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Self-Organized Routing in Body Area Sensors Networks: A Review, Analysis and Simulation-based Case Study

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Abstract

Wireless Body Area Sensor Network (WBAN) has emerged as special type of wireless sensor networks. This emerging networking technology has applications in healthcare, sports & fitness, activity monitoring and disability assistance. Most of the work in literature in WBAN focuses on MAC and Physical layer. In contrast to this, in this paper, we present a study of self-organized routing (network layer issue). In this paper, we first highlight the routing issues and challenges in multi hop WBAN. We then review and classify the existing WBAN routing protocols from the literature, including self-organized routing. In addition we compare and analyse the proposed protocols based on certain key parameters. Finally, we have performed a simulation based case study to analyse the requirements and necessities of employing self-organizing in WBAN.

Key Words: *Wireless Body Area Networks, Self-Organization, Performance Analysis, Simulation based study.*

1. Introduction

A wireless body area sensor network (WBAN) is a special type of wireless sensor networking technology. Therefore, In WBAN approximately all the sensors are different from each other in terms of functionality, data rates, computational ability, storage capacity, bandwidth, and transmission range. These sensors are either wearable or implanted in the human body, which can continuously monitor vital sign parameters and movements. Major WBAN application areas are healthcare, fitness, activity monitoring and entertainment [43]. A simple example of sensors used in WBAN is shown in Figure 1.

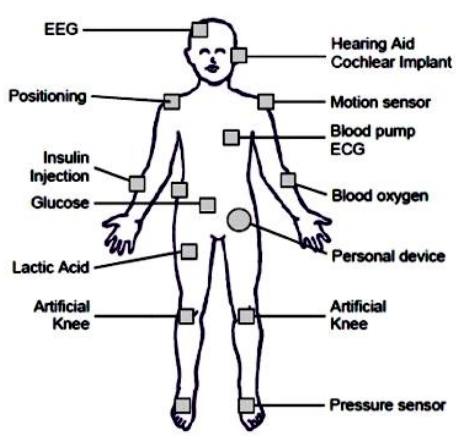


Fig. 1 Example of Wireless Body area Network

According to [1], self-organization is a general phenomenon that is used in almost all branches of science. It occurs in different chemical, biological, physical, social and cognitive systems. Self-organization is the term used for the adaptive ability of a system, in which system changes itself according to the conditions. The interaction between the entities of the system is localized but it leads to a global cause of the system without any central control authority as shown in Figure 2. In Figure 2 the main principle of self-organization is illustrated through an example of school of fish. Every fish in the school reacts and adjust itself according to its surroundings in distributed fashion. This behavior of each individual makes the school more adaptive, robust and scalable but makes it more complex and complicated.

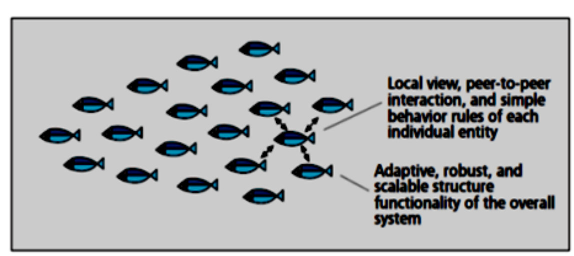


Fig. 2 Illustration of the main principles of a self-organizing system [1]

Self-organization in wireless sensor networks is challenging because the energy resources constraint and limited available bandwidth in these types of networks [2]. Therefore, the use of energy and bandwidth should be efficiently optimized. Self-organization in a network has four aspects:1) Self-Configuration, 2) Self-Optimization, 3) Self-Protection and 4) Self-Healing

1.1 Self-Configuration

The ability of element(s) of a system, to accommodate themselves in the system with the changes in environment such as scalability and relocation, based on defined policies for achieving the desire level of network performance.

1.2 Self-Optimization

It is the ability of a node or the networks to optimize certain parameters to maintain the required level of performance of the network.

1.3 Self-Healing

The reactive approach of a system for identifying the fault and attempting to fix them by employing defined approaches such as by downloading and installing the software updates. The main objectives of self-healing approach are fixing the fault in a way that system do not further damaged and a minimal performance to run the system achieved.

1.4 Self-Protection

It is a proactive approach of a system for defending itself from the penetration of any unauthorized user in the system and from any active or passive attack [44]. The main objectives of self-protection are to make the security of the system unbreakable and also make the data confidential and secure.

The most common issues and challenges associated with self-organization are:

i) How to design a local behavior of an entity?
ii) How to implement self-organized functions?
iii) Is overhead acceptable after implementation of self-organization?

WBAN has some similarities with WSN; however WBAN has additional unique challenges and constraints for example, different types of sensor in a single network (heterogeneity), dynamic topology (mobility), size of network, routing protocols and network technologies. These challenges and constrained enforce the development of its own protocols and algorithms as WSN protocols are not efficient in WBAN. Therefore, self-organized routing in this type of networks is a challenge.

The rest of the paper is organized as follows, section II describes the background study of WBAN architecture, section III describes the routing issues and challenges associated with WSN and specifically wireless body area networks. We review and classify the self-organized routing protocols in section IV. In section V, we present a simulation based case study to assess and analyze the requirement and need of self-organized routing in WBAN. Finally, we conclude the paper with given future direction in section VI.

2. Background

Body Area Networks have an enormous potential to modernize the healthcare monitoring system by identifying many chronicle diseases and providing real-time patient monitoring [3]. In this section, we first discussed about nodes, their types and types of architectures.

2.1 Node

In WBAN, a node refers to an autonomous device that has communication facility. These nodes either are sensors or coordinator where the coordinator could be a mobile phone or personal digital assistant (PDA). It gathers the data from the sensors and sends to nearby base station.

2.2 WBAN Communication Architecture

WBAN communication architecture consists of three tiers; Intra-WBAN (tier-1), Inter-WBAN (tier-2) and Extra-WBAN (tier-3). In literature various types of communication architectures have been proposed. We discuss few prominent architectures here in this section. For example, Jin Wang et al. [4] proposed a novel Three-Tier Diabetes Patients Monitoring Architecture for Hospital Environment as shown in Figure 3. In this architecture, the authors divided Tier-1 into two parts (indoor & outdoor). In outdoor part, the assumption is that the base station

(BS) is directly connected to sensors and gateway, thus the gateway transmits the data to the internet (Tier 2) and then cloud server (Tier 3). While in indoor scenario, the base station is responsible to forward the sensed data to the gateway. In this architecture, single hop architecture is consider therefore no routing. Chris Otto et al. [5] proposed system architecture of a WBAN for ubiquitous health monitoring. In this architecture, the authors present a scenario in which they select the WBAN (Bluetooth or ZigBee) as tier-1, tier-2 is a mobile device (wireless wide area network or wireless local area network) and tier-3 is medical server, which is connected through internet as shown in Figure 4. Again, it is also single hop architecture. Kamarudin et al. [6] proposed a Two-Tier e-Health Monitoring System. The authors claim that current architecture (i.e. Three Tier architecture) may have a security loophole because of the involvement of third party or web server. The architecture is shown in Fig. 5.

