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TEARP: New Temperature and Energy Aware Routing Protocol for Wireless Body Area Network (WBAN)

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Abstract

In the near future, the biomedical research will be one of the major applications for sensor networks. Wireless Body Area Networks (WBANs) consist of a set of bio-sensors that are implanted inside the human body to sense several health conditions, the communication between these sensors is made wirelessly. These sensors are charged by a battery. The nodes will transmit the sensed data through other nodes in the order it to the base station which is located outside the sensing environment which in this case represents the human body. The communication field consumed a significant amount of node's energy and minimizes the lifetime of the node. Furthermore, the sensor's operation generates heat which raises the tissue temperature around the implanted sensors. Therefore, the research majorly addresses these issues of communication, a new Temperature and Energy-Aware Routing Protocol (TEARP) has been presented for WBANs implementing a new route-choice system that seeks to equalize the use of energy of sensors and minimize their overheating. This method is depending on a formula that takes into account the remaining energy of sensor nodes, the distance between nodes as well as between nodes to sink, in addition to their temperature when selecting the following relay node. The simulation results show that the TEARP protocol has improved network lifetime efficiency by about 300%and 90%, stability by about 82% and 11%, and residual energy by about 71% and 74% compared to the M-ATTEMPT and Simple protocols respectively.
Keywords- Wireless body Area Network (WBAN), Cost Function, Residual Energy, Energy efficiency.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are utilized in monitoring systems, agricultural field monitoring, and smart homes to track a variety of factors. To monitor the field, these wireless sensors are deployed throughout the detecting region. [1]. WBAN is a brand-new, developing sub-field of WSN[2]**.** Health monitoring is one of WBAN's main applications [3]. To track vital signs including temperature of the body, heart rate, blood glucose level, and others. Wireless Body Sensors are applied to or implanted in the human body [4]. The costs associated with a patient's stay in the hospital are greatly reduced when WBAN technology is used to monitor vital signs. WBAN technology allows the monitoring of patients from home for a longer amount of time. Sensors constantly detect data and send it to the medical server. WBAN communication commonly comprises three tiers communication:
1-The First tier is intra-communication is achieved by the body sensor units that are placed outside or inside the human body. These sensors are in charge of finding the signals from the physiological data, converting the signals to digital form, and then transmitted wirelessly to the next tier.
2-The Second tier is inter-communication containing personal server units. These units get data from sensors and process results to convey to the upper third tier.
3- The Third tier is extra-body communication consisting of user hardware are professionals in data who can make decisions WBAN sensor nodes used a finite quantity of energy.
Because of the sensor's limited battery, power consumption management considers a significant problem that should be accounted for in the design of this network in order to minimize the power drain of the sensors and prolong the network lifetime. When sending information from sensor nodes to the sink, the needed power consumption must be as minimal as possible [5]. To solve this problem with battery recharging, an effective routing protocol is needed for prolonged patient monitoring[6]. A stable, efficient, and long-lifetime routing protocol for WBAN is suggested. Deployed sensor nodes in fixed locations on the body and the sink placed at the waist. These sensors have important information about the patient and needed little energy, high reliability, low temperature, and long life[7]. Data from these sensors is transmitted to the sink via their parent node, which they follow. It helps in saving the power of nodes and the network works for a longer time [8].
In this work, a new Temperature and Energy-Aware Routing Protocol (TEARP) was suggested. The new protocol adopted the concept of parent-child criteria for the routing path section. TEARP attempts to increase the network life by balancing the energy usage of sensor nodes while preventing the nodes' temperature from rising. As for reason, TEARP uses the energy, distance, and temperature of nodes as a mixture of three parameters as a routing metric when choosing paths.
The remainder of the paper is structured as follows: In section 2, review related work. In section 3 describes the proposed protocol. The protocol stages are presented in the section 4. Sections 5 and 6 offer performance measurements and simulation findings, respectively. Section 7 provides the conclusion in the end.

