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RESEARCH ARTICLE

A Multi-Hop QoS-Aware and Predicting Link Quality Estimation (PLQE) Routing Protocol for Reliable WBSN

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ABSTRACT Technological advancements and miniaturization of sensor have made it possible to use tiny size sensors nodes to monitor patients' physiological data in real-time at very low cost. The network of such small size sensor nodes is often called wireless body sensor networks (WBSNs). The patient's data is highly sensitive which required to reach reliably and timely at the destination node. However, short range wireless nodes and postural body movements cause frequent topological changes and recurrent network partitioning. The network partitioning leads to delayed and significant loss of critical patient's data such as Electrocardiogram (ECG), Electroencephalogram (EEG) and Electromyogram (EMG). Therefore, QoS requirement of WBSNs in terms of reliability, end-to-end delay and throughput are highly compromise. We in this paper propose a Predicting routing protocol PLQE to address reliable data transmission and network partitioning due to node mobility. The PLQE dynamically determines the efficient links by using beta probability density function, link quality and link delay estimation (LDE). The PLQE is composed of link reliability factor (LRF) and expected probability Indicator (EPI) to obtain most often updated status of the links to figure out stable and reliable end to end route to the destination node. The simulation results confirm the higher performance of the proposed scheme against state-of-the-art routing protocols in terms of packet delivery ratio, end to end delay, throughput and normalized routing load.

INDEX TERMS Link reliability, link quality, quality of service, routing protocol, wireless body sensor networks, network partitioning.

I. INTRODUCTION

The ever-growing population of the world is expected to reach 8 billion by 2025 [1], [2], [3], [4] and facing various challenges such as environmental degradation, malnutrition, and water scarcity etc. As traditional healthcare system is very complex and require unprecedented healthcare budget, therefore, today's healthcare system demands easy and affordable solutions [5], [6]. The sensor miniaturization and advancements in wireless communication enabled the use of Nano-size biomedical sensor nodes which having the advantage of diagnosing disease at their preliminary stage and long term patient monitoring [7]. The network of such Nano-size invasive and non-invasive nodes is called wireless body sensor networks (WBSNs) [8], [9], [10]. In the adhoc network model data is transferred in a cooperative manner to the central/destination node, therefore requiring high level of data accuracy and reliability [4].

Wireless communication in WBSN is vulnerable and prone to data loss, due to scarcity of resources such as low transmission range, network partitioning due to postural body movements, unpredictable traffic pattern, network instability,

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data redundancy and energy balance [11], [12], [13]. Therefore, to make fair use of the network resources, identification of reliable and efficient links between the source and the sink node is important. However, from the research it is observed that the routing protocol plays a key role in fair utilization of network resources to achieve QoS requirements of WBSN [14], [15], [16], [17].

A bunch of key routing protocols are available which consuming minimal network resources for data transmission [16], [18], [19]. However, most of the routing protocols mainly focus on energy efficiency and temperature rise of the sensor node installed on the human body, thereby ignoring the QoS requirements of WBSN specifically with respect to link reliability and route stability [17]. Moreover, for reliable and safely transmission of patient's critical data, the network must be operational for extended period of time. However, due to postural body movements such as sitting, standing, sleeping, walking, running and stringent characteristics, the network in WBSN frequently disconnects. Consequently, it results in unstable routes, delayed as well as loss of critical data packets. Therefore, WBSN s routing protocol must be designed with the aim to mitigate effects of frequent network partitioning, route stability, reliability, network lifetime, packet delivery delay and throughput.

We in this paper, propose a reliable and link quality aware routing protocol PLQE that integrates the QoS requirements in WBAN and link partitioning issues due to postural body movements.

