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Cost Based Routing Protocols in WBAN: a Review

T.Kaur[1*], N.Kaur[2], G.Sidhu[3]

Dept. of Computer Science, Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab, India

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***Abstract*—** In the current scenario, Wireless Sensor Networks (WSNs) have become a very essential tool to fix many challenges in real life. One of the major key challenge is healthcare monitoring. Wireless Body Area Networks (WBANs) constitute a key application of WSNs for monitoring the vital sign related data of human body. As the sensors worn on the human body are small in size, energy constrained and with small battery, it necessitates the design of routing protocols for WBANs to improve the energy efficiency for delivering the data from a given node to the sink. There are various factors such as energy, topology, temperature, mobility, radio range of sensors and quality of service that need to be considered while designing routing protocols. The main contribution of this paper is to provide a detailed review of existing cost based energy efficient routing protocols proposed in the literature. A state-of-the-art comparison of the existing Cost based routing protocols on the basis of techniques and various performances parameters is also presented.

***Keywords*—** Wireless Body Area Networks, Routing, Cost Function, Energy efficiency.

I. Introduction

The aging population and the growing cost of healthcare in developed countries have presented more significant challenges for the healthcare sector. With the increase in elderly populations, the quality of medical service would most likely drop, resulting in the increased health care and medical costs. Millions of people in the world die due to heart diseases and suffer from diabetes each year [1]. There is a trend of using growing wireless technologies to support patient monitoring in cost effective manner [2]. WBAN is one such emerging technology which allows, monitoring a person's health and providing services to patients at their doorsteps.

The term 'WBAN' was first introduced by Van Dan et al. in 2001. According to the definition of IEEE 802.15.6 "WBAN is a communication standard optimized for low power devices for their operation on, in or around the human body to serve a variety of applications including medical, consumer electronics or personal entertainment and other"[3]. Traditionally health care sensors attached to the human body with wires. Emergence of WBAN introduces wireless communication among sensors and hence increased the comfort of patient [4]. By using radio frequencies the WBANs create a wireless network in the human body to screen vital signs such as body temperature, glucose level, blood pressure, EMG and position. WBAN is a wireless network which consists of wearable or implanted computing devices that provides continuous health monitoring and real-time feedback to the user. Each sensor has specific features and is used for different applications in WBANs.

WBANs communicate with existing wireless technologies like ZigBee, Bluetooth, WSNs, Wireless Local Area Networks (WLAN), Wireless Personal Area Network (WPAN) and internet [5]. Figure 1 illustrates the 3-tier architecture of WBAN. Tier1 forms an Intra-WBAN where the bio-medical sensor nodes are worn on the human body to collect the data viz. temperature, heart rate, blood pressure etc and send to the body coordinator using ZigBee and Bluetooth wireless technology [6]. Tier 2 (Inter-WBAN) comprises of a BAN coordinator that sends the aggregated data from the patient to the sink node. Data can be transferred from Tier-1 to Tier-3 through this gateway. The tier 3 is an extra/beyond BAN where the sink sends the collected data to the remote medical centre or doctor through internet [7].

Nevertheless, there are a number of challenges viz. limited node energy, dynamic network topology, heterogeneous data generation rate, path loss, QoS etc that need to be addressed. Numerous routing protocols have been proposed in the literature to resolve these issues and challenges. This paper is an attempt to review the existing protocols and presents a compressive analysis for the same.

The rest of the paper is organized as follows. The design challenges of WBAN routing protocols are discussed in section II. Section III discusses various existing Cost Based routing protocols. Section IV presents the state-of-art comparison of discussed protocols. Section V finally concludes the paper.

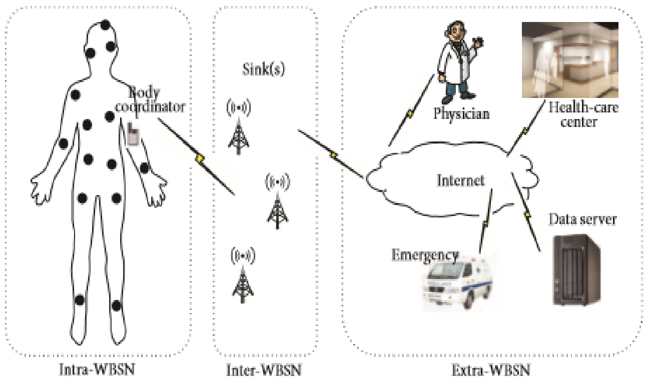

Figure 1.Architecture of Wireless Body Area Network [6]