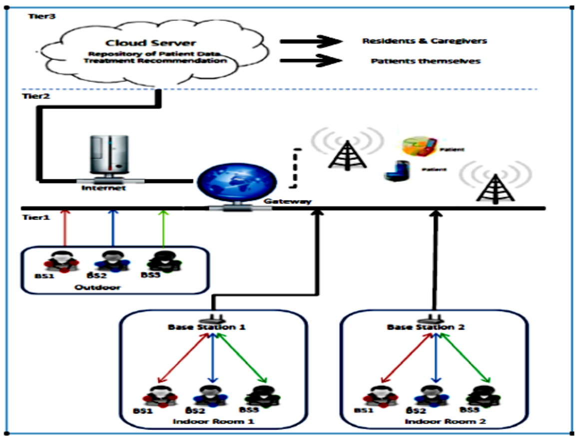


Fig. 3 Three-tier system architecture [4]

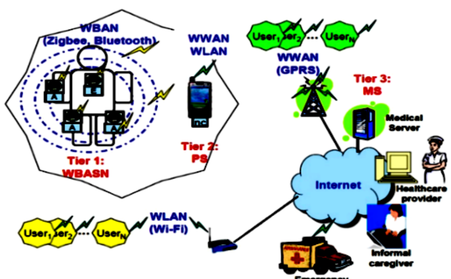


Fig. 4 Health Monitoring System Network Architecture [5]

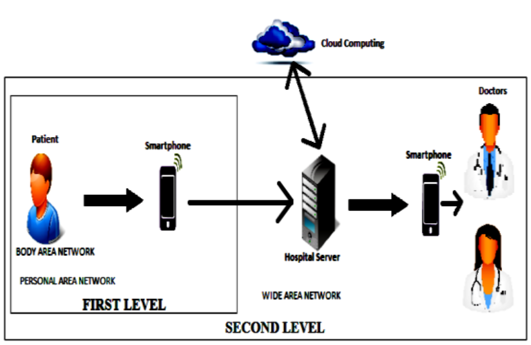


Fig. 5 Two-tier architecture e-Health monitoring System [6]

3. Routing Issues and Challenges in WBAN

There are two types of the communication exist in the field of wireless networks. The first is single hop communication and the other is multi hop communication. In single hop communication (star topology), it is assume that all the nodes are link directly to the sink node. While in multi hop communication, each node must not only generate its own data, but also forward/aggregate, the (neighbors) data towards the sink. Single hop scenario, requires more energy to receive /transmit the data, while these sensors have limited energy. Therefore, the energy source of a sensor is quickly drained which makes the lifetime of a sensor or the network short. Thus, currently most of the researchers' works on the routing in intra WBAN scenarios, although the routing is itself a challenging task. Figure 6 (a) and 6 (b) illustrate the single hop and multi-hop scenarios of WBAN respectively.

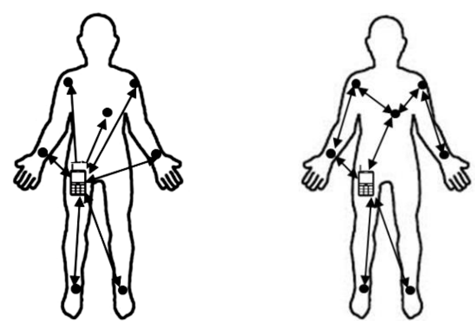


Fig. 6 **(a) Single Hop WBAN** **(b) Multi Hop WBAN**

In this section, we discussed the limitations and challenges in designing the routing technique in the multi-hop WBAN.

3.1 Energy Efficiency

The sensor devices have limited energy; therefore energy efficiency is the major concern in WBAN. The determination of the lifetime of a network is based on efficiency of energy consumption [8]. If sensor nodes are implanted inside the body, then it is not possible to change the battery, and if the sensor nodes are wearable bio-medical sensors, then replacing or charging the batteries might be a big issue because of the discomfortness of the patient who wear these sensors. Therefore, it is necessary to keep these constraints in mind for new routing algorithm. According to [7], energy is more consumed during the communication between the sensor nodes, compared to processing the data and sensing operation. So, the routing protocol should be able to choose the path efficiently according to the energy consumption of the nodes.

3.2 Limited Resources

The energy source is limited in sensor nodes and this also has an effect on the node transmission range. These sensor devices also have minimum processing capabilities; low storage capacity and low bandwidth which may be varied due to interference and noise [9].

3.3 Quality of Service (QoS)

In healthcare applications of WBAN such as remote monitoring of patient the QoS becomes electromyography (EMG), electroencephalogram (EEG), delay sensitive data like video streaming and reliability sensitive data, for example vital signs etc. It means that researchers also have to consider these QoS related issues for designing new routing protocols.

3.4 Hop Count Limitation

As we know that WBAN based on the IEEE802.15.6 [14] standard and according to this WBAN must have only one-hop or two-hop communication technique. Although multi-hopping will increase the reliability of the overall system by providing stronger links, but it is also not suitable for WBAN or even WSN because of consuming more energy consumption [15] and delay as well.

4. Classification of Routing Protocols for WBAN

First of all we classified self-organized routing protocols proposed in WSNs from the literature. Researchers did not consider the hop count limitation in their proposed routing algorithms. Figure 7 shows the classification of

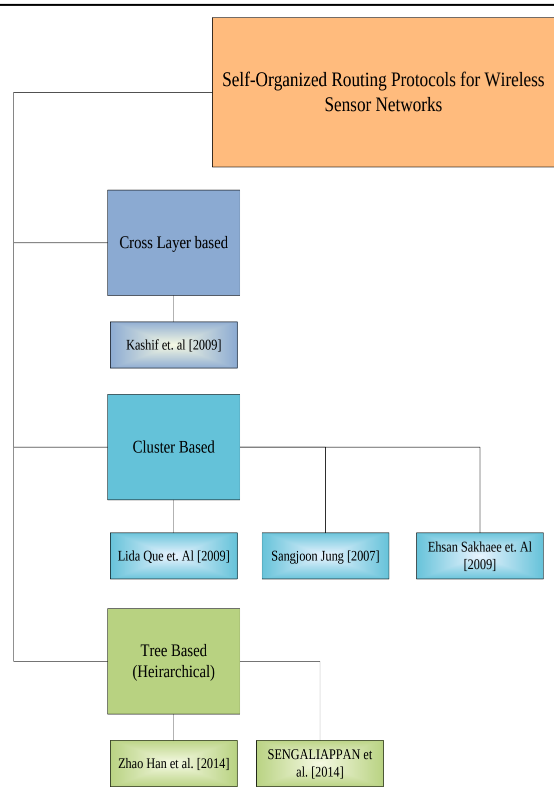


Fig. 7 Classification of self-organized routing protocol in WSN

self-organized routing protocols in WSN, they are mainly classified as cross layer based, cluster based and hierarchical based routing. The cross layer approach is different from the traditional layer stack approach. In cross layer approach, the information is exchanged between different non-adjacent or adjacent layers in the protocol stack.On the other hand, in cluster based routing, the sensor nodes divided into groups which refer as clusters.

The formation of a cluster depends on the methodology used in the given algorithm. A sensor node is chosen as cluster head (CH) for a specific cluster by applying different techniques. The CH is responsible for sending the data of cluster nodes to the sink node. A gateway node of a cluster is used for communication between the clusters. The concept behind the tree based algorithm is that the nodes are connected in hierarchical manners. However, there is no such classification of self-organized routing in WBAN exists in the literature in the best of our knowledge. This is mainly because most of the researchers so far have considered the WBAN node a limited function device (single hop WBAN) focusing on physical and MAC layer functionality. In contrast, we see WBAN node as fully functional device (i.e. multi-hop scenario where, it will forward packets for other nodes as well) in the future. Therefore, in this section, we present the classification of routing protocols which are used in a body area network. These routing protocols are classified based on Temperature Awareness, Clusters, Cross Layer approach, Cost Effective and Quality of Service (QoS) as shown in Figure 8.