This paper makes the following contributions:

- A detailed review of the existing state-of the-art routing protocols has been carried out by highlighting their demerits with respect to the QoS requirements of the WBAN.
- The proposed scheme incorporates LDE for estimating the delay between two connected links.
- The proposed scheme includes an exponentially weighted moving average for evaluating the link reliability thereby catering dynamic network behavior due to postural body movements.
- To determine the future behavior of the links in the network, the proposed scheme incorporate expected probability (EP) that makes use of beta probability density function to evaluate the route stability/link connectivity.
- Considering the aforementioned QoS-aware routing metric in the proposed scheme leads to the development of a reliable and delay tolerant routing protocol for healthcare applications of WBSNs.

The rest of the paper is organized as follows. Section-II discusses related work. In section-III we discuss research methodology, section-IV present result discussion and finally section-V concludes the paper.

II. LITERATURE REVIEW

In health care applications of WBSN, quality of service is assumed to be the ultimate requirement. In health care system, different biosensor nodes are deployed on/in body which are diverse in nature to carry out the physiological signals of the patients such as respiration, temperature, blood pressure, ECG, EEG, EMG etc., which demand high level of transmission accuracy. Most of the applications in WBSN are real time and life critical requires a strict guarantee of QoS in terms of reliability, timelines, data delivery, energy consumption, network life time, throughput etc. [15]. Due to hindrance in health care WBSNs which effects the transmission of patient's data such as link reliability, transmission range, node temperature, energy consumption, postural movement etc. [20].

Moreover, reliably and timely data delivery is essential in all WBSN application. Routing protocol plays a vital role in WBSNs which can identify the optimal routes to exchange data between nodes efficiently. Routing protocols for WBSNs are categorized into five different groups as QoS-aware, Thermal-aware, cross-layer, cluster-based, and postural body movement [16], [21], [22], [23]. These routing protocols exclusively focus on selecting routes based on the temperature, hop count, cluster information and mobility. However, these routing protocols do not optimize the route selection by taking into account critical network conditions such as channel diversity, intermittent disconnectivity, interference and QoS requirements for WBAN. Cross Layer routing protocols aims to address the challenges of network and other layers for reducing the energy consumption and producing high network throughput. These schemes under performs where frequently topology changes occurs such as postural body movements [6]. The cluster-based routing protocols significantly reduces the number of direct transmissions to transmit packets between source and the destination node. However, due to cluster head selection, this class of routing protocols suffers from high overhead as well delay [17]. QoS-aware routing protocols provides a modular approach to address various QoS requirements however, these scheme mainly suffered from high complexity due to incorporation of various modules for different requirements [18]. Temperature-based routing protocols aim to reduce temperature rise of sensor nodes due to wireless transmission that could damage sensitive tissues. As temperature-aware routing schemes avoids to forward packets form hotspot nodes thereby exhibits higher end to end delay and low throughput. In WBSN QoS-aware routing not only discovers the reliable routes between two or more sensor node, it also tries to satisfies the QoS requirement of the network such as reliable link, route stability, node mobility, network life time, energy, temperature etc. [16]. To date, many of the researchers contributed their work to address and overcome the QoS and reliability aware routing protocols which designed to overcome data transmission delay, route breakages, network routing load, node mobility, improved throughput, higher Packet delivery ratio, minimum path loss etc. [18].

In this paper, author presents a new QoS-aware routing protocol for WBSN specifically for Healthcare Monitoring System. IM-QRP considers energy, distance to select next-hop.

Authors claims its shows goods performance to its counterparts QPRD, CO-LEEBA in terms of residual energy, path loss, throughput, SNR [24]. In this paper author prosed new protocol ENSA-BAN [25], to consider the QoS requirements such as delay, reliability. Hop count and link cost parameters are used to select best next hop node for packet forwarding. To compute the link cost residual energy, available queue size and link reliability of neighboring node is considered. As discusses above Reliability plays a key role in routing to achieve overall reliability in network, a RAR [26] is proposed which shown high reliability for reliability constraint data packets(RCDP) because it considers path loss, thermal effect for selecting next hop node based on end-to-end and normal data packets. Two network models are designed RAR for direct communication between source to destination, (RARR) used relay nodes to send data from source to destination. It considers the path loss. In this paper a new Energy Aware Routing Protocol is designed which select next hop based on the residual energy and link quality. The quality of link is measured using the packet reception rate [8]. In [27] author address the above mentioned QoS issues by presenting multiconstraint-aware routing mechanism (modular-based) approach with two types of frame work with and without relay nodes. It classifies the generated data packets into four categories critical data (CD), reliability-conscious data (RCD), delay-conscious data (DCD), and non- conscious data (NCD). Routing is performed depending upon the type of generate d data. Two protocols are proposed MCARM without relay node, MCARMR with relay/forwarder node. Due to classification of generated data and selection of protocol based on type of data which depletes the more network resource leads to minimum network lifetime.

