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Research paper

A Novel Temperature Aware Protocol Based on Mobile Node in Wireless Body Area Networks

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Abstract

Background/Objectives: Due to direct implantation of sensor nodes on the body, temperature aware routing becomes critical and important technical issue to prevent damage of the tissue in wireless body area networks.
Methods/Statistical analysis: To prevent temperature rise, most of existing routing protocols are likely to take approaches, either detouring the hot spot area or dropping packet to avoid the excessive high temperature. However, these operations may cause long delay and low packet delivery ratio, accordingly. Thus, a new approach to adjust temperature of sensor node is demanded.
Findings: Unlike the existing protocols, we make use of mobile node to carry packet to the sink whenever any hot spot is found along the forwarding path. Thus, alternative path around hot spot becomes one of two, that is, detour and mobile path, according to expected delay to the sink. As compared to existing schemes, the proposed scheme does not cause overhead by making use of mobile node which is already implemented but not take any specific task for temperature control. Simulation results demonstrate that the proposed scheme can improve packet delivery ratio as well as reduce end-to-end delay rather than existing protocol.
Improvements/Applications: Improved routing algorithm was proposed to make use of mobile nodes and thereby to prove the applicability of the proposed scheme in wireless body networks.

Keywords: *wireless body area networks, mobile node, temperature, prediction, alternative path*

1. Introduction

Recently, WBAN[1] has attracted the interests from the research community as more applications such as monitoring patients have emerged in this area as well as taken it as underlying network technology. Since WBAN is basically based on typical wireless sensor network, some common research challenges are studied continuously. However, due to major difference between wireless sensor networks and WBAN, there are unique research areas and challenges for WBAN. Among them, in the point of deployment and implementation, WBAN is completely different from typical wireless sensor since sensor nodes in WBAN are usually implanted over or on the body in direct way. So, fewer sensor node is usually deployed around the body in WBAN than typical wireless sensor networks. Moreover, the side effect of heat and radiation of sensor node needs to be explored well to prevent damage on the body. That is, high temperature on sensor node may cause damage on the skin tissue so it is very essential to control overheating of sensor node in proper way. This is why temperature awareness becomes one of specific requirements in WBAN.
In order to take temperature aware property in WBAN into account, several temperature aware routing protocols[2] have been proposed by establishing data delivery path to avoid hot spot. In common, their approaches consist of three major phases, i) temperature measurement or prediction, ii) identification of hot spots and iii) detouring the hot spots. Based on the above operations, hot spots are usually excluded from the delivery path so high temperature node becomes normal by avoiding tasks on the node. To do so, each node tries to keep their temperature below the predetermined the threshold. However, due to severe constraints on the node for size and computing capability, their approaches are far from optimization. Moreover, they usually handle these hot spots in two different ways. If the alternative detour path is available, packet is transmitted along the new path. Otherwise, packet is discarded before being delivered to hot spot. Therefore, these approaches may naturally cause long end-to-end delay and low packet delivery ratio. When it comes to consider their constraints, their approaches seem acceptable but need to be explored further to enhance the performance. To address this problem, several mobility aware routing protocols have been proposed and presented in [3].
To solve this problem, in this paper, we focus on establishing new alternative path for hot spot area. In the proposed scheme, we try to select the one of detour paths, typical detour path with static nodes and new path with mobile node instead of conventional approach to find alternative path with static sensor node. Since the position of mobile node is dependent on human motion, there are frequent topology changes in WBAN according to person's gesture, for example, walking and running. This movement makes a new possibility for temporary link between mobile node and static node. Therefore, this link created by mobile node can be good alternative path to detour the hot spot temporarily. Moreover, since movement pattern is not random in WBAN, it is possible to predict for delay in this path. Based on above analysis, we utilize store-and-carry scheme of mobile node in Delay Tolerant Networks (DTN) and select it if the shorter end-to-end delay is predicted than typical detour path.

