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### RESEARCH ARTICLE

#### ROUTING PROTOCOLS IN WBAN: A PERFORMANCE EVALUATION FOR HEALTHCARE APPLICATIONS

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#### Abstract

Wireless Body Area Network (WBAN) consists of different heterogeneous nodes located on the surface or inside the human body to serve variety of applications. WBAN is a promising solution in healthcare field. Routing protocols are having a clear effect on the efficiency of WBAN. However, the current routing protocols in Wireless Sensor Network are not applicable for WBAN due to their performance limitations especially in the human body. In this paper, a new routing protocol is proposed for WBAN using weighted average optimization function. It is an enhanced version of Multipath Ring Routing Protocol (MRRP) where a weighted average function is used for determining the next hop node. A performance evaluation for different WBAN routing protocols for healthcare applications is presented. The protocols are evaluated in terms of energy consumption, packet reception rate, end-to-end delay and maximum temperature of sensor nodes. Simulation results showed that, compared to MRRP, the proposed protocol has better delivery rate for data packets.

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#### Introduction:-

WBAN is a special type of WSN (wireless sensor network) with more resource limitation (such as small battery, limited number of computational tasks, and limited computational power). The human body, as a communication channel, is significantly different than the usual WSN environments. Therefore, IEEE 802.15.6 (IEEE, 2012) standard was developed by the IEEE 802.15 task group 6 to fulfill the requirements of a monitoring system which operates on, in or around the human body. The currently available WLAN/WPAN technologies such as Bluetooth, Zigbee and Wi-Fi (IEEE 802.11) are not suitable for WBANs (Rashwand, Misc, & Khazaei, 2011) since they do not comply with its medical application.

Wireless Body Area Network (WBAN) consists of different heterogeneous nodes located on the surface or inside the human body (Qu et al., 2019) which wirelessly communicate with each other to provide information about the sensed environment. WBAN is applied on different applications such as healthcare, military training, interactive gaming, secure authentication and other areas. In medical applications, sensor devices aim to collect information (e.g. data about the patient) and send it to a specified sink node. The sink node is the node that is responsible for collecting the information from the sensor nodes. Then, it will send it to the healthcare center. Reaching the sink

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node can be done directly or indirectly via relay nodes. Each node consists of a radio transceiver, processor, and battery source (Qu et al., 2019).

WBAN will revolutionize the healthcare domain. It helps in reducing medical costs and improving the quality of life. The selected routing protocol or algorithm is the key factor to perform this. Therefore, there are different routing protocols proposed in order to facilitate WBAN, to ensure no delay for highly important data, and to avoid any harm to the human body. For example, TARA (Tang, Tummala, Gupta, & Schwiebert, 2005) is the first routing protocol for WBAN which consider the safety aspect by avoiding transmission via hotspot nodes. The hotspot is the node which temperature exceeds the threshold level of Specific Absorption Rate (SAR) due to data transmission. It needs to be avoided for transmission until it cools down. TARA performs well in terms of node temperature avoidance. However, it increases the number of retransmissions as the node will be back to search for alternatives after its already checked all the hotspot nodes. Multipath Ring Routing Protocol (MRRP) is enhanced by ATAR in order to provide a better control for node temperature, and to take the advantages of high packet delivery provided by MRRP. The main advantage of ATAR is having more control on node temperature. However, it consumes more energy than MRRP which will directly reduce the network lifetime. On the other hand, there is a need for considering the types of data and its priority to ensure no delay for the emergency and critical data.

In this paper, a new routing protocol is proposed for WBAN. The proposed protocol is an enhanced version of MRRP by considering energy, data priority, node temperature, and distance to sink node. The simulation results showed that the proposed algorithm has a better performance for packet delay. Also, a performance evaluation between the three routing protocols which could be applied on WBAN healthcare applications is provided. The evaluations of the algorithms are done in function of energy consumption, node maximum temperature, packet reception rate, and end- to-end delay.

The rest of the paper is organized as follows. First, related works are provided. Second, the proposed algorithm is presented and simulated using Castalia (Ngo, Huynh, & Huynh, 2018). Third, the simulation results are presented and compared with different state of arts. Finally, the paper is concluded in a conclusion section.

#### **Related Work:-**

The aim of WBAN is to monitor and report the changes about the sensed environment to a corresponding healthcare center. Such monitoring requires routing protocols to ensure fast and reliable delivery of data. In addition to the resource limitations, the safety and reliability aspects are major concerns for WBAN routing design. For example, the heat dissipation from devices causes tissue damage. Therefore, different thermal-aware routing protocols are proposed to avoid tissue damage due to the increase in sensor temperature as stated in (Mahmoud & Fadel, 2019).