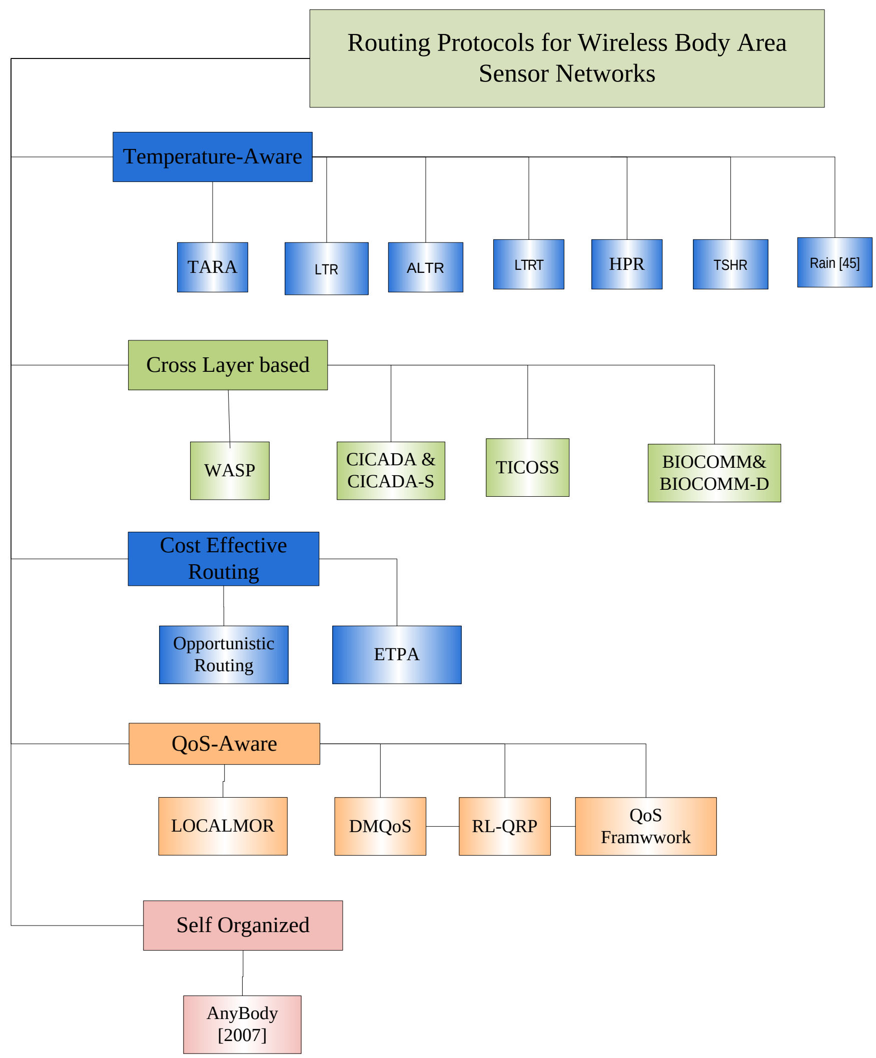


Fig. 8 Classification of routing protocol in WBAN

4.1 Temperature Aware Routing Protocols

Due to the power consumption of circuit and antenna radiation, the temperature of the sensor is increased and causes the reducing of blood flow in the human body [10]. It also affects the development of certain tissues, enzymatic reactions and if the sensor is placed for long time, that will result in damage of the surrounding tissues [11]. The rate of radiation energy is absorbed by tissues of a human body per unit weight (termed as Specific Absorption Rate) is specified in [10] as follows:

$$SAR = \frac{\sigma |E|^2}{\rho}\left(\frac{W}{K_g}\right)$$

Where σ is the electrical conductivity of tissue, E is the electric field induced by radiation and ρ is the density of tissue. After the several experiments, it is noted that SAR of 8 W/Kg for 15 minutes causes significant damage of a tissue. Therefore, in the last decade, scientists and engineers are working on the reducing of temperature and overheating problem with a sensor. Hotspot means a node which has temperature value more than its predefined threshold value. We now present some example of temperature aware routing.

4.1.1 Thermal Aware Routing Algorithm (TARA)

The first temperature aware routing protocol is TARA [10], which routes the data packets through the nodes which are not the hotspot. Every node monitors the communication activities of its neighbors by counting its received / transmitted packets to estimate the temperature level in setup phase. If a node has the temperature level higher than the threshold value, then it is declared as the hotspot node and is not used for routing until it drops the temperature level. If a node has the hotspots in its neighbor to route the data, then it sent back the packets to its previous node for alternate route as depicted in Figure 9 in routing phase, where red nodes are hotspot. This strategy is called the withdrawal strategy. If the destination of a data packet is a hotspot node, then the packet has been delivered only when the destination node drops the temperature level to below the threshold value. In his protocol, SAR (Specific Absorption Rate) is calculated. The temperature of each node is calculated through Finite Difference Time Domain (FDTD) [16], and Penne's Bio-heat Equation given in [17].

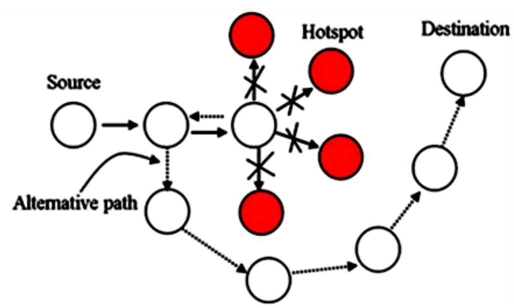


Fig. 9 Example of TARA [18]

4.1.2 Least Temperature Rise (LTR)

Least Temperature Rise (LTR) [19] is another protocol which used the temperature level in routing of the data packets. If a node has low temperature level in neighbors, then it is selected as next hop to forward the data packets as shown in Figure 10. In the figure the red circles are hotspots and the turquoise colored circles represent the low temperature nodes in selected route. In this protocol, the temperature level is also estimated as discussed in TARA [10]..A maximum threshold value of hop count depends on the coverage area is used. Hop count field in every packet is incremented after forwarding by each node to its next hop and if threshold value of maximum hops is exceeded then packet will discarded. Another field in the data packet is used for keeping the record of visited node to avoid the looping. The other objectives of this routing protocol are delay and power consumption.

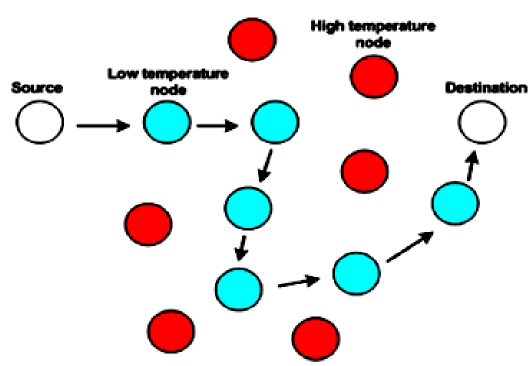


Fig. 10 Example of LTR [18]

4.1.3 Adaptive Least Temperature Rise (ALTR)

This protocol actually is the variation of ALTR [19]. In adaptive least temperature routing protocol (ALTR) [19], is the modified version of ALTR [19], where maximum hop count field is replaced with adaptive maximum hop count and if it exceeded its threshold value then it uses the shortest hop routing algorithm. The mechanism of ALTR is depicted in Figure 11. The representation of the color of a node is same as described in LTR.