As similar approach to employ store-and-carry scheme, Disruption Tolerant WBAN (DT-WBAN) was presented in [4]. In this approach, seamless handover between online and offline monitoring of vital parameters or activity data was considered in the area of healthcare. The authors provided how to synchronize the data and analyze the expected data rates with introducing DTN approach. Moreover, various simulation scenarios were given to demonstrate the suitability of functionality and limit. However, since DT-WBAN focused on data gathering for patient monitoring and transfer gathering data to the storage, it shows the completely different usage for store-and-carry approach with the proposed scheme. Another approach to make use of store-and-carry was presented in [5]. In this work, topology partitioning and alternative path scheme were addressed to achieve load balance. However, this approach was not related to temperature aware routing while the proposed scheme is specific for temperature aware routing to avoid hot spot. Therefore, the proposed scheme is likely to extend the previous work for specific protocol. Another scheme based on DTN routing protocol was mentioned in [6]. On-body DTN routing protocols was designed with a stochastic link cost formulation, capturing multi-scale topological localities in human postural movements. Furthermore, performance evaluation with other DTN approaches was analyzed and compared through simulation. However, its main objective is not hot spot prevention so there is clear differences between the proposed scheme and on-body DTN approach. Based on these research motivation, we present a new routing protocol to avoid hot spot through mobile node.

The rest of this paper is organized as follows. Followed by the introduction, we describe the related work, temperature aware routing and mobility support in WBN. And then, we explain a new scheme in the section 3. In the section 4, we explain the simulation results and analysis. Finally, we make a conclusion and further study.

2. Overview of Existing Schemes

2.1. Temperature Aware Routing

Thermal-Aware Routing Algorithm for implanted sensor networks(TARA)[7] was the first protocol to employ temperature aware routing concept. In TARA, greedy forwarding algorithm is introduced to select the coolest node as next hop along the path. Thus, if all neighbors become hot spots, there is no available path to forward the packet. If this situation happens, packet is not dropped. Rather, it is returned to previous node to inform that there is no available node along the path. By this operation, packet is not forwarded to hot spot any more so hot spot node becomes normal. Even though TARA takes temperature as link cost to forward packet, greedy forwarding algorithm leads to long delay and hops. Also, backward forwarding for hot spot causes additional transmission delay. However, it is worthwhile mentioning that temperature issue in routing protocol is addressed by the TARA. So, further temperature aware routing is basically based on TARA and improves it.

Since greedy forwarding approach is main source for long delay and low packet delivery ratio, Least Temperature Routing (LTR)[8] is proposed to prevent temperature rise of whole networks. In LTR, each node selects the next hop as the coolest node to reach the destination. The main difference between LTR and TARA is packet drop policy which can be caused by greedy forwarding. To achieve this goal, if hop count field of the packet exceeds MAX_HOPS, the corresponding packet is dropped. However, important and critical data packet can be lost. Another scheme called Adaptive LTR(ALTR)[8] is presented in the same paper to address the limitation of TARA and LTR. Unlike LTR which drops a packet with hop counter larger than MAX hop, ALTR takes shortest hop routing algorithm (SHR) to forward data. So, packet delivery ratio increases and end-to-end delay decreases.

On the other hand, Hotspot Preventing Routing algorithm for delay-sensitive biomedical sensor networks (HPR)[9] is the complete different scheme in that it takes hop count for major link cost into account. And then, temperature aware property is concerned as the second metric. That is, if the next hop with the shortest hop is hop spot, the coolest node among neighbor is set to next hop. Otherwise, the shortest hop node is selected.

In addition to research work for link cost, temperature metric is concerned in end-to-end path. That is, the temperature along the path is used to select the next hop. As a good example, LTRT[10] establish the end-to-end path by accumulating each node's temperature. Among the multiple path, the lowest sum of temperature on the path is selected as the path between source and destination. To achieve this goal, weight graph and shortest path algorithm are employed in LTRT. However, there are additional overhead to build the graph of networks so it causes scalability problem when the number of nodes increases. The mentioned approaches are designed to support homogenous traffic simply.

As for heterogeneous and multiple traffic support, Thermal-Aware localized QoS routing protocol (TLQoS)[11] is proposed to multiple traffic models through temperature aware routing. It categorizes traffic into four different ones according to the importance. So, each traffic possess different QoS requirements in the aspects of delay, reliability and temperature. These metrics are used to select the next hop in TLQoS. Each routing metric is calculated under cross layered architecture and the best next hop is chosen by greedy algorithm,. However, these calculation increases the complexity of computation so it has adaptability problem in WBAN.