II. DESIGN CHALLENGES OF ROUTING PROTOCOLS

Routing protocols are used to identify the specific choice of route from source to destination for delivering the data [8]. It plays an important role in the network performance in terms of energy efficiency, delay, throughput etc. In WBANs, development of routing protocols requires unique requirements and specific characteristics which is a very challenging task [7]. Numerous challenges of routing protocols are listed below:

A. Heterogeneous Environment

In WBANs, several types of sensor nodes are required to sense and monitor the different health parameters of the human body, viz. QoS, data rate and data power supply [7]. WBAN faces several challenges in term of heterogeneous nature of nodes. So, there is a need for energy efficient routing protocols that may dissipate the energy from all nodes in a homogeneous fashion.

B. Network Topology

WBAN poses a dynamic network topology due to energy constraints, body postural movements, short transmission range and heterogeneous nature of the nodes [7]. Data communication takes place through single hop communication or multi-hop communication.

C. Path loss

Path loss is the reduction in the power density of an electromagnetic wave. Wireless communication between the sensor nodes is through the human body, where the path loss exponent varies from four to seven, which is very high as compared to the free space [14].

D. Security and privacy

The design of routing protocols must respect the security and privacy of confidential and private patient data.

E. Quality of Services

The heterogeneous data of WBAN has different quality of services requirements. Patient data is generally classified into reliability sensitive data, critical data, delay sensitive data and ordinary data based on its QoS requirements [7].

F. Energy consumption

In communication, the sensor nodes consume more energy as compared to sensing and handling data. The greater distance between communicating nodes, regular data sensing and transmission are the main factors of more energy consumption [1]. Batteries in WBANs cannot be frequently recharged or replaced; therefore energy consumption remains a major issue to be resolved.

G. Mobility support

The frequent mobility of the patient changes the network topology. This results in a high loss of data [10]. The routing protocol design must consider the mobility aspect of the network.

H. Limited resources

WBANs have limited energy resource, restricted storage capacity, terrible computation capabilities and radio frequency transmission. These limitations need to be addressed while designing a routing protocol for WBAN.

I. Temperature Rise and Interference

The interference occurs when important data is read from one WBAN to another WBAN, as multiple people are wearing the same WBAN component. The nodes transmission power needs to be low for reduced interference.

III. CLASSIFICATION OF COST BASED ROUTING PROTOCOLS FOR WBAN

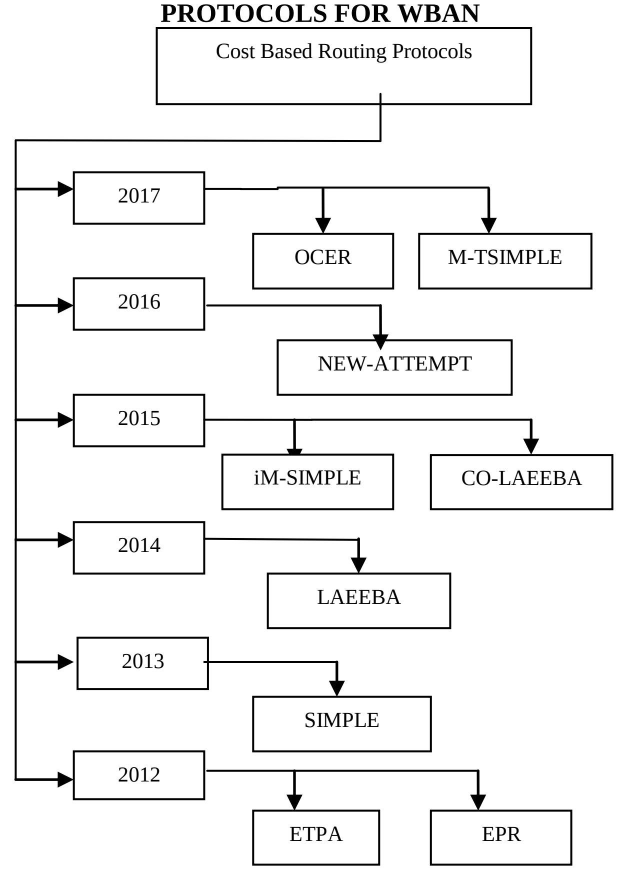

Figure 2.Classification of Cost Based Routing Protocols

A. OCER (Optimized Cost Effective Energy Efficient Routing Protocol)

OCER protocol [11] is energy efficient and reliable routing scheme for WBAN that provides minimum energy consumption and high throughput of the network. This protocol also considers all energy consumption sources viz. processing energy, sensor sensing, transient energy and reception. The energy consumption, path loss model and reliability model is presented in this protocol. Figure 3 shows a WBAN communication system of OCER [8]. The OCER is designed for communication from Body Coordinator (BC) to CDD (Centralized Display Device) through PDD (Patient Data Display). The finest next hop node PDD is selected with a minimum value of cost function. Body Coordinator forwards the data to PDD using Bluetooth and Zigbee network and after that PDD forwards the data directly to CDD such as the hospital, medical server and emergency through the internet. The cost function is based on three parameters viz. residual energy, path loss and link reliability as formulated in equation 1.