II. RELATED WORK

There are many different routing schemes that proposed for WBAN technology. Many suggested routing protocols discussion in this section. Temperature-Aware Routing Protocols are suggested as a solution to the node overheating issue. These routing protocols use node temperature as a metric while choosing a routing path. The temperature-aware routing protocols belong to a category of routing protocols will be main focus of what follows[9]. The first routing algorithm to use a node's thermal as an evaluation metric was Thermal-Aware Routing Algorithm (TARA) [10]**.** TARA took electromagnetic (EM) radiation from the antenna into consideration, but it largely disregarded production of heat inner the circuit board of a node owing to various electrical processes. The TARA's fundamental routing technique is followed by least temperature routing (LTR) [11]. Particularly, the method of route estimation is comparable to TARA. These routes are updated frequently, and shorter distance nodes on the routing path are chosen, although this results in delays and large distances. In order to solve this problem, LTR introduces a hop count threshold during the rerouting procedure. Packets are dropped when this limit is reached. Adaptive LTR is a further development of the LTR methodology (ALTR**)** [12]**.** The predecessor's LTR protocol's packet drop issue was addressed by this expanded protocol. ALTR also popularized the idea of "proactive delay." Though, ALTR discovers swap among latency and thermal. The shortest hop count routing method combined with the LTR protocol produces the lowest overall route temperature (LTRT**)** [11]**.** The temperature was a key performance measure for the LTRT algorithm. When a network starts, node temperature rise is measured as well as an updated route computation. The shortest hop count routing is taken into account during the route computation process, however, only those routes that have the fewest hot nodes are chosen as the final ones.
Energy efficiency is one of the prime concerns for designing the routing protocol in WBAN. The authors in [13]proposed a very popular protocol called SIMPLE: Stable Increased-throughput Multi-hop Protocol for Link Efficiency, a protocol for WBAN. As for identifying the nodes that are most effective in terms of long-term stability and throughput, the SIMPLE protocol uses a cost function. This protocol provides more network stability and a longer network lifetime compared to other protocols.
M-ATTEMPT (Mobility Supporting Adaptive Threshold-Based Thermal-Aware Energy-Efficient Multi-hop Protocol) was suggested by[14] , the route with the least amount of power exhaust is selected for when there several paths with the same quantity of hops. According to the operation of M-ATTEMPT protocol suggested the zones and levels are defined, representing a parent-child relationship. A node asks the appropriate parent node to join when it disconnects and joins another zone. If there are less than three child nodes, the parent node will only accept the request. Multimode Energy-Efficient Multi-hop Protocol (M2E2) suggested by [15]. M2E2 is a stable, high-throughput, and energy-efficient routing solution for WBANs. It fixes vulnerabilities in the M-ATTEMPT protocol if a parent node rejects to receive a query from a migrating node, for example. However, there is no effective technique for a mobility aid, so there are no alternative means for providing information to clients when a node die.
In [16] had proposed an Adaptive Thermal-Energy-Aware Routing (ATEAR) based on the blockchain In this research work, that achieved stability and efficiency in the routing of WBAN but the results evaluations illustrated that network life was decreased.
The authors in [17] had proposed an Efficient Energy Aware Routing (EEAR), the new protocol that constructs a path cost function based on three parameters: residual power, number of hops to the base station, and the distance between the nodes. Additionally, the power harvested method is implemented to longer the network lifetime. The result showed the high performance of the protocol mechanism in terms of network lifetime and residual energy, but they do not take into account the dynamic movement of the body.

III. PROPOSED PROTOCOL

A. Presentation of TEARP:

This section briefly describes the overall system model used in the analysis of the proposed protocol. It includes network features, radio model, and stability model used in wireless communication of information packets.
In this scheme, eight sensor nodes are deployed on or inside the human body. Sensor nodes are heterogenous each one has its characteristics and has different initial power. The sink node is located at the waist. The location of nodes and sinks on the human body are depicted in Figure (1). The suggested protocol's features and assumptions are as follows:

1) The nodes are implanted and deployed inside the human body at specific locations according to their sensing activities.
2) Dynamic parent selection: which mean that a new parent node will be selected in each round.
3) Heterogeneous: Each sensor node has a different energy level, processing and storage capabilities (at the start of the operation).
4) Centralized: the sink will be in charge of the majority of computing tasks.
5) Non-probabilistic: a higher degree of determinism will be utilized to choose the parent and child based on cost function and parameters.
6) There are no energy limits on the sink because it is in stationary mode.
7) The sensors have always a sensed data that needs to be sent according to their assigned time slot. These time slots will be assigned by the sink in order to prevent the collision during the transmission and receiving activities.
8) The intra-communications between the sink and the nodes will be in multi-hop mode through the certain head node (parent node).
9) To avoid tissue damage because of the node’s high heat, the node’s temperature will be taken into consideration.
10) The new round will be started based on various metrics such as the power level of the node and the temperature level.