RL-QRP [28] a reinforcement learning based QoS-aware routing protocol for WBAN, in this scheme source node find the best route to the sink, using the Q-learning algorithm to meet QoS metrics end-to-end delay, packet delivery ratio. This protocol is not good for large scale networks to achieve global optimization, also not consider energy metric.

In DMQoS [29] a new next hop selection using multi-objective lexicographic optimization approach is proposed in which data packets are classified into Critical Packets (CP), delay-driven packets (DP), Ordinary packets (OP) and Reliability-driven packets. Next hop is selected upon the QoS metric of residual energy, distance to the destination. This approach rises traffic load on the network due to this required end-to-end delay or reliability is not achieved. QPRR [30] for hospital body area network is proposed in which different modules are used as routing, packet classifier, HELLO message and queuing module. Link Reliability between two nodes is calculated using acknowledgement of successful transmission passed from MAC layer to Network layer. QPRR use CSMA/CA in QoS metric which is unreliable and unsuitable for BANs due to this low throughput is achieved.

Link Aware and Energy Efficient Scheme [31] for WBAN is proposed, in which both network architectures (single-hop/multi-hop) communication schemes are used to reduce the path-loss and increase the network lifetime. Cost function is developed which considers the high residual energy and minimum distance to the sink for selection of forwarder node. Network overhead is increased due to calculation of cost function at every round. To address delay sensitive data in WBAN QPRD [32] is presented, which classifies the data packet into ordinary packets and delay-sensitive packets to meet QoS requirements. QPRD performs better in those applications which requires higher transmission rate and lower overall network traffic load. QPRD does not consider the reliable transmission in the network. In this paper author proposed Traffic Prioritization scheme for QoS-aware routing [33]. The LLTP-QoS is designed to enhance the transmission of critical data in a privileged manner (reliability) and avoids the end-to-end delay. This scheme is good for static nodes but is not appropriate in node mobility and data-intensive applications. In this paper [34] author proposed a routing protocol (referred to as MIQoS-RP) which is designed to select an efficient end-to-end route by considering the metric composite routing metric LQM, LIR and LDR. This protocol will not achieve desired output if there is node mobility, inter-BAN interference and high data rate applications.

Researchers in this paper [35] presented new protocol which will give secure, reliable, QoS aware data delivery. To improve the reliability proposed a modified adhoc on-demand distance vector (AODV) protocol called RelAODV (Reliable AODV) which considers the multi-hop routing technique to address the changes in topology due to node mobility and high propagation losses. RelAODV select the direct nodes to improve the overall reliability of the network. Improved Packet Delivery is achieved but overall routing overhead high, which is not acceptable in many WBAN applications.

In this paper author [36] address the challenging QoS requirements of energy consumption and reliability in WBAN and proposed a routing protocol based on the relay node selection. Proposed scheme designed two criteria for selection of relay node i) Estimated distance based on RSSI, ii) Direction based on the MUSIC algorithm. This approach will not perform well in frequent node mobility because it depletes the energy for computing the estimated distance for every movement.