$$\textbf{Cost}= w_1\left|\frac{E_{max}-E_k(NT)}{E_{max}}\right| + w_2\left|\frac{LinkR_{max}-LinkR_{K(NT)}}{LinkR_{max}}\right| + w_3\left|\frac{PL_{max}-PL_{K(NT)}}{PL_{max}}\right| \quad (1)$$

Where $w_1+w_2+w_3=1$ are nonnegative weights, E_{max} is maximum residual energy, $LinkR_{max}$ is maximum link reliability and PL_{max} is maximum path loss. The node with the minimum value of cost function is selected as the next hop. OCER protocol provides better performance as compared with EPR protocol in terms of energy consumption and throughput.

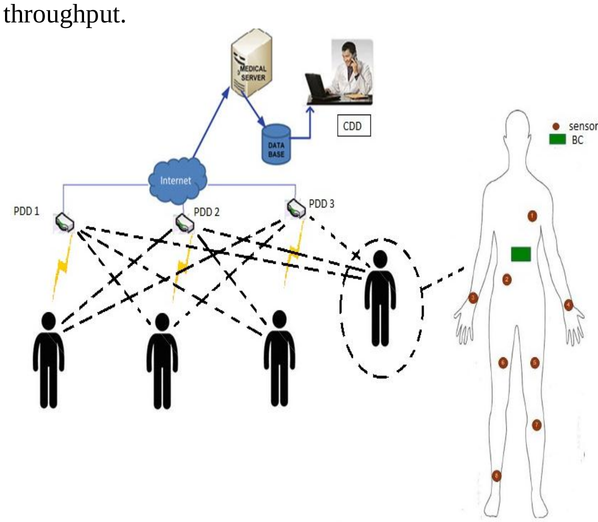

Figure 3.WBAN communication systems [11]

B. M-TSIMPLE (Mobility Supported Threshold Based Stability Increased Throughput to Sink Using Multi-hop Routing Protocol for Link Efficiency)

A movement of nodes plays a very significant part in designing energy efficient routing protocols in WBANs. M-TSIMPLE [12] routing protocol support mobility of nodes and also provides less energy consumption, path loss and delay. This protocol proposed a threshold based data transmission technique that uses next hop node which is based on mobility of nodes for WBANs. Figure 4 shows a WBAN topology and its corresponding tree structure of M-TSIMPLE protocol [12] that uses two type of nodes viz. Child node (c1 to c7) and the parent node (p1 to p3). These ten heterogeneous nodes are worn on the human body at their specified locations and the sink is placed at the centre of the human body. The ten heterogeneous nodes are divided into two categories; SC and SP.

$$SC=\{C1, C2, C3, C4, C5, C6, C7\},$$
$$SP=\{P1, P2, P3\},$$

Where C is child node and P is parent node. On the basis of cost function the child node and parent node is selected in each category. The cost function of SP and SC is calculated using equation 2 and 3

$$\boldsymbol{Cost\ Function_{sc}}=\frac{\boldsymbol{Distance(i)}}{\boldsymbol{Residual\ Energy(i)}} \quad (2)$$

$$\boldsymbol{Cost\ Function_{sp}}=\frac{\boldsymbol{Distance(i)}}{\boldsymbol{residual\ Energy(i)}} \quad (3)$$

The neighbor node is selected in SC category and next hop node in SP, depending upon less distance and higher residual energy. Two techniques are used in this protocol, the first one is threshold based data transmission technique and the second one is next hop selection based transmission technique. The first technique can detect abnormal values. In the data transmission, time division multiple access (TDMA) slot is assigned to parent node as well as child node to avoid the collisions with other nodes. The child nodes transmit their data to the parent node within given scheduled time and the parent node receives the data and aggregates it and directly sends it to the sink.

Forwarder node directly sends the data to sink, if it has minimum energy as compared to threshold value. So, M-TSIMPLE routing protocol is able to stay away from replicated and regular transmission in the network.