11) Sleep mode consumes very little energy and has a minor impact on overall consumption according to this, it will be neglected during the calculations. [18][19].
12) Harvesting: the proposed design adopted thermal harvesting which means that the nodes can charge themselves using body heat. This will maximize the energy level of the node[3].

The protocol's execution is separated into two major actions (setup step and steady state step).

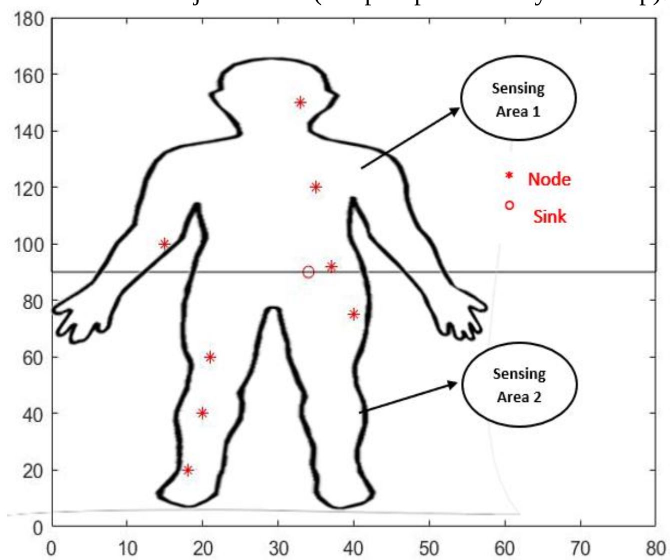

Figure 1. Node and Sink Positions on the Human Body.

B. Radio Model

The simple radio model will be adapted to compute the amount of energy used for transmission and reception. Figure (2) illustrated that the power attenuation depends on the transmitter's and receiver's distance [2], Equations 1 and 2 showed the energy used to transmit and receive a k-bit throughout a distance [20].

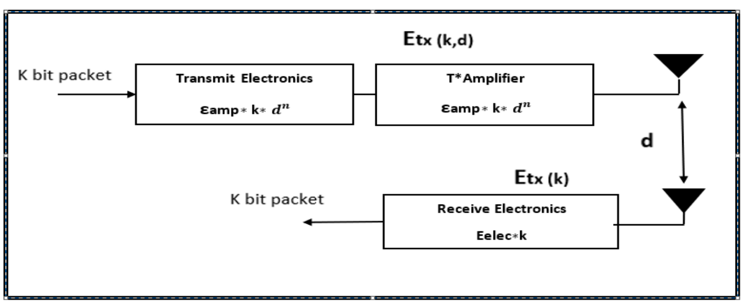

Figure 2. Model of Radio Power Consumption (redrawn from[20])

$$E_t = E_{elec} \times k + \varepsilon_{amp} \times k \times d_n \quad (1)$$

$$E_r = E_{elec} \times k \quad (2)$$

Where E_t= power consumed to transmit data in Joule (J),
E_{elec}= power consumed in the electronics = 50nJ/bit,
E_r= power consumed to receive a k-bit data in Joule (J),
K= packet size in bits,
d = the distance between two nodes in meter
n = path loss exponent,
ε_{amp} = power consumption in power amplifier in Joule (J),
The fixed variables **n** and ε_{amp} in the equations above were chosen based on the radio propagation model.

IV. PROPOSED PROTOCOL GENERAL STAGES

A. Initial Stage:

Initially, the sensor nodes and the sink are deployed. Sink already knows the sensor node position and energy current for each node. The operation of the protocol will be based on assumption that the sensing area will be clustering into two parts: upper (sensing area

1) and lower (sensing area 2) as shown in figure (1).The sink starts to calculate the distance with the other node and checks to which part the sensor node belongs, and makes a table for each part that contains (SN ID, E_level, and coordinate of the node) as shown in figure (3).

