *et al*. [10] proposed to utilize the multi-parameter maximum benefit function to select the next hop with good state through dynamic adjustment of weights of functions according to the priority of data. In the proposed scheme, residual energy, transmission efficiency, available bandwidth, and the number of hops to the sink is concerned for the function. Thus, the best next hop node is a one with more residual energy, higher transmission efficiency, wider available bandwidth and smaller hops to sink. But, if the selected node has the residual energy lower than that threshold, it only transmits its own packets by not forwards information of other nodes. When it comes to consider temperature as one of multiple parameters, Javed *et al*. [11] proposed Temperate Aware and Energy Optimized (TAEO) to not only deal with the thermal aspects and hot spot problem, but also to extend the stability and lifetime of a network. The main approach is to detect and avoid a hop spot node with Specific Absorption Rate (SAR) value. Based on the SAR value, a node with less temperature and distance from the sink along with higher residual energy is selected as Data Forwarder (DF). And, the DF is allowed to transmit the data packet only if it has a value below the predetermined threshold. In the aspects of network lifetime and stability, distance between two nodes is computed and used to control transmission power. A closer node is selected as DF to reduce required transmission power. Even though these approaches can lead to improve the network performance, their performance is significantly affected by cost function to combine the multiple parameters. So, fuzzy logic is introduced to replace them because it can handle the imprecise and uncertain information in the existing approaches.

Wang *et al*. proposed a protocol called fuzzy control-based Energy-Aware Routing Protocol (EARP) that considers both the residual energy, link quality and hop count in [12]. These three parameters are used to select data forwarder while considering the limited sensor energy, data loss and delay, and timeliness and reliability of data transmission. Each parameter is computed through the process of fuzzification, fuzzy inference, and defuzzification. And then, maximum path benefit function is applied to select the best forwarder node. The proposed scheme is composed of three main procedures, that is, initialization phase, forwarder node selection phase, and data transmission phase. Another approach to apply fuzzy logic controller for WBAN was presented by Javaheri *et al*. in [13]. Since the proposed scheme targets to build clustering architecture, fuzzy logic makes use of essential multiple parameters such as the temperature of cluster header, number of similar neighbors, number of neighbors, remaining energy, and path loss. In addition to this model, another fuzzy logic is applied to control transmission for inter-WBANs. To achieve this, the number of patients, packet delivery ratio, and distance between cluster headers are used for input of fuzzification in the second model. Finally, a new hybrid metaheuristic algorithm was presented to tune the parameters and fuzzy rules. Even though above temperature-aware routing schemes were proposed, there are still some deployment issues. In the former model, it just considers the current value parameters only so it cannot provide stability for routing. On the other hand, since the latter was designed under a clustering scheme, it is an unrealistic model for use in the real world.

In the aspects of deployment and improvement of standard IEEE 802.15.6, key functions for routing and interaction between layers were presented by Kim in [14]. New features included temperature estimator with SAR, topology control and radio resource control. Also, MAC layer management entity is newly defined in the proposed scheme. Based on above new components, functions for temperature-aware routing are described and implemented in the network simulator.

3. MATERIALS AND METHODS

3.1. Proposed Approach: Tarpel

The proposed temperature-aware routing protocol based on fuzzy logic (TARPFL) consists of two main procedures: collecting temperature-aware parameters and evaluating potential neighbors for the next hop.

3.1.1. Collecting Parameters

In the TARPFL, we set temperature-aware parameters in terms of current and expected value. The expected value is calculated by number of packets in the buffer and retransmitted packet. We compute the parameters in every period, *T*. At the n^{th} measurement, the current temperature $C_i^{n\text{-}1,n}$ indicates the average temperature of sensor node *i* at the periodic measured period between (*n-1*) × *T* and *n* × *T*. In addition, the buffer occupancy $B_i^{n\text{-}1,n}$ is presented by how much buffers are occupied in the measured period. This is obtained by dividing current buffer size by maximum buffer size. And, we compute average in the measured period. Finally, the link quality is computed using the average received signal strength (*RSS*, $RSS_i^{n\text{-}1,n}$). Both $B_i^{n\text{-}1,n}$ and $RSS_i^{n\text{-}1,n}$ are closely related to the temperature rise of a node. The former indicates the temperature rise in sending the buffered packets, and the latter indicates the expected rise for retransmitted packets.

Each sensor node periodically measures these parameters and exchanges them with neighbor nodes through BEACON messages. To select the suitable next hop to the coordinator based on a BEACON message, the hop count is carried to the coordinator.

3.1.1.1. Fuzzy Logic Controller

To determine the next hop in the TARPFL, the following steps are followed: fuzzification, mapping and combining of rules, and defuzzification.