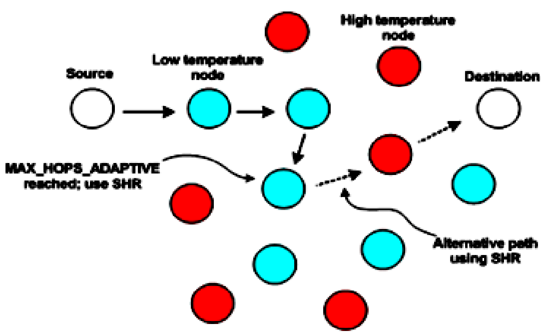


Fig. 11 Example of ALTR [18]

4.1.4 Least Total Route Temperature (LTRT)

Takahashi *et al.in [20]*, proposed a protocol called least total route temperature (LTRT) based on weighted graph. After observing the neighbors communication activities to estimate their temperature level, each node transferred that temperature level into a weight of that node. Following steps are used to achieve the objectives of LTRT.

- A weight is assigned to a node by observing the temperature of the node.
- These weights are further used formaking weight graph.The weight graph isused for calculation of all the possible routes with minimum weightfrom source to destination as described in Figure 12.
- For calculating the routes which have least total temperature from source to destination, a Single Source Shortest Path (SSSP) algorithm is applied to the weight graph.

Routes are periodically updated due to avoidance of the excessive rise of temperature of the node.

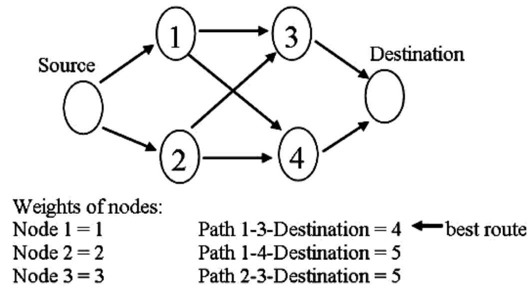


Fig. 12 Route selection of LTRT [18]

4.1.5 Hotspot Preventing Routing (HPR)

Hotspot Preventing Routing (HPR) 0 is proposed for preventing the network to form the hotspot nodes. Each node interchanges its initial temperature value and shortest path with others to construct a routing table for each node in setup phase. In routing phase, each node must consider the following:

- A threshold value of hop count is defined and the path with least hops is selected for routing the packet. If hop field is exceeded from the threshold value then the packet will discarded.
- If the destination is in neighbours then data is sent them directly but if not, then the node which has the temperature level less than or equal to the threshold temperature value is selected as next hop. The threshold value of each node is calculated through the sum of neighbours average temperature and a node's own temperature.

This makes HPR is different from other routing techniques where temperature threshold values are predefined. In this algorithm, the method of calculating the temperature threshold is based on self-organization.

The nodes having temperature level higher than threshold are identified as hotspots and avoided for routing. The packet then forwarded through non-visited neighbour node which has least temperature. A list of visited nodes is maintained in each and every packet to avoid routing circle or routing loop.

4.1.6 Thermal-Aware Shortest Hop Routing (TSHR)

Thermal-aware shortest hop routing protocol TSHR [22] is proposed to drop the rise in temperature level without any delay and disturbance to reliability. Each node constructs the routing table for itself in setup phase. The routing phase deals with the routing of packets according to best shortest path. As compared to other temperature-aware algorithms, TSHR is based on two threshold values for controlling the temperature of a node which are: T_S and T_{DN}, where 'T_S' is a static threshold which cannot be violated by any node by surpassing it while 'T_{DN}' is dynamic and will be calculated as:

$$T_{DN} = temp_n + 0.25\sqrt{temp_n} + 0.25\sqrt{avg_n}$$

Where '$temp_n$' is a node's temperature and 'avg_n' is the average temperature of its neighbors. If a node has high temperature than as compared to TDN then it is declared as a hotspot.

4.1.7 Routing Algorithm for network of homogeneous and Id-less bio-medical sensor Nodes (RAIN)

In [21], authors focussed on how to overcome two constraints commonly associated with wireless body area network. The first one is how to deal with temperature rise and the other one is how to use power which resulting the less power consumption. In setup phase of RAIN algorithm, temporary IDs are used instead of a global static ID, so therefore this routing protocol termed as ID-less. It is assumed in RAIN that a node is used a 16 bit random number generator which generates random numbers in between 1 and (2^{16}–1) while number 0 is used for sink node. The generated number is used as temporary ID for the operational life of a specific node. These temporary IDs are local and only known by its neighbours. After generating a node ID, a hello packet is broadcast by each node including Sink which contains their ID. In the routing phase, packet is forwarded to sink by using multi-hop way with increment of one at each hop in *hop-count* field. The format of each packet is based on a unique packet identifier which is [N, T, and R], where N represents the ID of a node, T is the time of the generation of a packet and R is random number. By using this format the probability of collision is extremely negligible. Each packet contains a *hop-count* field, which is used for prevention of infinite loop. If the value of hop-*count* goes beyond the hop threshold value HOP-THRESH, then packet will be discarded. A list of packet IDs is maintained by each and every node to avoid duplication of packet transmission. If a packet with an ID is received and that ID is already exist in list, then that packet is discarded. Another function of RAIN is temperature-awareness, which is obtained at each node by estimating the temperatures of its neighbour nodes with the help of observing the communication activities performed by the neighbours. The packet is sent directly if the destination of the packet resides in neighbours, otherwise the packet is sent to a neighbour node which is selected on a probability function and probability function is defined as inversely proportional to the temperature of the node. Status update phase is used for update in status, so whenever sink received a packet, an *update* message is broadcast by sink to its neighbours which contains packet id of packet. The nodes which received that *update* message add packet id into their list of IDs.

4.2 Cross-Layer Routing Protocols

Cross layer approach is used for solving the challenges and problems at multiple layers at the same time. This ability makes these protocols very useful for improving the overall performance of a network. Some cross layered protocols generally working on MAC and network layers are discussed here.

4.2.1 Wireless Autonomous Spanning Tree Protocol (WASP)

In Wireless autonomous spanning tree (WASP) [15], the nodes are arranged as a spanning tree shown in Figure 13(right) according to the sensors placed on human body in left. WASP introduces WASP-Cycles by dividing time into distributed slots. These cycles

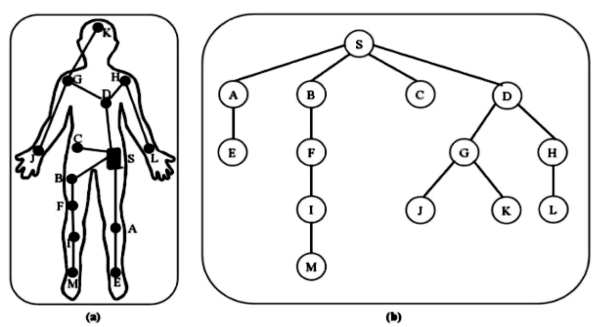


Fig. 13 Network on the Body (left) and Abstract view of the network (right) [15]

are used for communication in both the MAC and network layers. Through a special type of messages called WASP schemes, parent nodes assigned a unique time slot to each of their child nodes. In only these slots, child nodes can communicate with other nodes.These WASP Schemes are unique for every node and generated by the node that initiates this scheme.

These schemes are used by parent nodes for controlling the data traffic and child nodes also used these schemes for requesting about more resources to their parents. In this protocol authors claim that, this protocol has minimum coordination overhead and give 94% throughput depending on levels used.