B. Selection of next hop:

A multi-hop strategy for WBAN was proposed to keep power and increase the efficiency of the network. Presented parameter for selection a node to become a parent node or a child node in this step. The protocol elects a new parent during every round to equalize power consumption across nodes and lower network energy usage. The sink knows the ID, distance between nodes, the residual power situation of the nodes, and temperature of the node that as shown in figure (3). Each node in the network is a startup temperature of 37℃. The designed routing protocol's major purpose is to reduce the negative effects of temperature rise in on-body nodes on human skin.

SN ID	Energy level	coordinate of each node	Temperature

Figure 3. Sink to Nodes Information Packet

After that, the sink computes and transmits the node's total cost function. Sink selects whether or not to become a parent depending on the cost function stated in equation (3). The non-parent nodes will be known as child nodes. If (i) is the number of sensor nodes, then the cost function of (i) nodes is:

$$\boldsymbol{C.F\ (i)} = \frac{\boldsymbol{d(i)*\Delta T}}{\mathbf{E_{current}}} \qquad (3)$$

d(i) distance between the node i and sink,

$\boldsymbol{\Delta T}$ change in the temperature of the anode that temperature increment per packet 0.01 c̊ [16].

$\boldsymbol{E_{current}}$ power of node (i).

$\boldsymbol{E_{current}}$ determined by subtracting the consumed energy of node from the starting total energy and collect it with energy harvesting as shown in equation (4) below:

$$\boldsymbol{E_{current} = E_{inital} - E_{con.} + E_{harvisting}} \qquad (4)$$

$\boldsymbol{E_{inital}}$ represents the start-up energy level of the node, while $\boldsymbol{E_{con.}}$ represents the power that has been consumed by the node in the current round. Where $\boldsymbol{E_{harvisting}}$ will represent the amount of energy that will be charged to the node battery to prolong the battery's lifetime by converting the energy sources in the environment into an electrical signal [21]. Thermoelectric transducers can then be used to transform thermal energy into electrical energy, with a maximum power of 60 micro watt per square centimeter that mean the node harvested power ΔT=5 c̊[22] .

C. Steady state stage (provide the necessary data and transmission):

Overall, and after receiving the parent selection notification Nodes start to send information and the sink will keep monitoring the node energy level according to equation (4). It's critical to remember that process of choosing a parent node is dispersed over all nodes, this means that until all other nodes have been picked, the node would be chosen as the parent node for current round cannot be selected as the parent node as the next rounds. Parent node aggregates information and forwards it to the sink. Because the parent node has the majority residual power, less temperature, and shortest distance to sink, it uses the least amount of power to send data to the sink.

D. New round startup:

According to the assumption in this thesis, the round duration cannot be constant or assumed randomly. according to this, in the proposed design, the new round will be started under several conditions as listed below:

(i) The parent nodes' energy level is minimum than the energy average level of the nodes within a single cluster. Sink should be recalculated the $E_{current}$ and temperature of each sensor node before start new round according to equation (4), so the Energy average calculated at each round.

(ii) The temperature of the parent and/or child node is exceeding the normal degree (equal to or greater than 40°C). This will useful to avoid the body tissue damaging by the heat [23].

V. PERFORMANCE METRICS

For the proposed protocol, tested the critical performance measures. The following subsections define performance metrics.

1) Network lifetime: that means the period from the network's startup till the last nodes have died.
2) Stability period: the time duration until first node death. The time period after the death of the initial node is referred an unstable period.
3) Residual Energy: describes the differential between starting energy and consumed energy of the node.

VI. SIMULATION RESULTS AND ANALYSIS

A comparison of the suggested protocol's behavior with two main WBAN protocols M-ATTEMPT [14]and SIMPLE [13] is performed in order to demonstrate its efficacy. Utilized MATLAB simulations with the parameters listed in Table 1 and the assumptions stated in the system model and assumptions section.

Table 1. Simulation Setup.