Lately, the routing problems of WBAN have gained great interest, and many routing protocols are being proposed. There are different types of WBAN routing protocols: cluster-based routing, thermal aware routing, posture-based routing, and QoS (Quality of Service) routing protocols (Qu et al., 2019). Each protocol is designed for different QoS improvements such as improving data delivery, providing fault-tolerant routing, controlling node temperature and so on. In healthcare applications, following are the most important parameters:

1. Energy: It is very hard to replace the sensors located inside human body as they may need for a surgery to replace them. Therefore, increasing the network lifetime is one of the main important metrics by having energy efficient routing protocols.
2. Delay: Sensor nodes are implanted inside the human body for reporting different medical status about the abnormal behaviors. Delayed information for the critical statuses is useless and cause direct effects on human safety.
3. Temperature: Increasing in sensor's temperature due to antenna radiations and power squandering by circuits of sensor nodes have a notable effect on its surrounding human tissues. Hence, one of the important safety aspects of WBAN is to ensure that nodes are not exceeding their temperature threshold value. All thermal aware routings are tending to avoid data transmission via a hotspot. The generated heat can be measured using two important measures (Ahmed, Mahmood, & Islam, 2019; Tang et al., 2005). First, the Specific Absorption Rate (SAR) which is a measure for absorption rate of human tissue when it exposed to a radio frequency (RF) electromagnetic field. Second, Penne's bioheat equation method (PBHTE) to determine the rate of rising in temperature. Also, Finite-difference time-domain method (FDTD) (Sullivan, 2000) and sensor-centric thermal-rise model (Monowar & Bajaber, 2017) are used for modelling the heating effects.

4. Data priority: Monitored information about the patient do not usually fall into the same priority. For example, data related to human temperature is less priority than data related to early detection of cancer symptoms. Therefore, considering the type of data and its priority is a major concern for WBAN routing protocols.

#### **Multipath Ring Routing Protocol:-**

Multipath ring routing protocol (MRRP) (Huang, Tao, Liu, & Liu, 2013) is used in WSN in order to improve the data delivery. The number of delivered packets is considered as one of the important factors in healthcare applications. MRRP consists of two phases:

#### **Construction phase:**

The main idea of construction phase is to arrange the sensor (nodes) into groups (levels) around the sink node. The sink node starts the process by sending the first setup packet with level equal to zero. Then, each node will increment the ring level of the received setup packet by one. Hence, the level of the node is same as the hop count from this node to the sink node. The format of the setup packet is as follows:

Source node ID	Destination node ID	Sink node ID	Packet Type	Sequence Number	Ring Level
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Unlike the other protocols which focus only on one path with minimum energy cost, MRRP provides better distribution of node energy. It depends on broadcasting concept where each node sends the setup packet to all other nodes. The nodes on the sender's transmission range will accept the packet and re-broadcast it again. The process in construction phase will continue until all nodes are assigned a level number.

#### **Data transmission phase:**

The sensor node will keep looking for abnormal behaviors, hence, it will broadcast the data to all other nodes. Unlike flooding algorithm, only the nodes with level less than the sender level will accept the packet and re-broadcast it again. This process will be repeated until the sensed data are successfully reaching the sink node.

#### **Adaptive Thermal Aware Routing Protocol (ATAR):-**

ATAR (Jamil, Iqbal, Amin, & Kim, 2019) is considered as the latest enhancement of MRRP in WBAN applications. Rather than the broadcasting technique used in MRRP, ATAR proposed a novel idea for next hop selection based on node temperature. ATAR applied MRRP in WBAN application by considering the node temperature and data priority in order to insure no delay for high priority data. The efficient temperature control on ATAR make it applicable for implanted sensors inside human body. The simulation results showed that nodes in ATAR protocol are not reaching the threshold value of temperature (40 C). For handing data priority, ATAR assumes that all nodes have enough transmission power to send the data directly to the sink node. It depends on this assumption for sending the high priority packets directly to the sink. The phases of ATAR algorithm are:

#### **Setup phase:**

The goal of setup phase is to arrange the nodes into levels. ATAR increased the size of MRRP setup packet by adding the node temperature value. The setup packet format is as follows:

Source node ID	Destination node ID	Sink node ID	Packet type	Sequence Number	Ring level	Node temperature.
----------------	---------------------	--------------	-------------	-----------------	------------	-------------------

The process for distributing the setup packet is ATAR is similar to MRRP with node temperature added to control the temperature. Each node will update the setup packet with its current temperature level upon receiving the setup packet, then, it will re-broadcast the packet to its neighbors. This process will continue until all nodes knows about the temperatures of all of its neighbors.