4.2.2 Cascading Information Retrieval by Controlling Access with Dynamic Slot Assignment (CICADA)

CICADA [26] is supposed to be an improved version of WASP [15] as it uses the same strategy to create the spanning tree and distributed time slots. In this protocol, each node performs two guesstimates; calculate the number of time slots for data sending and the number of time slots for waiting to get the data from its child nodes. The transmission cycle contains two sub-cycles. The control sub-cycle uses the control scheme which defines the length of the control sub-cycle, the depth level of the tree and a sequence which will be used for communication to child nodes about their control scheme. The data sub-cycle uses the data scheme which defines the waiting period and the length of data scheme. These schemes are sent to all nodes during the control sub-cycle. Data period is use for sending the data packets to the parent nodes by child nodes and waiting period (sleep mode) is used for saving energy. A table is constructed at each parent node. This table contained the number of slots in which child can transmit their data to them and the number of slots in which they can receive the data from their child nodes. If a node wants to join the tree, then it can send a message of *JOIN-REQUEST* in the particular slot available to that node in each data sub-cycle.

4.2.3 Time-zone Coordinated Sleeping Scheduling (TICOSS)

Time zone Coordinated Sleeping Scheduling (TICOSS) [27] is actually based on MERLIN [28]. MERLIN supports multi-hop communication by dividing the network into different time-zones over IEEE standard 802.15.4. In association phase a 16 bit ID is used instead of standardized 64 bit to reduce the overhead and energy consumption. In this phase nodes exchanges the basic information with to be linked up with the network. In next phase network is divided into different time zones. The sink node initiate a time zone message containing the information about zone of the transmitter (T_xZone) initially set to be zero and timing information and send to the neighbors. The neighboring nodes set their time zones with incrementing by one and forward it to their neighboring nodes and this will repeat until the very last node. This process is also repeat after a predefined time interval to update their information because the messages are expired after a given to support mobility in the sense of connecting and disconnecting of a node from the network. A table is maintained and used for storing the updates having the timestamps and an ID of the source node. In this technique, the V-scheduling table is used for allotting a time slot to each node of the network.

4.2.3 BIOCOMM and BIOCOMM-D

BIOCOMM [29] below is another cross-layer protocol uses the Cross layer Messaging Interface (CMI) for exchanging the status information between MAC and network layers to optimize the overall network performance. A hop count metric is used for avoiding loops. If hop-count is exceeding to a predefined threshold value, then the packet will be discarded. The status of a neighbor node is maintained at both layers. At the MAC layer, the status of the neighbor nodes set as Blocked (B) or Free (F). The status table at the network layer is updated through MAC layer status. In response, network layer updates the MAC layer regarding free space in packet buffer BIOCOMM-D is the improved form of BIOCOMM which is designed for reducing the overall packet average delay.

4.3 Cost-Effective Routing

Some examples of cost effective routing are as follows:

4.3.1 Opportunistic routing

In [30], authors proposed a routing algorithm for WBAN to increase the network lifetime and also support mobility. There are three nodes are used which are sink, relay node and the sensor node. Sink is placed on wrist, relay is placed on waist and sensor is placed on chest. Both the Multi-hop and single hop communication are used in this protocol. During walk, wrist is moving forward and backward and so the sink. If sink is in front of the body then sensor send the data to sink in single hop way through line of sight (LOS) communication, but if sink is in back side of the body then relay node is used for data forwarding from sensor to sink. If sink uses LOS communication then a RTS (request to send) with minimum power send so only sensor can hear it and if the sensor is free then it send back the ACK (acknowledgement) and communication between the sink and sensor start. After successful communication a RACK (received acknowledgement) is sent to the sensor. If RACK signal is not received, then mentioned procedure will be repeated again.

4.3.2 Energy Efficient Thermal and Power Aware (ETPA) Routing

Energy Efficient Thermal and Power Aware Routing (ETPA) [31] is a cost effective protocol deals with temperature and power issues. ETPA calculates the cost function for routing based on the energy and temperature levels of the node and received transmission power from adjacent nodes. A TDMA (Time Division Multiple Access) scheme is used for dividing the frames into different time slots, and each node can only transmit in its own time slot. After every four frames during each cycle, all nodes broadcast hello messages containing the level of energy and temperature to calculate the cost function. A node forwards the packet through a route which has minimum cost and if it does not find any route, then it buffers the packet up to two frames. If a packet is buffered for more than two frames then that packet will be discarded. ETPA uses a predefined number of hops for minimizing the delay. If a packet has more than a predefined threshold value of hop count then it will be dropped.

4.4 QoS-aware Routing

The use of QoS (Quality of Service) in designing of a routing protocol for WBAN is an important but challenging task because QoS based routing protocols are generally based on modules and these modules use different metrics. We now discuss some examples of QoS based routing protocols.

4.4.1 New QoS and Geographic Routing (LOCALMOR)

In [12], authors presented a protocol which considers three QoS requirements reliability, energy efficiency and delay. The patient's data is classified into four classes: Regular data, Reliability-Sensitive data, Delay-Sensitive data and critical data and each class is assigned a module. The first is an Energy Module or Power Efficiency Module, deals with the regular data and ensure that less energy will consume during the communication of regular data with the help of weighted Min-Max approach.

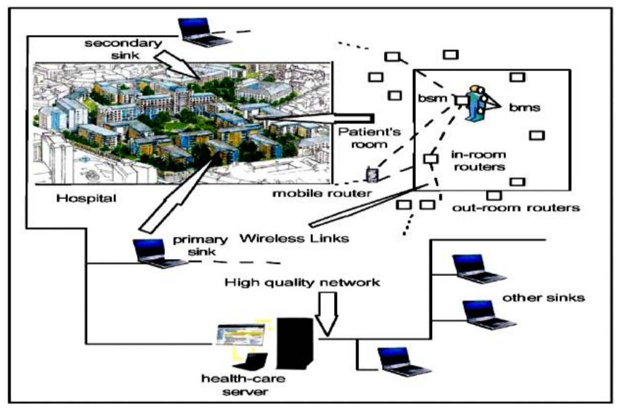


Fig.14 Architecture of LOCALMOR [12]

The second module is a Reliability Sensitive Module, which calculates the reliability of the path and, routes the reliability-sensitive data packets to both sinks (primary and secondary) for guaranteed delivery to ensure the reliability. The third module is The Delay Sensitive Module, which is responsible to deliver the data in a given time deadline by using Pocket Velocity Approach discussed in 0. The Neighbor Manager module is used to communicate the Hello packets between neighbors. Information about the neighbors in neighbor table is updated by these Hello packets. The architecture of LOCALMOR is shown in Figure 14.

4.4.2 Data-Centric Multi-Objectives QoS-Aware Routing (DMQoS)

In [13], the authors categorized the packets into four categories, Critical Data Packets (CP), Ordinary

Data packets (OP), Delay-Driven Data Packets (DP) and Reliability-Driven Data Packets (RP). The sensed data is sent by the sensor nodes to a body mote device which is also called cluster head (CH). This cluster head is supposed to be having higher energy and high computation power as compared to sensor nodes.

After processing, CH forwards that data to the nearest sink using multi-hop approach through another cluster head. Figure 15 illustrated the routing architecture of DMQoS. The routing architecture contains five modules, which are: dynamic packet classifier, delay control module, reliability control module, energy-aware geographic forwarding module, and multi-objectives QoS aware queuing module. The data is classified by dynamic packet classifier which collects the data packets from the upper layers or neighboring node.These data packets forward accordingly to their relevant modules on of first come first serve basis. The next-hop node will be decided by the energy-aware forwarding module on the basis of minimum distance and relatively high level of residual energy as discussed in [34]. The reliability of the next hop of (RP) is determined by the reliability control module. The delay control module receives the DPs and CPs and finds the next hop with least delay. The queuing module is used for prioritizing the data packets and forward accordingly.