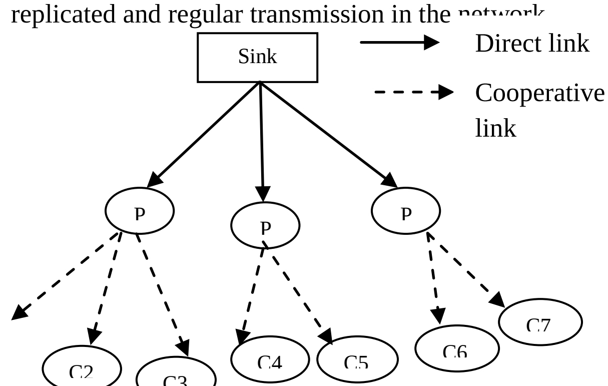

Figure 4.Corresponding network flow tree structure [12]

C. NEW-ATTEMPT (Modified new Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol)

In WBANs, NEW- ATTEMPT protocol [13] operates on heterogeneous sensor network in the human body. This protocol provides longer stability period, minimum energy consumption of nodes and longevity of the network.

NEW-ATTEMPT protocol evaluated the cost function to find the optimal route to forward the data to sink. This cost function is calculated using three parameters viz. distance, average data rate and residual energy of nodes.

Figure 5 shows a nodes deployment in NEW-ATTEMPT that uses eight sensor nodes that are worn on the human body, where all have equivalent specific power and computation abilities. Nevertheless, each node preserves unique data rate. The sink node is inserted at the waist. Sink broadcasts the hello packet to all nodes which contain the location of sink, neighbour and all feasible routes to sink. Equation 4 calculates cost function to select forwarder node with the minimum distance to sink, high residual energy and average data rate.

$$\boldsymbol{Cost\ Function}(\boldsymbol{i}) = \frac{\boldsymbol{R.E(i)}}{\boldsymbol{d*q}} \quad (4)$$

Where i is the node ID, $R.E_i$ is the residual energy of node i, d is the distance between the sink and node i and q is average data among all nodes. Glucose monitoring and ECG nodes send their data directly to the sink within own schedule time. High data rate sensor nodes are placed near to the sink. NEW-ATTEMPT routing protocol facilitates less energy consumption, more time stability period and more reliability of the network.

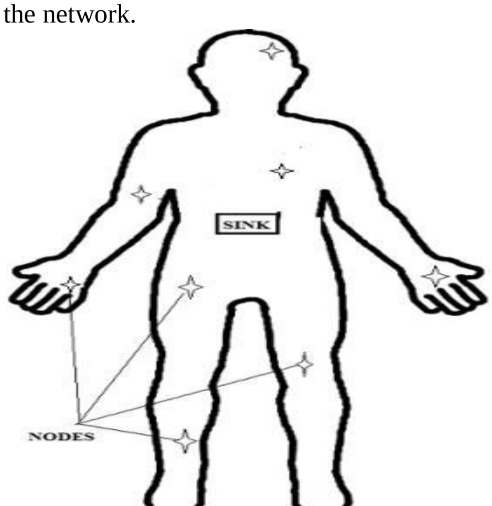

Figure 5.Node deployment in NEW-ATTEMPT [13]

D. iM-SIMPLE (iMproved stable increased-throughput multi-hop link efficient routing protocol)

The mobility patterns of human body arm and node posture could lead to great path loss in the network. The iM-SIMPLE routing protocol [14] uses multi-hop communication to minimize energy consumption of the network. This protocol supports mobility of nodes and also considers two body postures shown in figure 6. A cost function is used in this protocol to choose the forwarder node with lowest energy consumption and smallest distance to sink. The proposed cost function is based on two parameters viz. high residual energy and minimum distance to sink. Forwarder node is selected with minimum value of cost function. This protocol also recommended liner programming based mathematical model to reduce energy consumption and optimum throughput of the network for WBANs. The cost function is computed through equation 5

$$\boldsymbol{Cost\ Function}(\boldsymbol{i}) = \frac{\boldsymbol{d(i)}}{\boldsymbol{R.E(i)}} \quad (5)$$

Where i is the node ID, $d_i$is the distance between the node i and sink, $R.E_i$ is the residual energy of node i. When the residual energy of nodes drops below a specific threshold energy level, the sensor nodes utilize direct transmission with sink.