#### **Data transmission phase:**

In data transmission phase, the sensor will search for the node with the least temperature and send the packet to it. ATAR sorts the node temperature into ranks based on its temperature value. Then, it selects the node with the best rank to send the data to. This is the node with the least temperature value.

A comparison between the two routing protocols is provided in the table below:

Protocol	Energy consumption	Supporting Data priority	Node temperature	Delay
MRRP	Medium	No	High	Low
ATAR	High	Yes	Low	High

**Table 1:** Comparison between MRRP and ATAR.

### Weighted Average Routing Protocol:-

In this paper, we have introduced a new Weighted Average Routing Protocol (WARP) using weighted average function. WARP is based on MRRP. The proposed protocol considers the critical parameters for medical applications: energy consumption, node temperature, distance to sink and data priority. The protocol is a cross layer protocol where data priority is taken from the application layer. In this protocol, we have assigned all the parameters with same weight to make the parameter changes uniform such as:

$$\sum_i W_i = 1$$

Where  $W_i$  is weight for parameter  $i$ . Assigning equal weights ensure that the traffic load is equally distributed among all the relay nodes in the entire network. The proportion of these weights can also be adjusted as per the application requirements.

WARP protocol consists of two phases:

#### Setup phase:

The setup phase of WARP is based on MRRP in order to arrange the nodes into levels. During the setup phase, nodes will have information about the neighbors' temperature, remaining energy and distance the to sink. During the data transmission, selecting the next hop is depending on the node with best weight. The setup packet format is as follows:

Source node ID	Destination node ID	Sink node ID	Packet type	Sequence Number	Ring level	Node temperature.	Remaining energy
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#### Data transmission phase:

In this phase, sensed data will be transmitted in multi-hop manner. Once the node got a data to be transmitted to the sink, the next hop node will be selected as per the weighted average function. Each node is assumed to have information about its neighbors. To ensure that the path will be selected toward the sink node, the list of candidate nodes will be selected from the list of neighbors with levels less than the sender level. The algorithm for selecting the next hop node is as follows:

#### Algorithm 1: Data Transmission of WARP Protocol

Given:

- Data Packet  $d$
- List of candidate nodes  $C$
- Number of nodes  $n$
- $weight = 0.25;$
- $weightedTable [] = neighborTable$
- $nextHop = -1$

Steps:

$maxsum = 0;$

**for** ( $i = 0; i < n; i++$ )

$weightedTable[i].currentTemperature = neighborTable[i].current\_Temperature * weight;$

$weightedTable[i].currentEnergy = neighborTable[i].currentEnergy * weight;$

$weightedTable[i].currentLevel = neighborTable[i].currentLevel * weight;$

$sum = weightedTable[i].currentTemperature + weightedTable[i].currentEnergy + weightedTable[i].currentLevel;$

**if** ( $sum > maxsum$ ) {

$maxsum = sum;$

$nextHop = neighborTable[i].id;$

}

```
return nextHop;
```

**Simulation:-**

The simulation is done for the three protocols: MRRP, ATAR and WARP. We used Omnet++ (Varga & Hornig, 2008) with C programming language using Castalia 3.2 (Ngo et al., 2018) framework. The used simulation parameters are presented in the table below. The simulation area is a network of  $2 \times 3 m^2$ , where different number of sensor nodes are deployed with random distribution. Each node has a transmission power equal to -25dB and packet size 296 bits. The scenario assumed that sink is at the center of the surface and nodes are located into different levels from the sink (nodes are not all on the same level). The application is considered to be sending five packets per second.

Parameter	Value
Number of implanted nodes	12 with sink at the center
Number of sinks	1 at center
Initial temperature	37C
Initial power	18720 J
Size of a Packet	296 bits
MAC	IEEE 802.15.6
Wireless environment	Ideal
Transmission power	-25dB
Node type	Homogeneous
Node mobility	Not supported

**Table 2:-** Simulation Parameters.

The performance for the proposed algorithm is presented and measured according to the following performance metrics:

1. Maximum temperature of the node: It is calculating the maximum temperature that the node reaches after the simulation time. The threshold temperature that we want to avoid is 40 C.