Finally, Thermal-Aware Field Theory based Routing (TAFTR) protocol[12] is recently proposed by S. Chelloug. In this work, the author presents the problem of temperature prediction model and their impact of their model. Instead of prediction, TAFTR is based on the field theory to avoid the hotspots and shows better performance than existing TARA and LTR.

2.2. Mobility Support Protocol

One of the different feature between typical wireless sensor networks and WBAN is topology changes according to human's gesture. That is, topology in WBAN is frequently changed according to motion such as walking and running. However, few research studies have been conducted to address mobility support in WBAN. Recently, there is a good comprehensive survey paper[3] to analyze the existing scheme In this work, the existing schemes are categorized into groups according to mobility pattern or research objective, that is, mobility modeling and mobile communication.

Also, store and carry based approach for WBAN is proposed in [13]. In this work, a prototype WBAN has been constructed to characterize as well as handle on-body topology disconnections according to human postural mobility. To avoid disconnection, a novel delay model to make use of single-copy on-body DTN routing protocols is proposed. Also, end-to-end routing delay for a series of protocols such as opportunistic, randomized, utility based and other mechanism that capture multi-scale topological localities in human postural movements has been evaluated. Performance of the analyzed protocols is then evaluated experimentally to compare with the results obtained from the developed model.

Another well-known mobility supporting temperature aware routing protocol is M-ATTEMP[14] which supports heterogenous traffic model and solves the portioning problem. In M-ATTEMPT, two kinds of traffic, that is, critical and normal data are concerned. For the critical data, single hop transmission is performed. On the other hand, multi-hop transmission is accomplished according to remaining energy. Moreover, in the aspects of temperature aware routing, a node disconnects all the links with neighbors if its temperature is higher than threshold. By this way, a node becomes normal without any additional task. However, this single hop transmission cause another battery usage and unbalanced energy consumption. Furthermore, there is no scheme to make use of mobile node for forwarding while only topology control is proposed.

2.3. Analysis of Existing Protocols

As described before, there are several routing protocols including temperature aware routing for WBAN. Also, there are many required evaluation metrics for healthcare applications. They include network lifetime, path loss, stability period, residual energy, end-to-end delay and packet delivery ratio. Thus, it is very important and essential to choose appropriate routing protocol while considering evaluation metrics and constraints in WBAN. To achieve this goal, V. Bhanumathi and C. P. Sangeetha[15] present unique properties of each routing protocol and suggest the selection of routing protocols. The existing protocols are divided into as cluster-based, cross-layered, postural movement based, QoS aware and temperature-aware routing protocols. Moreover, after analyzing the current schemes, if the system is for vivo networks, mobility-supporting adaptive threshold-based Thermal-aware energy-efficient multi-hop protocols are considered as the suitable ones. Furthermore, the authors present Future challenges and comparative analysis of routing protocols.

3. Proposed Scheme

In the proposed scheme, a data packet is basically forwarded to next hop by the shortest path algorithm at the normal stage where next hop is not hot spot. For the proposed scheme, cost on each link is set to measured delay between two nodes. The delay is measured by periodical Hello_Message to recognize the neighbors. But, due to heavy loads on specific node which locates at the nearest position to the sink node, a node easily turns into hot spot as the temperature increases. When there are normal and hot spot nodes, the proposed scheme takes following steps to avoid hot spot, i) identifying the hot spot, ii) expecting the delay for alternative path if available, iii) choosing the alternative path according to delay and connection time with sink. Moreover, since few sensor nodes are usually deployed in WBAN, alternative path selection is performed with whole topology information. In the proposed scheme, we follow the temperature measurement and prediction model in TARA as described in [7].

3.1. Identifying Hot Spot

Each sensor node selects next hop with the least delay between nodes. But, when a selected next hop is recognized as hot spot which exceeds the predetermined temperature threshold, the packet is not delivered to this hot spot. Instead, next expecting delay procedure is performed. Based on this basic operation, the basic concept of the proposed scheme is very similar to HPR.