Component	Description
Simulation Area	80 * 160 cm
Number of nodes	8
Sink Node	1 static
Primary Node power	0.5,0.38,0.44,0.45,0.47, 0.4,0.35,0.3 (j)
Initial node temperature	37°c
Size of a Packet	4000
Temperature threshold value	40°c

A. Network Lifetime

The suggested scheme's average network lifetime is depicted in Figure (4). The new cost function to pick parent nodes in every round that is proposed makes a useful function to optimize the power consumption by the nodes. According to Figure (4), the suggested protocol has a longer lifetime. This is predicted, due to the careful choice of new parents in every round. As a result, all nodes practically consume the same amount of power throughout each cycle, and they all nearly die simultaneously. In M-ATTEMPT, the forwarder nodes' temperature rises, and nodes choose a different, longer route that uses higher power. As a result, these nodes die quickly. In SIMPLE node with maximum energy and the minimum distance is elected without respect to temperature but in the proposed scheme there is a balancing between energy and temperature.

The results confirm that the proposed protocol's last node dies at the 15241 rounds. Whereas the last node of M-ATTEMPT [14] and SIMPLE [15] dies at around 3800 and 8000 respectively. The proposed protocol (TEARP) achieves nearly about 300% prolonged network lifetime compared to the M-ATTEMPT protocol and achieves nearly about 90% prolonged network lifetime compared to the SIMPLE protocol.

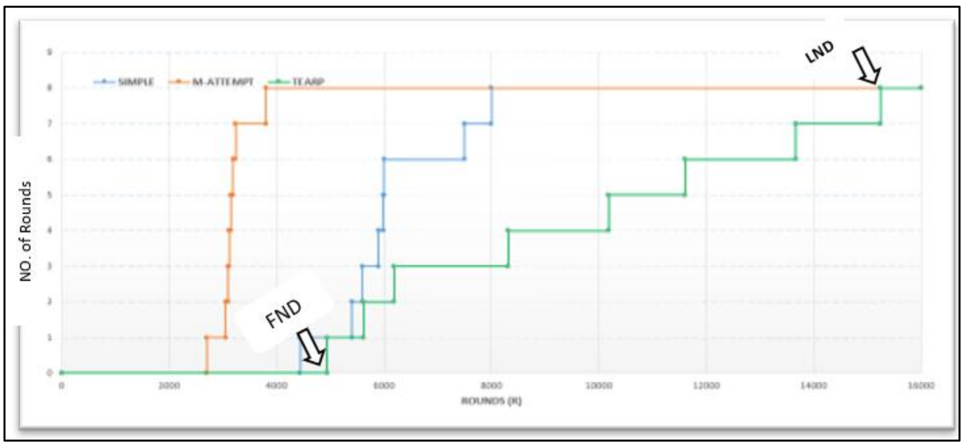

Figure (4). Network lifetime of nodes.

B. Stability Period

One of the primary performance standards used to assess any sensor network technology is stability period. Figure (5) compares the suggested protocol's network stability results to those of other protocols. The results show that the suggested protocol's first node dies at round 4937 while the first node of M-ATTEMPT [14] and SIMPLE [13] dies at around 2700 and 4436 respectively. This show that the proposed routing protocol and parent node chosen achieve a higher stability period as compared to other protocols. Proposed protocol (TEARP) achieves nearly about 11% longer stability period then SIMPLE protocol and achieves nearly about 82% larger stability period than M-ATTEMPT protocol

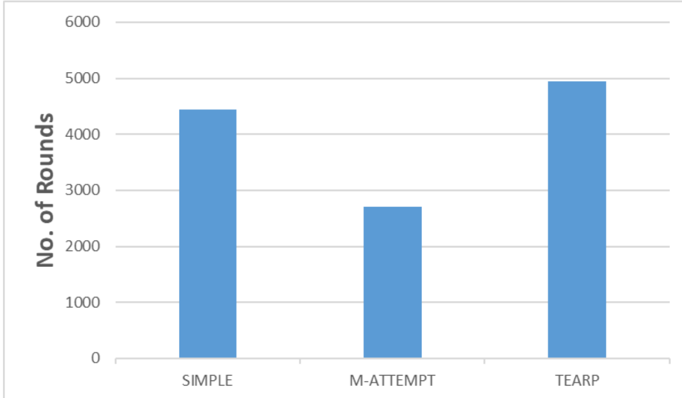

Figure 5. Stability Period.