2. Packet reception rate: It is the rate of packets received by the sink node. It is calculated as per the following:

$$\text{Reception Rate} = \frac{\text{no. of received packets}}{\text{no. of packets sent}} * 100 \tag{1}$$

3. Energy: It is the energy consumed by sensor nodes within a specific time period.

$$\text{spent energy} = \text{initial energy} - \text{remaining energy} \tag{2}$$

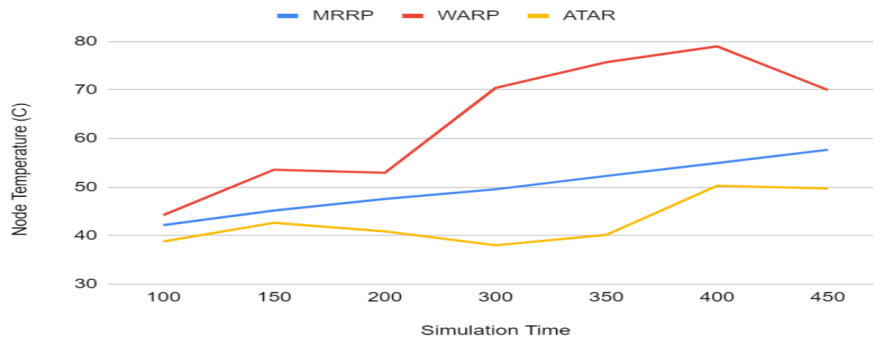
4. Latency: It is the end to end delay for the packets sent from the nodes to sink node.

$$\text{Latency} = \text{packet reception time} - \text{packet transmission time} \tag{3}$$

**Results and Evaluation:-**

In this section, the results of the performance evaluation of studied protocols are presented as follows:

**Max node temperature:**

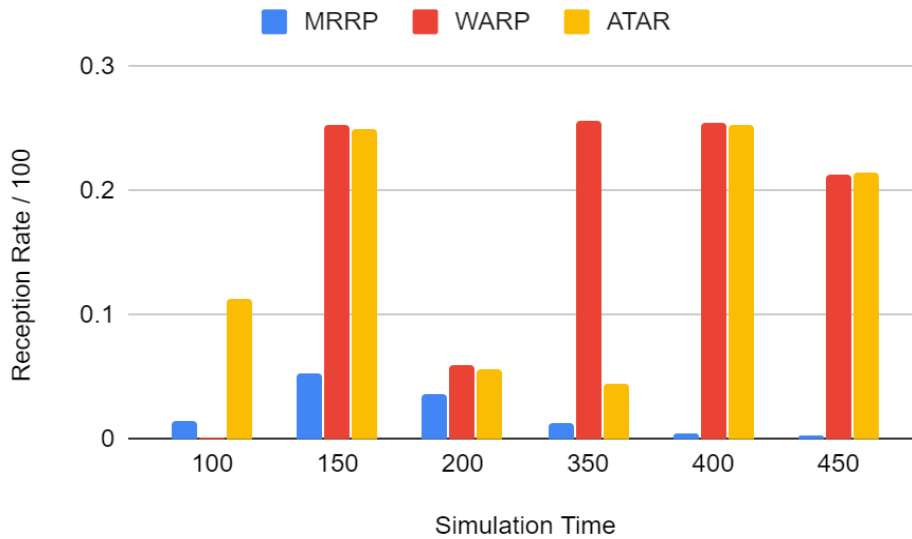


**Figure 1:** Max temperature of node vs. Simulation Time.

As shown in figure 1, ATAR is the best algorithm for controlling node temperature. This is because ATAR is avoiding the transmission over the nodes with high temperature by selecting the node with minimum temperature.

However, the algorithm has increased overhead in the setup packet due to monitoring the node temperature. On the other hand, all the compared protocols exceeded the threshold value of temperature with increased simulation time.