Sink assigns Time Division Multiple Access (TDMA) slots to the forwarder as well as the other nodes. The child nodes deliver their data to chosen forwarder node in offered scheduled time slots and the forwarder node delivers the aggregated data directly to sink. If wireless links between the nodes get turned off because of body movements, data reduction issue may appear. To minimize the path loss, the sensor nodes make use of the lowest distance for enhanced packet delivery to sink node. iM-SIMPLE routing protocol provides better performance as compared to SIMPLE routing protocol in term of maximizing stability period and throughput of the network.

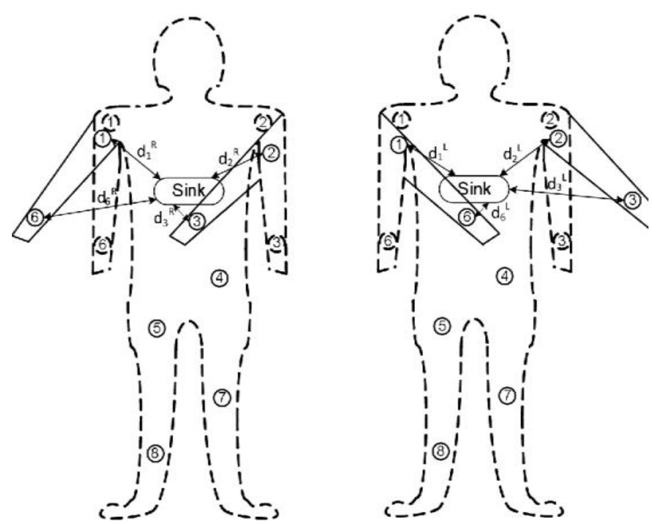

Figure 6.Mobility of nodes in iM-SIMPLE protocol [14]

E. CO-LAEEBA (Cooperative Link Aware and Energy Efficient scheme for Body Area network)

Co-LAEEBA protocol [15] is an innovative edition of LAEEBA [16] protocol. This is energy efficient and Cooperative Link-Aware routing protocol for WBANs. Co-

LAEEBA protocol uses cooperative transmissions in case of relay node failure detection in the network. This protocol introduced the cost function to select the most optimal path to forward the data from given node to sink. There are two types of nodes that are used in this network, advanced nodes and normal nodes.

Nodes 1, 4, 5, 7 and 8 are normal; whereas 2, 3, and 6 are advanced nodes as shown in Figure 7. The sink is inserted at the centre of the human body and eight sensor nodes are deployed on the human body in Co-LAEEBA protocol. In Co-LAEEBA, three advanced nodes are the cooperative nodes. Advanced nodes carry more energy in comparison to normal nodes. The normal source nodes transmit data together on two links via cooperation to stay away from data decline. When cooperative nodes are inactive, then normal nodes directly move their data to the sink. If the data is normal, the cooperative nodes utilize single-hop communication and normal nodes observe cooperative routing. Nodes 1, 4, 5, 7 and 8 forward their normal data to sink through cooperative nodes. Nodes 2, 3, and 6 are cooperative nodes which collect and forward data of normal nodes to sink. The sink is alert of ID, distance and residual energy status of all the nodes in the network. It computes the cost function of the relay nodes to choose next hop for transmitting its data directly to sink. The cost function is calculated through equation 6

$$\boldsymbol{C.F(i)} = \frac{\sqrt{\boldsymbol{d(i)}}}{\boldsymbol{E(i)}} \quad (6)$$

where $d(i)$is the distance between the sink and node i, and $E(i)$ is the residual energy of node i. The cost function of relay node is dependent on its residual energy. The main objective of this protocol is to avoid redundant transmissions and maximize the network throughput.

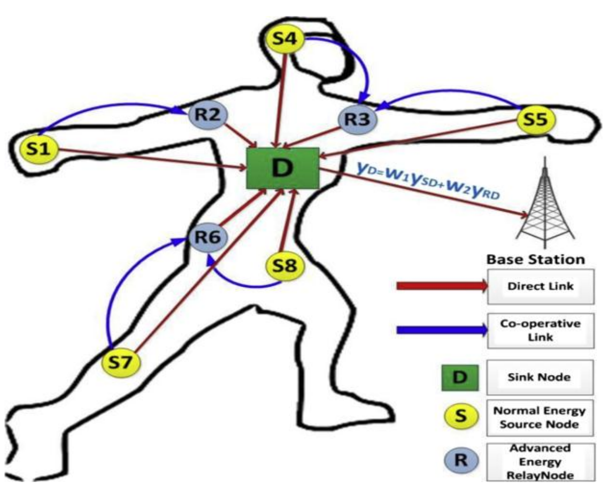

Figure 7.Nodes' deployment on human body in CO-LAEEBA [15]