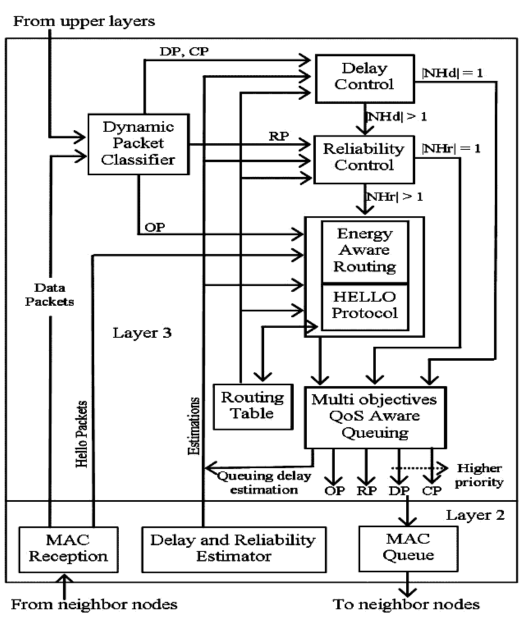


Fig. 15 Routing architecture for DMQoS [13]

4.4.3 Reinforcement Learning Based Routing Protocol with QoS support (RL-QRP)

In [35], author proposed a protocol, which is based on location based information and distributed Q-learning algorithm. In this scheme authors used a reinforcement technique similarly as described in [37], each node considered as a state s, and for a neighboring node ś there is an action *a*, which is described as P (ś | s, *a*) = 1 as shown in Figure 16. The quality of action *a*, at state s is represented by Q-value, defined as Q (s, a). A list of Q-values is maintained at each node and considered as a routing table. In this algorithm, a node calculates the routes according to the QoS requirements of a data packet and link quality of routes which are available. After this each node forward this data packet to its neighbors and these neighbors act as a relay node and further forward it to their neighbors until the sink node is reached.

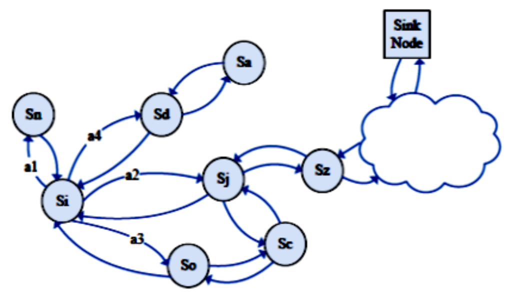


Fig.16 Reinforcement learning based routing model [26]

After forwarding the data packet, each node gets a reward either positive or negative. The reward, together with an expected future reward is used for updating of the Q-value list which is used for future decisions. In this scheme, authors used two types of nodes (mobile nodes and stationary nodes). The random waypoint model is used as for mobile nodes. In this scheme, authors consider the end to end delay and packet delivery ratio (PDR) as QoS metrics. The major drawback of RL-QRP is it did not considered the energy as a metric.

4.4.4 QoS framework

In [36], a QoS routing protocol focusing on providing support for differential QoS and prioritizing the routing service of the network is proposed. The four modules are used in this framework which are: Application Programming Interfaces (APIs) module, Routing Service module, Packet Queuing and Schedule module and System Information Repository module. The module API is used as an interface between routing service module and user application. There are further four sub-modules of API. The first is QoS metrics selection sub-module used for dealing with power consumption, end to end delay and packet delivery ratio. In second sub-module which is packet receiving / sending module, data packets are received from user application (Application layer) and sent to the neighboring node or sink. The priority of data is set by packet priority level setting sub-module. The feedback regarding the condition of the network is returned to user application by admission control and service level control sub module. The routing table of a node is maintained and constructed by the second module which is routing service module. These routing tables are constructed and maintained accordingly with the help of status information shared with neighboring nodes. All the packets, either control packets or data packets prioritized in eight different levels. However, data packets have less priority as compared to control packets. The third module which is Packet Queuing and Schedule module is used for informing the user application about decreasing the service level and level of willingness of a node for becoming a router or aggregator if there is network congestion. The fourth module is System Status Repository module which maintains two types of tables. The first is a link state table, which contains end to end delay, communication bandwidth, and link state of the node, quality of the link, average PDR (Packet Delivery Ratio) and willingness table which shows the status of a node to act as a router.

4.5 Self-Organized Routing

As mentioned earlier, self-organization is the area which is mostly overlooked by researchers in body area network. We found only one protocol for WBAN which claims to fulfil the requirement of self-organization and that is AnyBody.

4.5.1 AnyBody

Thomas Watteyen et al. [24] present anyBody, a self-organized protocol for body area sensor network. In this scheme, authors proposed a data gathering protocol, which uses the cluster routing to reduce the number of direct transmissions to the remote base station. Anybody based on five stages, which are neighbour discovery, density calculation, contacting cluster head, setting up the backbone and setting up the routing path. Anybody adopts self-organization in the form of making clusters and choosing cluster heads in a specific time interval and then cluster head aggregate the data to its nearby cluster's head and it will go on until the ultimate destination (Base Station) is reached. Anybody based on (Low Energy Adaptive Clustering Hierarchy) LEACH [25] that randomly chooses a cluster head (CH) at fixed time intervals in order to spread the power dissipation. The CH collects the all data and sends it to the base station. LEACH is widely used in wireless sensor network (WSN). In LEACH, an assumption is used that all nodes are within sending range of the base station. Anybody solves this problem by changing the cluster head selection and constructing a backbone network of the cluster heads.

The main advantage of Anybody is, it makes less clusters despite the increase in the numbers of nodes, but the main concern of WBAN is energy which is overlooked in this scheme, also reliability is not considered. AnyBody is Also, not optimized for WBAN because it has high delay and significant overhead, which is supposed to be not considered for WBANs due to their limitations regarding energy, bandwidth and computational power.

In literature we also have found a self-organized MAC protocol [38] for WBAN. This MAC protocol addresses the QoS, low power consumption and low latency at MAC layer level. It uses the super frame (SF) structure proposed in BATMAC 0 to reducing the power consumption of nodes. SF contains different time slots like beacon period, poll slot for polling, contention free period (CFP), contention access period (CAP) and priority access period (PAP). There is no other protocol found for WBAN as mention previously very limited work has been done so far on self-organization aspects in WBAN. However, we see the WBAN nodes as fully functional devices in future; therefore we investigate the need for self-organization in WBAN in this paper.

4.6 Comparison and Analysis

In this section, we now compare the WBAN routing protocols discussed in this paper. We compare these routing protocols based on their routing metrics, mobility support, network lifetime, delay, hotspot prevention, loop free, energy consumption, performance, scalability and self-organization.