C-Residual Energy

Figure (6) shows the network's average power for each round, each remote node in the TEARP protocol sends information's to the sink via the parent node using a multi-hop topology. The parent node is chosen using the mentioned cost function. The choice of a suitable parent node in every round contributes to saving the power of transferring data packets to the sink, proposed topology uses different parent nodes in each round according to 3 criteria, this prevents a specific node from becoming overloaded. Figure (6) shows the residual power of the suggested protocol, M-ATTEMPT and SIMPLE protocols. More than half of the power in sensor nodes with underlying M-ATTEMPT was lost through round 2000, whereas the TEARP protocol used about the same amount of power in nearly 4500 rounds and SIMPLE scheme until 3000 rounds. By comparisons with M-ATTEMPT and SIMPLE protocols in 2 points at the first rounds nearly at round 2000, at the middle rounds nearly at round 5000, as depicted in Figure (6) and calculates the average between them, that concludes "TEARP" protocol raises the overall remaining power by 74% more than SIMPLE protocol and by 71% more than M-ATTEMPT protocol.

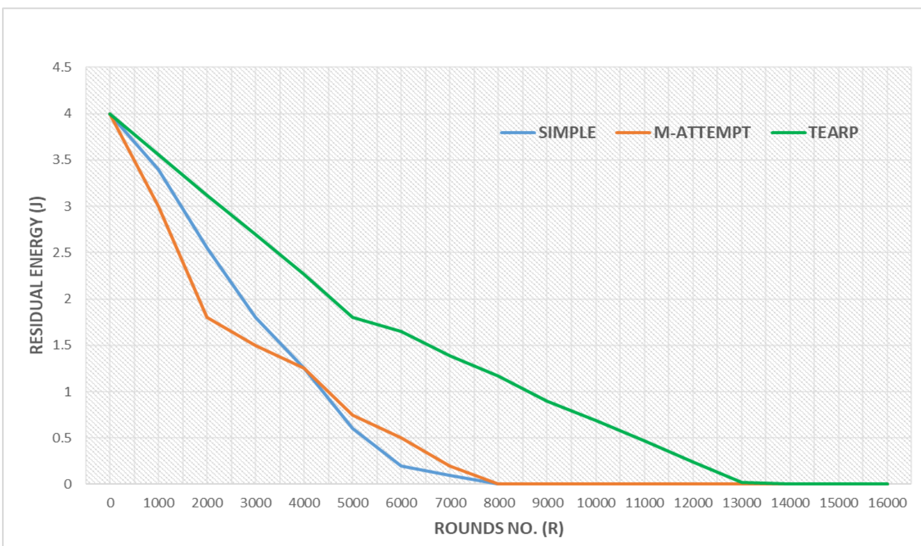

Figure 6. Analysis of Energy Consumption.

VII. CONCLUSION

This paper proposes a Temperature and Energy-Aware Routing Protocol (TEARP) for WBAN. The suggested routing protocol's primary objective is lower energy consumption, and minimize temperature levels to avoid any damage in the nodes that will minimize network lifetime and damage the tissue of the human body. Adopted the protocol of multi-hop communication between nodes and designed a new route selection mechanism that aims to lower the overheating of sensors and balance their energy usage. This process focuses on a cost function that considers the remaining nodes' remaining power, the distance between nodes and between nodes to sink, and their temperature when choosing the next parent node. The result shows "TEARP" protocol improves the network lifetime by an average of 300% and 90% over M-ATTEMPT and SIMPLE protocols respectively and controlling the nodes' temperature at a comfortable level. Moreover, "TEARP" granted stability enhancement with 82% and 11% while decreasing the power consumption by an average of 71% and 74% in comparison with M-ATTEMPT and SIMPLE protocols respectively. The results indicate that TEARP protocol preserves high network performance about of network lifetime, stability, and residual power of the node compared to other protocols.

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