• Fuzzification: we use predefined linguistic variables and membership functions to convert the current temperature, buffer occupancy, and link quality factor to the corresponding fuzzy values. For all $C_i^{n-1,n}$ and $B_i^{n-1,n}$, we introduce the degree factor belonging to (High, Medium, Low). In addition, the link quality is set to (Good, Medium, Bad).

• Mapping and combining of rules: we employ IF/THEN rules to map the fuzzy values to predefined rules and combine the rules to obtain the rank of the neighbor as a fuzzy output value. Rank can be defined as (Good, Acceptable, Bad).

• Defuzzification: we use the predefined output membership function and defuzzification method to convert the fuzzy output value to a numerical value. For the defuzzification, the center of gravity (COG) method is used in TARPFL.

Table 1. Fuzzy rule of rank of each link.

Rule	C	B	RSS	Rank
1	L	L	Good	Good
2	L	L	Medium	Acceptable
3	L	L	Bad	Bad
4	L	M	Good	Good
5	L	M	Medium	Acceptable
6	L	M	Bad	Bad
7	L	H	Good	Acceptable
8	L	H	Medium	Bad
9	L	H	Bad	Bad
10	M	L	Good	Good
11	M	L	Medium	Acceptable
12	M	L	Bad	Bad
13	M	M	Good	Good
14	M	M	Medium	Acceptable
15	M	M	Bad	Bad
16	M	H	Good	Bad
17	M	H	Medium	Bad
18	M	H	Bad	Bad
19	H	L	Good	Acceptable
20	H	L	Medium	Bad
21	H	L	Bad	Bad
22	H	M	Good	Bad
23	H	M	Medium	Bad
24	H	M	Bad	Bad
25	H	H	Good	Bad
26	H	H	Medium	Bad
27	H	H	Bad	Bad

3.1.2. Construction of Fuzzy Rule

To rank neighbor nodes based on the fuzzy value of the current temperature, buffer occupancy, and link quality described in the previous section, each node uses the IF/THEN rules (as defined in Table **1**) where C represents current temperature. Moreover, B represents buffer occupancy and RSS means received signal strength which are defined in section 3.1. The linguistic variables of the rank are defined as {Good, Acceptable, Bad}. We define the following rule in Table **1**. As shown in Table **1**, choosing the next hop with a low current temperature and buffer occupancy as well as a good RSS is desirable. Conversely, a bad rank indicates a high temperature and buffer occupancy under bad RSS values, such as Rule 27.

3.1.3. Algorithm for Selecting the Next Hop

After each node measures three parameters and exchanges them through a BEACON message, a node selects the next hop towards the sink node. Algorithm 1 shows this process.

Algorithm 1: Selection of Next Hop

INPUT: H_i ← Hop count from node *i* to sink

N_i ← Neighboring nodes of node *i*

$R_{i,j}$ ←Rank of link between nodes *i* and *j* according to Table **1**

VAR: CL_i ← Candidate link set for next hop in node *i*

LH_i ← New link set sorted by hop count in node *i*

OUTPUT: $NEXT_i$←Next hop of node *i*

1: LH_i ← Make_New_List(N_i)

2: **For** j = 0 to $|LH_i|$

3: **If** ($R_{i,j}$ == *Acceptable*) {

4: $NEXT_i$ ← j

5: **RETURN**

6: }

7: **Else If** ($R_{i,j}$ == *Good)*

8: $CL_i = CL_i$ U {j}

9: **Else**

10: **CONTINUE**

11: **End For**

12: **If** $|LH_i|$ is not empty

13: $NEXT_i$ ← Randomly_selected (CL_i)

14: **Else**

15: $NEXT_i$ ← First element in LH_i

The details of each step are as follows:

• INPUT, VAR, OUTPUT: This algorithm takes three inputs for each node *i* and outputs the next hop. One link set is managed.

• Line 1: For the neighboring nodes of node *i*, we create a new link set sorted by the decreasing hop count. Thus, the first element in LH_i is the closest neighbor node to the sink.

• Lines 2-6: For all elements in $LH_{i,}$ we check the rank of the link from node *i* to a neighboring node. If this link rank is "**Acceptable**" according to Table **1**, this node is set to the next hop of node i, and the algorithm is terminated.

• Lines 7-9: If the rank of a link is "**Good**," this node is inserted into a new link set, LH_i. Otherwise, the neighbor node is ignored for the next hop.

• Lines 12-13: If the LH_i is not empty, we randomly choose one element in LH_i and then set this node as the next hop of node i.

• Lines 14-15: If LH_i is empty, the rank of all neighboring nodes is "**Bad**." Here, we choose the next hop as the closest node to the sink node with the minimum hop count.

4. EXPERIMENTAL AND RESULTS

To conduct the simulations, we have implemented TARPEL based on our previous work [14] which is represented as PREVIOUS in Figs. (**1**-**3**). We employ it over the NS-3 network simulator [15]. Table **2** lists the PHY/MAC parameters used in the simulation.