We also add a very brief description of methodology and indicated the major contribution of these routing protocols in Table 1. Our key observations from the analysis are as follows:

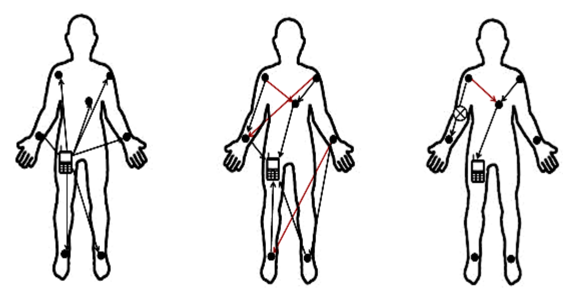
TABLE I
COMPARISON TABLE OF WBAN ROUTING PROTOCOLS

Author	Protocol Name	Routing Metrics	Mobility Support	Network Life time	Delay	Hotspot Prevention	Loop Free	Energy Consumption	Performance	Scalability	Self Organization	Methodology	Contribution
Qinghui et. al (2005) [10]	Thermal Aware Routing Algorithm (TARA)	Temperature	Not Considered	Very Low	Very High	No	No	Very High	upto 88.75%	Not Mentioned	No	If all the next hop of a node are hotspot, then sent back to previouse node and forth	First routing algorithm based on Thermal aware
Bag et. al (2006) [19]	Least Temperature Rise (LTR)	Temperature, MAX_HOP	Not Considered	Not Considered	High	Yes	Yes	High	upto 92.5%	Not Mentioned	No	Avoid hotspot area for routing	Introduced a routing algorithm that select a low temperature node as next hop
Bag et. al (2006) [19]	Adaptive Least Temperature Rise (ALTR)	If MAX_HOP ADAPTIVE then SHR	Not Considered	Low	High but lower than LTR	Yes	Yes	High	upto 96%	Not Mentioned	No	If Hop count limit is reached, Shortest path is selected	Proposed a technique to reduce packet droppage
Bag et. al (2006) [20]	Least Total Route Temperature (LTRT)	Temperature as weight and SHR	Not Considered	Very High	Low	No	Yes	Low as compare to TARA,LTR, ALTR	upto 99 %	Not Mentioned	No	Calculate and select routes with least temperature	Proposed an algorithm in which a weight is assigned against the temperature level
Bag et. al (2008) [11]	Hotspot Preventing Routing (HPR):	Temperature and SHR	Not Considered	Low	Very Low	Yes	Yes	High	upto 99 %	Yes	Yes (while calculating the temperature threshold)	Coolest neighbor or non visited node is selected for routing	Another protocol which is designed to prevent the making any hotspot
Bag et. al (2008) [21]	Routing Algorithm for network of homogeneous and Id-less bio-medical sensor Nodes (RAIN)	Temperature and Cost of route	Not Considered	High	Very Low	Yes	Yes	Low	upto 96.25%	Yes	No	The packet is forwarded to the coolest neighbor, unless its packet-id present in Id-queue and and hop count limit reached	First thermal aware protocol which works on energy-hole problem faced by neighbours of SINK
Tabandeh et. al (2009) [22]	Thermal-Aware Shortest Hop Routing (TSHR)	Temperature of Next node < TDN	Not Considered	Very High	High	Yes	Yes	Low	upto 99 %	Yes	No	Calculate TDN for setting up the threshold value to route the packet	Propsed a technique to identify the dynamic threshold temperature value of nodes
Latre, et. al (2006) [45]	Wireless Autonomous Spanning Tree Protocol (WASP)	WASP schemes	Not Considered	Not Considered	Depending on number of levels	X	X	Low	upto 94%	Yes	No	A spanning tree is created and used for routing the data toward the sink and to assign the different slots in a distributed manner in which it can communicate and selecting a route on giving condition	The first cross layer routing protocol proposed for WBAN
Latre, et. al (2007) [26]	Cascading Information Retrieval by Controlling Access with Dynamic Slot Assignment (CICADA)	Data sub-cycle and Control sub-cycle	Yes	Not Mentioned	High due to mobility & data aggr.,otherwise Low	X	X	Low when performance is compromised	Throughput is high when energy efficiency is compromised	Not Mentioned	No	Use control sub-cycle for sending control packets and data sub-cycle for sending data packets also creation of spanning tree is same as defined in WASP	The main focus of this protocol assured the reliability and introduced two way communication in cross layer approach
Ruzzelli et. al (2007) [27]	Time-zone Coordinated Sleeping Scheduling (TICOSS)	SHR through TxZONE	Yes	High	Not Defined	X	X	16 bit ID is used to overcome energy consumption	Not Considered	Yes	No	It provides multi-hop support, overcome hidden terminal problem, and divides the network into time zones to coordinated sleeping	Used a 16-bit ID generator and introduce a time zones phenomenon.
Bag et. al (2009) [29]	BIOCOMM	CMI and SHR	No	High	High	Yes	Yes	Very Low	upto 98%	Yes	No	Used cross layer messaging interface (CMI) for exchaning information between MAC and network layers	Used CMI for updating the information in between MAC and network layer
Bag et. al (2009) [29]	BIOCOMM-D	CMI and SHR	No	High	Low as compare to BIOCOMM	Yes	Yes	Very Low	upto 60% (when increasing load)	Yes	No	Same as BIOCOMM but with delayed packet dropping to decrease the delay	Enhancment in BIOCOMM in the form of delay
Maskooki et. al (2011) [30]	Opportunistic routing	NLOS,LOS, RTS, ACK and RACK	Yes	High	Low	X	Yes	very Low	High	No	No	When Sensor node and Sink is in LOS, then direct communication is considered otherwise a relay node is used as data forwarder in NLOS communication	A relay node is used as data forwarder instead of using a sensor node
Movassaghi (2012) [31]	Energy Efficient Thermal and Power Aware (ETPA) Routing	Cost Function of temp, energy, RSSI	Yes	High	High	Yes	Yes	Low	High	Yes	No	A cost function is calculated considering energy and temperature levels, and received signal power of adjacent nodes. A route with minimum cost selected.	Proposed a cost function for routing by using energy, temperature and RSSI
Watteyen et. al (2007) [24]	AnyBody	CH, GN and Sink	X	X	X	X	X	X	High in terms of making less clusters	Yes	Yes	Neighbour discovery, density calculation, contacting cluster head, setting up the backbone and setting up the routing path	First self organization routing protocol proposed for WBAN

- We observe that some proposed algorithms such as [10, 11, 19, 20, 21, 22, 31] use temperature as their main routing metric. Few of them address the issue of heat produced by the sensors during the operation and prevent a sensor become a hotspot. This category of routing protocols is called temperature aware. Among the temperature aware routing protocols LTRT [20] is produced best results in terms of low delay, maximum PDR (performance), energy consumption, network lifetime.
- Cross layer routing protocols such as [26, 27, 29, 45] works on both MAC and network layer. We observe that the BIOCOMM [20] produced a relatively better performance compare to other cross layer protocols.
- In opportunistic routing, we observe that algorithm proposed in [30] produce better result in term of low energy consumption as compare to the one proposed in [31].
- The only self-organized routing protocol is AnyBody propose in [24]. In AnyBody authors focus on self-organized clusters formation while increasing the number of nodes therefore they overlooked the energy consumption, network lifetime and delay.
- HPR [11] and LTRT [20] are the two routing protocols which have the greatest packet delivery ratio, while CICADA [26] shows the trade-off between energy consumption and packet delivery ratio.
- Energy consumption is one of the main concerns in WBAN, and protocols like [10, 11, 19, and 20] are pretend to consume more energy than other protocols.
- Mobility is another factor which causes the delay and link failures. Protocols proposed in [26, 27, 30, 31] support mobility.