3.2. Expecting Delay

In this procedure, delay for multiple possible paths is estimated. For the static node, a new path excluding the hot spot is computed by Equation (1) where node ***j*** is the second least delay node among neighbor nodes of node ***i***. In addition, delay for path with mobile node is predicted by Equation (2) if there are any mobile node within transmission range.

$$D_s(i,Dest) = D_s(i,j)+D_s(j,Dest) \quad (1)$$

$$D_m(i,Dest) = D_s(i,M) + \mathrm{MIN}(I(M,Dest), (\mathrm{Dist}(M,Dest)/Velocity)) \quad (2)$$

In Equation (1), $D_s(i,Dest)$ represents delay for two static node between ***i***and ***Dest*** where ***Dest*** represents destination node. If the candidate node for next hop, ***k***, is notified as hot spot, we choose node ***j*** with the second least delay among neighbor nodes and recalculate the delay. Second, for the mobile node, $D_m(i,Dest)$ is expected by adding delay between node ***i*** and mobile node ***M*** and one of both expected delays, that is, intermeeting time between ***M*** and ***Dest*** and delay computed by distance and node velocity. Intermeeting time represents how much time is taken for each mobile node to meet ***Dest*** node. If a mobile node meets ***Dest*** periodically, this value can be replaced by the meeting frequency for simplicity. In other case, each mobile node needs to keep average intermeeting time for the computation. In the other hand, another type of delay can be estimated by dividing the distance between mobile node and ***Dest*** into node's velocity. We take the minimum in two values. By this way, we can estimate delay for static and mobile node for next hop.

3.3. Alternative Path

In case that there is only one candidate for static and mobile node, we just compare $D_s(i,Dest)$ with $D_m(i,Dest)$. Thus, the proposed scheme chooses the minimum value of them and set the next hop to it. But, when multiple nodes are detected, we need to find the minimum value of D_s and D_m among multiple values. After that, we compare these two minimum values and choose the next hop according to the value.
However, there are various scenarios depending on existence of alternative path. First, if there is only either static path or mobile path, corresponding path is set to alternative path without comparing the delay. Second, if there is no alternative path expects for hot spot, the packet is discarded without further forwarding.
Figure 1 illustrates the example of operations in the proposed scheme. In Figure 1 (a), normal operation without hot spot is performed through the shortest path algorithm. But, if red colored node becomes hot spot, there are two possible paths to avoid the hot spot. Figure 1 (b) shows the detour path with static nodes. In order to avoid hot spot, the longer path than one in normal case is established. On the other hand, Figure 1 (c) reveals that detour path with mobile node. According to movement of mobile node, packet locates closer and closer to the sink node. Eventually, a packet is passed to the sink node as shown in Figure 1 (c). By this way, a path is dynamically established for static and mobile node.

4. Performance Evaluation

In this section, we present the results of performance evaluation through simulation which was implemented in Matlab. In order to recognize the impact of routing protocol only, we did not consider various functions in other layer. That is, packets are simply passed toward upper/lower layers without any additional task. Each source node generates a packet with a size of 32 bytes of payload every 0.5 second interval. The interval of Hello Message is set to 1 second. The simulation scenario is as follows. First, we assume that the sink/destination node locates in the center of body. For the mobility, we capture walking posture for our simulation. We have four mobile sensor nodes on the two arm and legs, respectively. Also, twenty sensor nodes are implanted on the body in grid way while considering density. We measure the packet delivery ratio and end-to-end delay in varying number of sending source node. For the mobility speed, velocity is set to around 1m/sec. For the comparison, we choose Hotspot Preventing Routing [9] which has the similar objective and operations to the proposed scheme.
Figure 2 illustrates the packet delivery ratio as the number of source nodes increases. The increasing the source nodes indicate the higher possibility of occurrence for congested areas. Consequently, more intermediate nodes become hot spot since more packets increase temperature on a node. As you can see in

Figure 2, as the number of source nodes increases, packet delivery ratio shows rapid decrease in case of HPR. The lower packet delivery ratio is significantly brought by the longer path which is more likely to experience contention with other nodes continuously. So, there is higher possibility of packet drop in the longer path. However, as compared to HPR, the proposed scheme shows the similar value without regard to number of nodes. Due to mobile node and alternative path, hot spot is efficiently prevented and easily recovered to normal node by detouring. Also, dynamic selection between static and mobile node leads to temperature decrease while HPR has limitation for this adaptability.