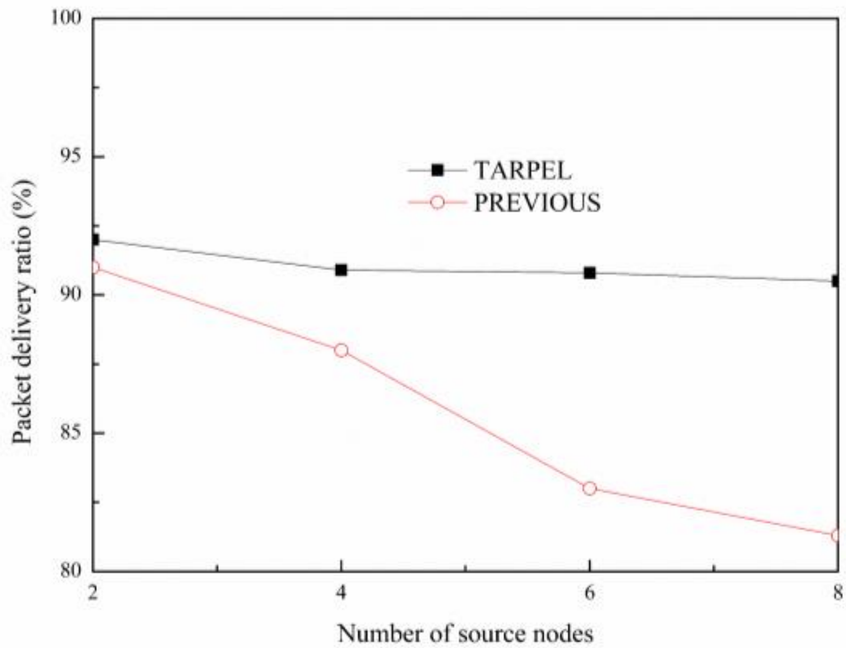

Fig. (1). Comparison of the packet delivery ratio.

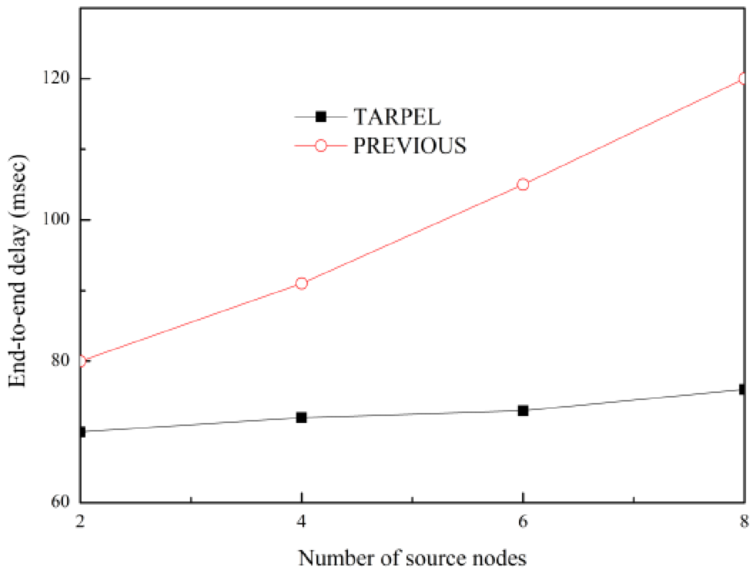

Fig. (2). Caption required.

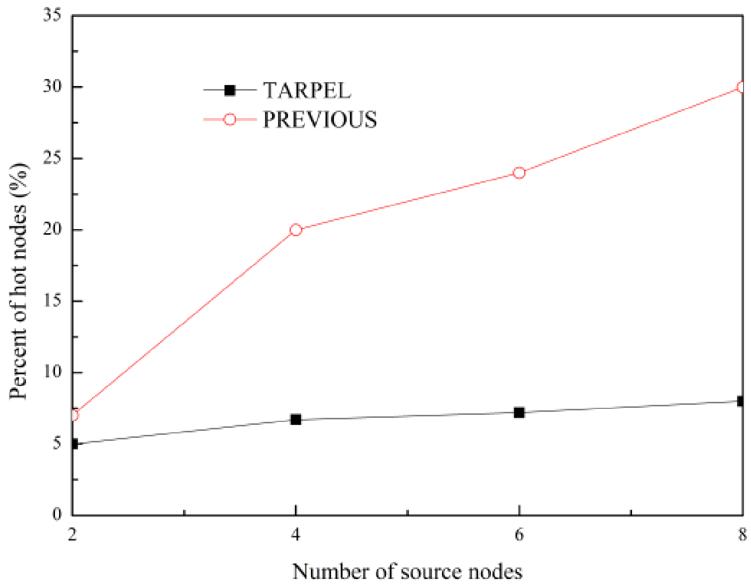

Fig. (3). Comparison of high-temperature nodes.