5. Case STUDY: Need for Self-Organization in WBAN

In this section we present a simulation based case study to analyse the requirement and necessity of using self-organization in WBAN. We used Castalia framework [40] which is based on OMNET++ [41]. OMNET++ is a discrete event based simulator extensively used for simulating WSN. While Castalia is specifically designed with the support to simulate WBAN, as we know that the area of WBAN is approximately 2 meters (2m). Therefore, Castalia use bypass routing for WBAN scenario, which means, routing is not considered (bypassed) in Castalia for WBAN and star topology is used. By using star topology, it means nodes are connected to the sink node (coordinator) in the single-hop manner. We modified the existing example scenario of Castalia to simulate the multi hop scenario and incorporate routing in WBAN.Node positions are illustrated in Figure 17 (a) and links in between nodes are illustrated in Figure 17 (b) and 17 (c) while two different types of routing information are given in Table 3 and Table 4. In these tables we described the node number and the placement of each node according to the Figure 17.In our simulation we used two types of nodes. The first is a Sink node which will be a PDA (Personal Digital Assistant) or a mobile device and others are sensor devices.



(a) (b) c)

Fig.17 (a) Node position and hello packet to all nodes (b) Route Established and route selection (Black) (c) Link Failure and Alternate route (Red)

Table 2 General Simulation Parameters

No. of Nodes	8
Simulation Time	50 seconds + 1 second for MAC setup
Routing Protocol	Static Routing
Energy of nodes	1 joule (By default)
Data rate	1024 Kbps

As we discussed earlier that we supposed the WBAN node as a functional device therefore the wearable sensors attached on human body can communicate each other wirelessly. These sensors have limited energy and once the battery is drained, then it becomes the dead sensor node. If a sensor is shut down, then the link between that sensor and its neighbours is broken. This breakage of link(s) or link failures will affect the routing. Another cause of breakage of link(s) is mobility of human body. Due to the mobility of hands and legs, the links between sensors are frequently disconnected. For example, if a sensor is placed on the wrist and it is connected to a sensor placed on the chest, then due to hand movement the link between these two sensors may be affected which cause the link failure. We believe incorporating self-organizing module will improve the WBAN performance in these link failures. Therefore, we are investigating here the effect of link failures on the network performance through simulation. Therefore in this study we used two scenarios to measure the performance of WBAN, the first is WBAN with no self organization and the other one is WBAN with limited self organization. We analyse network throughput as a measure of network performance. We use general simulation parameters of Table 2.

5.1 WBAN performance with No Self-organization

In this scenario no self-organization is considered. The nodes in the network route packets according to the position of the nodes are illustrated Through Table 3.There are seven sensor nodes and a sink placed on the body. We observe the network performance with variation in the link failure due to depleted energy and mobility of nodes. The graph in Figure 18 shows the network performance degrades considerably as the percentage of link failures increase. This is mainly due to the time the routing/ data aggregation techniques take to realize and fix the broken link.

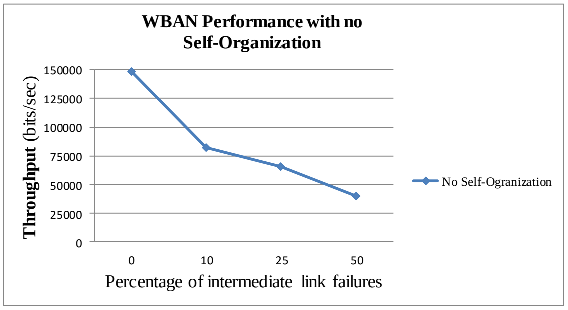


Fig.18 Throughput vs Link Failures with no self-organization

Table 3: Routing table (Scenario-I)

Node ID	Destination	Next Hop	No. of Hops	Placed
0 (Sink)	NA	NA	NA	Right hip
1	0	4	1	Left wrist
2	0	0	0	Right wrist
3	0	0	0	Left ankle
4	0	0	0	Right ankle
5	0	0	0	Chest
6	0	5	1	Left Shoulder
7	0	2	1	Right Shoulder

5.2 WBAN performance with Limited Self-organization

In this scenario we used a limited implementation of self-organization to the routing scheme as illustrated in Table 4. An alternate route is given to the nodes which are far away from the sink node. So, if an intermediary node is dead or is moved out from the network due to mobility, then the algorithm immediately jumps to the alternate route.

Table 4: Routing table (Scenario-II)

Node ID	Destination	Next Hop	Alternate Hop	No. of Hops	Placed
0 (Sink)	0	0	0	0	Right hip
1	0	4	3	1	Left wrist
2	0	0	0	0	Right wrist
3	0	0	0	0	Left ankle
4	0	0	0	0	Right ankle
5	0	0	0	0	Chest
6	0	5	2	1	Left Shoulder
7	0	2	5	1	Right Shoulder

The graph in Figure 19 in general shows the slight improvement in the network performance with the introduction of limited self-organization.

The improvement is clearly represented in the graph of Figure 20. Initial simulation results of the two scenarios clearly suggest that self-organization in routing / data aggregation in WBAN could improve the network performance in terms of throughput.

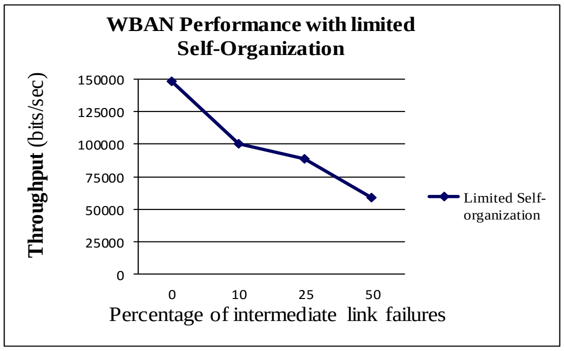


Fig.19 Throughput vs Links Failures with basic self-organization

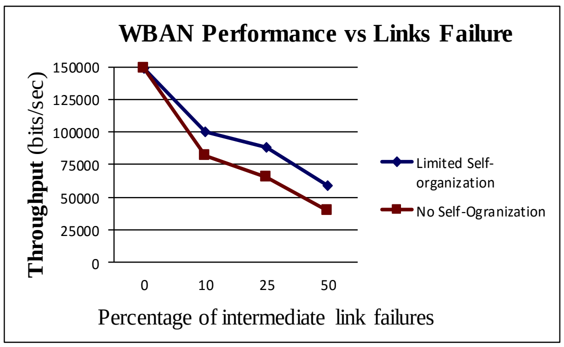


Fig.20 Difference between first scenario and second scenario

Therefore, considering the importance of WBAN enhanced performance in its application, we believe further efforts in terms of self-organization are required to improve the performance in multi-hop communication in WBAN.

To best of our knowledge the only self-organized routing protocol is AnyBody where authors only focused on making least or constant number of clusters and selection of cluster heads in predefined time interval considering multi WBAN scenario. Therefore, they applied self-organization only in selection of cluster head and to form new clusters and did not focus on network performance. While in our case we applied self organization in selection of routes in single WBAN scenario. We focused on network performance in terms of throughput. This is the major reason we can not directly compare our proposed routing protocol with AnyBody.

6. Conclusion and Future Direction

Self-organization is the area which is mostly ignored by researchers in wireless body area networks because of its uniqueness which differ it to wireless sensor networks. Wireless body area networks (WBAN) are the special type of Wireless Sensor networks, but with some difference and limitation. In this paper, we classified some self-organization implemented routing protocols for WSN. Unfortunately, there is not much work is done in WBAN to date. So we thoroughly discussed some routing protocols for WBAN and classified them. We found only one protocol, AnyBody [34], which fulfilled the criteria of self-organization in terms of making clusters and cluster heads. There is another routing protocol which partially adopted the self-organization such as HPR [10] in which calculating the temperature threshold value is somehow self-organized. In future the idea is, to design a routing protocol, which has the capability that if the network is disrupted then each node can react accordingly without any assistance from a sink or base station.

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