F. LAEEBA (Link Aware and Energy Efficient Scheme for Body Area Networks)

LAEEBA protocol [16] utilizes the single-hop and multi-hop communication schemes to minimize path-loss consequences and maximize network life span. Figure 8 show a systematic structure for LAEEBA protocol that uses eight sensor nodes deployed on a human body obtaining similar power and the sink node is placed at the waist. Node 1 is the sensor for sensing ECG while other node is the sensor for sensing Glucose. Sink node broadcasts the information packet to all nodes which contain its node ID, location of sink and its energy status. The sensors replace their position of neighbour's nodes. LAEEBA protocol elects new forwarder in each round and it computes the cost function of all nodes on the foundation of high residual energy and minimum distance to sink. A node with minimum cost function is selected as a forwarder. The cost function is calculated through equation 7

$$\boldsymbol{C.F(i)} = \frac{\sqrt{\boldsymbol{d(i)}}}{\boldsymbol{E(i)}} \quad \textbf{(7)}$$

Where d_i is the distance between the node i and the sink and $, Ei$ is the residual energy of node i. ECG and Glucose nodes transmit data directly to sink because they are near to the sink. Other nodes have maximum distance to sink and they can transmit their data to the sink through the relay node. LAEEBA protocol provided better network performance as compared to SIMPLE protocol. LAEEBA protocol not only minimizes the path loss of the sink but also leads to high throughput.

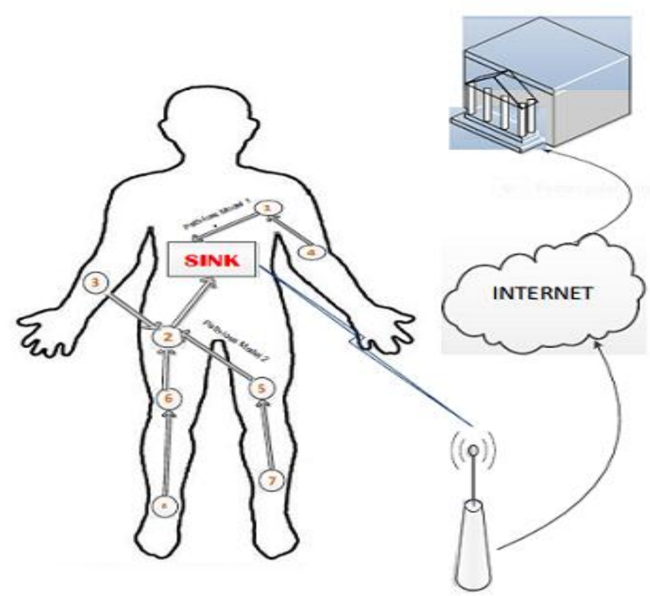

Figure 8.Systematic structures for LAEEBA Protocol [16]

G. SIMPLE (Stable Increased-throughput Multi-hop Protocol for Link Efficiency)

SIMPLE routing protocol [17] provides a reliable, high throughput and power efficient network for WBANs. This protocol uses multi-hop technique to achieve minimum energy consumption and longer network lifetime of nodes. Figure 9 shows the nodes deployment in the SIMPLE protocol where eight nodes are positioned at unique areas on the human body with sink at the waist. Sink broadcasts a short information packet to notify the nodes about its location on the human body. The forwarder node is chosen based upon its distance from the sink and its residual energy status. The node with minimum distance and having highest residual energy is chosen as a next hop or forwarder as computed in equation 8.

$$\boldsymbol{Cost\ Function}(\boldsymbol{i}) = \frac{\boldsymbol{d}(\boldsymbol{i})}{\boldsymbol{R}.\boldsymbol{E}(\boldsymbol{i})} \quad (8)$$

Where i is node ID, $d_i$is the distance between the sink and node i and sink and $R.E_i$ is the residual energy of node i. Child nodes deliver data to the forwarder node, which aggregates the acquired data and directly sends to the sink. In the scheduling phase, forwarder node designates TDMA based time slots to its children nodes. All the nodes transmit data in their scheduled time slots to prevent any collision and damage of data. In this way, data is properly routed from nodes to sink.