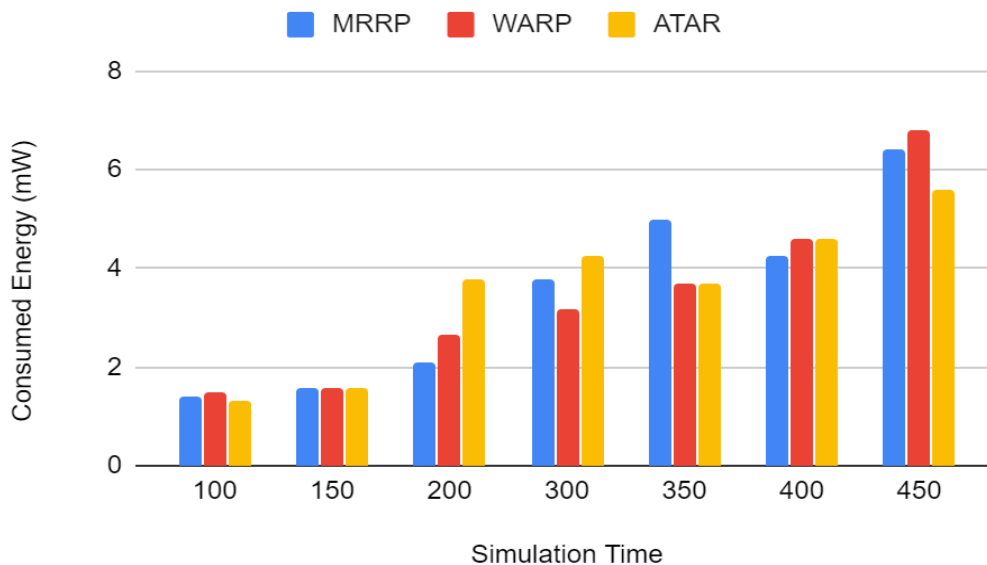
**Data reception rate:**



**Figure 2:** Packet Reception Rate vs. Simulation Time.

With increased simulation time, figure 2 shows that the reception rate is decreased in MRRP. However, WARP and ATAR are providing better results. WARP is the best choice if throughput is the main concern of the medical application. However, more work and researches are needed in order to increase the percentage of received packets to be applicable for implanted sensors where the lifetime is a critical factor.

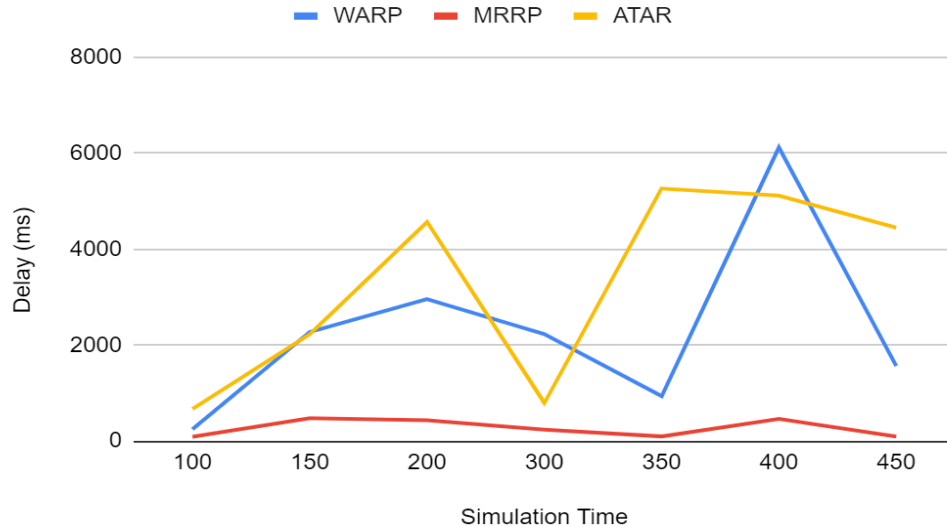
**Energy consumption:**



**Figure 3:** Energy Consumption Vs. Simulation Time.

As per the above figure, the three algorithms are having comparable results in terms of energy consumption of the sensor nodes. However, in high priority applications, where most of the data are having top priority, ATAR consumes more energy due to direct transmissions.

#### End to end delay:



**Figure 4:** End to End Delay vs. Simulation Time.

Weighted average is having better delivery time in comparison with ATAR. Therefore, it could be used for delivering critical data where delay is the main concern. However, with increased simulation time, MRRP provides more stable values for packet delay. Data priority is supported on ATAR by having two types of data: normal and critical. It is assumed that critical data could be transmitted directly to avoid any delay. However, the direct transmission for the data is not applicable in real environment specially inside human body where the sensors are having very low transmission power. Also, path loss inside human body is not considered. The proposed weighted average protocol provided a weight for data priority. However, it needs an enhancement to ensure no delay for high and critical data packets.

#### Conclusion:-

WBAN is one of the promising solutions for medical applications. Sensor nodes can be implanted inside a human body in order to provide accurate information about patient health. Routing protocols are the key factor for having better delivery of the sensed data about patient's health status. This paper provided a performance evaluation for three different routing protocols in order to evaluate their efficient use in WBAN healthcare applications. The simulation is done using Castalia 3.2 simulator and the results showed that ATAR is better in terms of node temperature control. However weighted average is providing better values for packet delivery rate while MRRP is having better delay. Therefore, there is a need for more research in WBAN routing to ensure more stable results for having WBAN in healthcare applications. In conclusion, WBAN routing should have lowest delay, reduced packet loss, controlled node temperature to avoid tissue damage and adapt to human movement. It should be fault tolerant to support critical health applications.

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