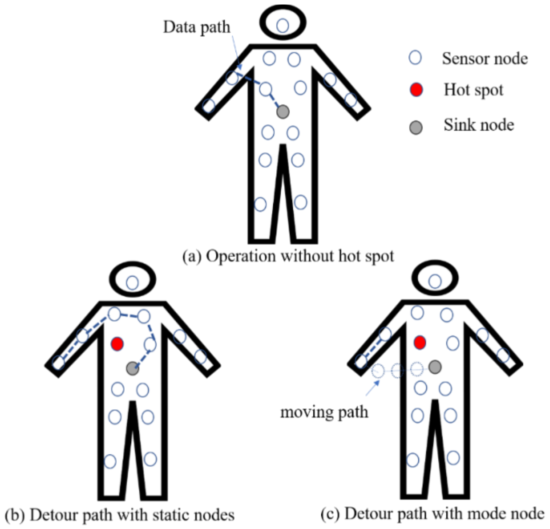

Figure 1: Example of operation

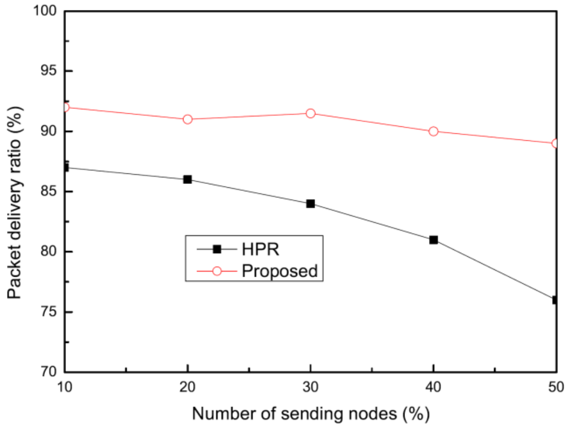

Figure 2: Packet delivery ratio as a function of number of sending nodes

Similar pattern is observed in Figure 3 where end-to-end delay is measured as a function of source nodes. As the number of nodes increases, the end-to-end delay of HPR increases accordingly. Furthermore, if number of source nodes becomes large, delay is longer than one in small number of source nodes. Since detouring makes another hot spot consequently, procedure to establish alternative path is repeated accordingly. This implies that detouring path to the same path happens frequently in high overload networks. So, the effect of detouring seems to be reduced but the end-to-end delay become longer. In the case of proposed scheme, detouring is performed in two ways, static path or dynamic path. These two alternative path improves the effect of detouring as well as contributes to prevent hot spot in simple way. But, as the number of sending nodes increases, the end-to-end delay slightly increases.

Furthermore, we measure the variance of temperatures onall nodes. The variance is calculated by figure out by finding the highest and lowest temperature on each node. While the larger variance is observed in HPR, the smaller variance is measured in the proposed scheme. Due to dynamic selection of static and mobile node, the temperature of static node turns normal without regard to amount of traffic. This implies that alternative path of mobile node contributes to improve the performance of temperature aware routing.

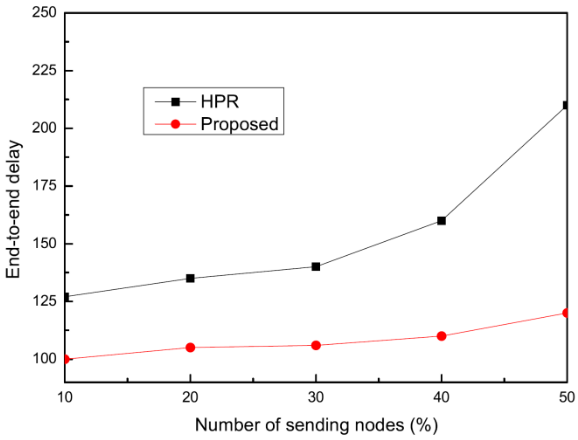

Figure 3: End-to-end delay as a function of number of sending nodes

5. Conclusion

In this paper, we proposed a new alternative path scheme to make use of mobile node. Unlike the typical detouring protocol, an alternative path through mobile node was additionally considered for path selection. Also, since short end-to-end delay in both alternative paths was considered, the impact of detouring was enhanced by preventing hot spot in proper way. Two simple simulation results were presented in the aspects of packet delivery ratio and end-to-end delay to prove superiority to previous scheme.

Related to this scheme, more analysis for delay prediction and its diverse performance evaluations will be performed. Also, since delay is very sensitive to MAC layer, a study for MAC protocol is also required as further study. In addition, various simulation scenarios over NS-3 will be conducted and analyzed.

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