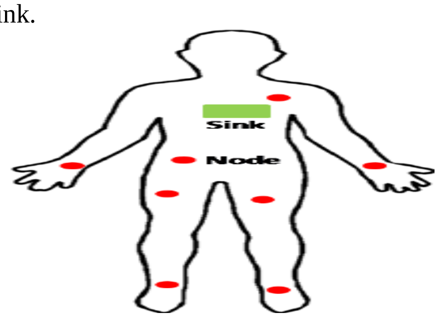

Figure 9.Node deployments in SIMPLE protocol [17]

H. ETPA (Energy Efficient Thermal and Power Aware Routing)

ETPA protocol [18] is designed to minimize the energy consumption and reduce the temperature rise in a network. This protocol is based on the posture-movement of the human body. Figure 10 shows the framework of ETPA protocol that consists of seven biosensor nodes, which are placed on the human body at different locations. Two sensors are placed on upper arms, two are placed on thighs, two are placed on ankles and one biosensor is placed on the waist. Multi-point-to-point and non-real-time data transmission takes place between these sensors.

TDMA slots are applied in data transmission and it classifies the frame into time slots. All biosensor nodes broadcast a hello message to neighbour nodes. ETPA calculates the cost function to selected next hop node which has minimum temperature and energy consumption. The cost of transmission from node i to node j is calculated through equation 9

$$\boldsymbol{C_{i,j}} = \boldsymbol{\alpha_1}\left(\frac{\boldsymbol{P_m}-\boldsymbol{P_i^j}}{\boldsymbol{P_m}}\right) + \boldsymbol{\alpha_2}\left(\frac{\boldsymbol{T_j}}{\boldsymbol{T_m}}\right) + \boldsymbol{\alpha_2}\left(\frac{\boldsymbol{E_m}-\boldsymbol{E_j}}{\boldsymbol{E_m}}\right) \quad (9)$$

Where α_1, $\alpha_2$and $\alpha_2$are non-negative coefficients. P_i^j is the received power from node j to node i, P_m is the maximum received power, $T_m$is the maximum temperature allowed and E_m is the maximum available energy at every node. The biosensor node looks for an effective minimum cost path. If a minimum cost path is identified then data is transmitted otherwise it buffers the data packet. If data packets are buffered more than two frames, they will be removed. In order to avoid more energy consumption and large delay, multi-hop communication is used. If data packet meets the max hop count, it will be removed. ETPA protocol helps in decreasing the delay in the network.

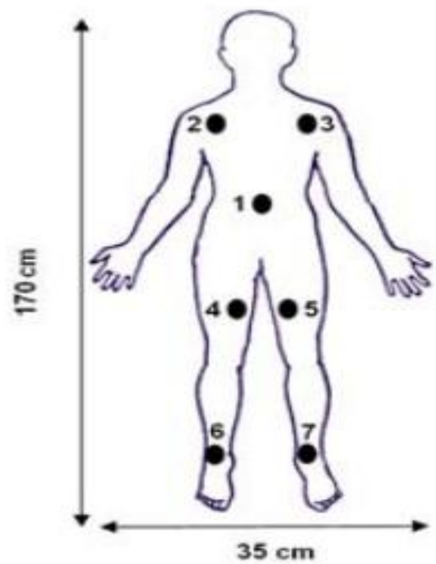

Figure 10.Structure of ETPA protocol [18]

I. EPR (Energy-Aware Peering Routing protocol)

EPR protocol [19] is structured on both centralized and distributed techniques. This protocol is developed to show the patients' real-time data inside a hospital. In order to avoid the network visitors, the patient's data is divided into normal data, critical data, delay sensitive data and reliability sensitive data. Figure 11 shows a network structure of the EPR protocol, which used three types of communication devices: Type 1—Nursing Station Coordinator (NSC), Type 2—Medical Display Coordinator (MDC), and Type 3—Body Area Network Coordinator (BANC). NSC is a centralized device with continuous power supply and provides interaction information of all BANCs. MDCs are display devices with exchangeable power supplies. These devices gather the data from the bio-medical sensor nodes and forward it to the specific MDC(s). The BANC will try to access the NSC to get the peering and communication type (p-p or p-mp) information of MDC(s), and it will find out the MDC(s) to show the data. The selection of next hop node is based on the aforementioned device types, geographic information and residual energy of the neighbour nodes as computed in equation 10

$$C_j = \left(\frac{T_j \times D^2_{(i,j)}}{E_j}\right) \quad (10)$$

Where C_j communication cost for node is j, $D_{(I,\ J)}$ is the distance between nodes i to node j, T_j is lower device type and E_j is the residual energy of each node.