Table 2. Simulation settings.

Parameter	Value
PHY/MAC	IEEE 80215.6
Data rate	404.8 Kbps
Random Access	CSMA/CA
Payload size	255 bytes
Tx Power	0 dBm
Rx energy	4.5 mA

A WBAN comprises 1 coordinator and 16 sensor nodes. The initial position of each node is determined by the type of medical application. If the temperature of a sensor node is over 4.5 °C, its status is considered to be H because tissue damage is reported at approximately 4.5 °C [16]. We measured the packet delivery ratio, end-to-end delay, and number of sensor nodes exceeding the temperature threshold. For all scenarios for evaluation in this section, we set the number of source nodes from 2 to 8 among 16 sensor nodes toward a coordinate. Only source nodes are able to generate the traffic while others relay traffic. As the number of source nodes increases, heavier traffics are generated in the networks. This is to identify how the evaluation metrics are affected by increases traffics.

4.1. Comparison of the Packet Delivery Ratio

To compare the packet delivery ratio, we increased the number of source nodes ranged from 2 to 8 among 16 sensor nodes toward a coordinator. The packet delivery ratio is affected by how a large number of data packets is handled. Fig. (**1**) shows that the proposed TARPFL reveals a higher packet delivery ratio although a great difference is not observed in one source case. When the number of source nodes increases, the TARPFL does not exhibit a significant impact, whereas the previous method exhibits a lower packet delivery ratio. Because the TARPFL considers the amount of buffer to choose for a parent node, it leads to distributing the packets along different paths. In addition, the higher packet delivery ratio originates from the consideration of link quality. To choose a good link quality, the number of retransmitted packets is reduced. This is reasonable because the retransmitted packet cannot be detoured to the other path.

4.2. End-to-end Delay

Similar to the packet delivery ratio, the end-to-end delay is affected by the congestion. In addition, the hop count and link quality are another reason for increasing the end-to-end delay. The proposed TARPFL properly distributes the packets based on the number of packets in the buffer, resulting in a decreased end-to-end delay. Moreover, the hop count is the most important parameter to choose for the parent. Thus, the shortest good-rank node for the parent is likely the most desirable choice. Reducing the number of retransmissions is another resource for the improved performance. Fig. (**2**) compares the end-to-end delays, where the end-to-end delay using the TARPFL is evidently shorter than that using the previous method.

4.3. Percent of High Temperature Nodes

Fig. (**3**) illustrates the number of nodes that earn the high-temperature status for the two protocols. Although both protocols use the temperature values to select the parent, the performance of the TARPFL is better than that of the previous method. This is because of the aforementioned suitability of fuzzy logic for conflicting factors. A high-temperature node is avoided by considering the current temperature and packets in the buffer. Therefore, the packets are well-distributed and transmitted to a low-temperature node. Fig. (**3**) illustrates this comparison, where the impact of the increased number of source nodes is not significant for the TARPFL.

5. DISCUSSION

Based on the performance evaluation through a simulation, we observed that the TARPFL exhibits a better packet delivery ratio, end-to-end delay, and number of temperature nodes in terms of an increased number of source nodes. The TARPFL maintains an acceptable performance while the comparative scheme exhibits a degraded performance. The TARPLE reveals around 10% higher packet delivery ratio and 36% shorter end-to-end delay than the previous approach. In addition, total number of hop spot nodes are observed 22% less than previous one. The major source for the higher performance is the proposed fuzzy logic solution. It efficiently considers the multiple parameters together and contributes to obtaining better performances.

Moreover, a high temperature node is typically requested to be stop once the temperature is below threshold. This interruption makes the network unstable. Compared with the number of hot spot nodes, a higher number of nodes contributes to lowering the packet delivery ratio and lengthening the end-to-end delay. Although fuzzy logic leads to a high performance, the three chosen parameters are another key component. These three parameters are key for preventing high temperature nodes.

CONCLUSION AND FUTURE DIRECTION

In this paper, we proposed a temperature-aware routing protocol based on fuzzy logic. To design the fuzzy logic to prevent high temperature nodes, three parameters were considered and used to choose the parent node. A new algorithm for selecting the parent was presented and compared with that of a previous study. The improved performance was observed and analyzed as a function of the increased number of sources.

In the aspect of deployment of WBAN, fault tolerance is essential to collect peoples' vital information. So, we will develop an improved fault tolerant temperature-aware routing protocol to replace the failed forwarding node dynamically by adding new parameter and constructing new fuzzy rule.

LIST OF ABBREVIATIONS

WBAN	=	Wireless Body Area Network
TAEO	=	Temperate Aware and Energy Optimized
SAR	=	Specific Absorption Rate

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

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