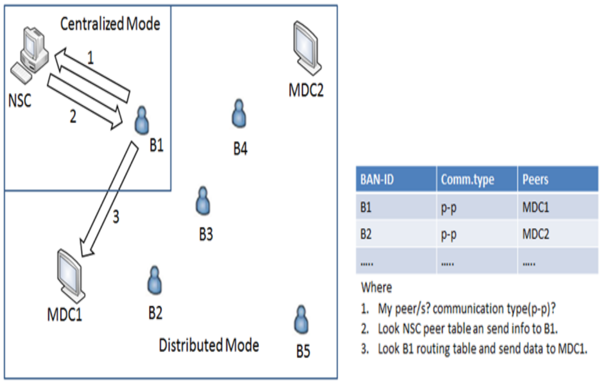

Figure11.Network structure of the EPR protocol [19]

IV. COMPARISON OF ROUTING PROTOCOLS FOR WBANS

The objective of Cost based routing protocols is to reduce the energy consumption of the nodes and select the forwarder node to send the data to sink with minimum energy consumption through optimal route selection. Table 1 presents the comparison between different cost based routing protocols for WBANs in terms of the goal, mobility, throughput, energy consumption, delay, pros and cons.

Table1. Comparison of Cost Based Routing Protocols of WBAN

Mobility	Throughput	Energy consumption	Delay	Pros	Cons
Yes	High	Very low	N/A	Inter BAN communication using multi-hop approach and support mobility	Delay has no consideration in OCER
Yes	High	Average	Large	Avoid repeated and continuous transmission	Priority mechanism and inter BAN communication are not
No	Average	Low	Low	Maximize throughput & node stay alive for a longer time	Mobility and increased radio transmission are not supported
Yes	High	Low	Low	Provide longer stability period and handle mobility	Number of dropped packets are more
No	Very High	Very low	N/A	More stability period , high residual energy and low path loss	Many cooperative links are required
No	Average	Low	Low	Less path loss and minimum energy consumption	Large number of data packets
No	Average	Average	High	Longer stability period	Mobility situation is not handled
Yes	High	Low	High	Better link quality	Large number of packets discarded
Yes	High	Low	N/A	Lower average traffic load	increased overhead due to large number of hello packets

S. No	Protocols	Goal
1	OCER [15]	To reduce the overall energy Consumption of network
2	M-TSIMPLE [16]	To detect the anomalies in medical
3	NEW-ATTEMPT [17]	To decrease energy consumption and increase lifetime of network
4	iM-SIMLE [18]	To accomplish high throughput and reduce energy consumption of network
5	CO-LAEEBA [19]	To find the disaster node in the network, maximize throughput and low power loss
6	LAEEBA [20]	To decrease path-loss consequences and increase network lifetime
7	SIMPLE [21]	To improve the throughput and minimize the energy consumption
8	ETPA [22]	To decrease the temperature rise and energy consumption
9	EPR [22]	To lower network traffic and energy consumption

V. CONCLUSION

The development of routing protocol for WBAN is quite challenging due to its unique in-body and on-body constraints. Various parameters that affect the performance of the network are energy efficiency, throughput, delay, mobility and QoS etc. This paper is an attempt to provide a comprehensive analysis of the existing cost based energy efficient routing protocols. The comparative statement of the protocols reveals that the cost function based technique to select the next hop node saves the energy and increases the throughput of the network. Nevertheless, important factors have not been taken into consideration while proposing routing protocols by many researchers. The future routing protocols should consider reliability, mobility, thermal-effects security along with energy efficiency. Moreover, for better routing in WBANs, more precise and effective network architectures must be designed.

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Authors Profile

Tejinder Kaur received Bachelors in Information Technology (2015) from Guru Nanak Dev Engineering College, Ludhiana in India. She is currently a Masters in Computer Science and Engineering candidate in the Department of Computer Science at Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, India. Her current research interests include Wireless Body Area Networks.

Navneet kaur obtained her B.Tech. (Computer Engg.) degree from Panjab Technical University, Jalandhar in 2000, M.E. (Computer Sc. & Engg.) Hons and Ph.D Degree from Panjab University, Chandigarh in 2007 and 2018 respectively. She is working as Assistant Professor in the department of Computer Science and Engineering in Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab. She is the Life Member of CSI and Member of ACM and IEEE. Her research interests include Wireless Sensor Networks, Wireless Body Area Networks and Wireless Adhoc Networks.

Gurleen Sidhu obtained her B.Tech. (Computer Engg.) degree from Panjab Technical University, Jalandhar in 1999, M.E. (Computer Sc. & Engg.) from Panjab University, Chandigarh in 2004. She is working as Assistant Professor in the department of Computer Science and Engineering in Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab. Her research interests include Wireless Body Area Networks and Image processing.