To address the energy and reliability issue in WBSN a new protocol is proposed by researchers (ERRS) [6], which improve reliability and stability period for resource-intensive WBAN. This scheme considers two novel techniques Forwarder Node Selection and Forwarder Node Rotation. ERPS used the adaptive static clustering-based routing technique to attain the longer network lifetime and stability period via selecting the forwarder node in WBAN and then rotate the role of forwarder node amongst the deployed nodes to ensure the uniform load balancing. In case of node mobility this scheme will not provide the desired results.

TABLE 1. Summary table.

Protocol	Link Reliability	Link Delay	Postural Body Movement	Expected Probability
IM-QRP [24]	Yes	Yes	Yes	No
MCARMR [27]	Yes	Yes	Yes	No
ERRS [6]	Yes	Yes	No	No
Relay Node Selection for ER WBAN[36]	Yes	No	Yes	No
MIQoS-RP[34]	Yes	Yes	No	No
LLTP-QoS[33]	Yes	Yes	No	No
EAR [8]	Yes	No	No	No
ENSA-BAN [25]	Yes	No	No	No
QPRR[30]	Yes	No	Yes	No
RelAODV[35]	Yes	No	No	No
QPRD[37]	Yes	Yes	Yes	No
RAR [26]	Yes	No	No	No
LAEEBA[31]	No	Yes	No	No
DMQoS[29]	Yes	Yes	No	No
RL-QRP[28]	No	Yes	No	No
PLQE	**Yes**	**Yes**	**Yes**	**Yes**

Table 1 provides the summary of QoS-aware routing protocols which addresses various QoS parameters such as Link Reliability, Link Delay, Postural Body Movement, Probabilistic Behavior of the links. The Literature review cited above suggests that the routing protocols specifically designed for healthcare applications must consider QoS parameters. From the literature, it is evident that most of the WBAN routing schemes exclusively deal with the temperature-aware routing for avoiding hotspot nodes in the route selection and energy-aware routing for enhancing network lifetime. However, most of these routing schemes overlook dynamic/changing link status due to frequent network partitioning caused by node mobility/ postural body movements thereby incurring compromised network performance in terms low throughput, extended number of packet retransmissions, frequent route breakages and most importantly delayed delivery of time-critical data packets. The critical data packets need to be delivered reliably and timely at the destination node to handle emergency situation. Therefore, to address these mentioned challenges we propose a Predicting link quality aware (PLQE) routing protocol that dynamically identifies the optimal and reliable route to disseminate data at the destination node.

III. PROPOSED ROUTING SCHEME

For the proposed routing scheme, we considered three types of nodes i.e the sensor nodes for observing different characteristics/parameters of the human body referred as biomedical sensor nodes, the relay nodes for forwarding received data towards the destination/sink node and a sink node that accumulate and forwards data to the central station.

The connectivity graph of the network model is shown in Equation (1).

$$CG = (S, L, P) \tag{1}$$

where S, describes the sensor and relay nodes such that

$$\begin{aligned} S &= \{Bs\} \cup \{Rn\} \\ Bs &= \sum (b_{s1}, b_{s3}, \ldots .b_{sn}) \\ Rn &= \sum\nolimits_{i,j} (r_1, r_2, r_3, \ldots .r_n) \end{aligned} \tag{2}$$

The links between the relay node, biosensor node and the sink node is represented by Equation (3).

$$L = \sum (l_1, l_2, l_3) \tag{3}$$

The proposed routing scheme (PLQE) integrates a composite Route Cost Function (RCF) that is comprised of *Link Reliability Factor (LRF) and Link Prediction Factor (LPF)* of the link to evaluate stable and reliable routes for making routing decisions as shown in the Equation (4).

$$RCF = LRF_{i,j} + LPF(t)_{i,j} \tag{4}$$

Furthermore, LRF divided into two sub components a packet forwarding ratio (PFR) and link estimation delay (LDE) as shown in Equation (5).

$$LRF_{i,j} = linkR_{i,j} \times (1/Link\_Delay_{i,j}) \tag{5}$$

where, reliability of link between two nodes ($linkR_{i,j}$) is computed by using the exponentially weighted moving average (EWAD). *Where total number of received packets* ($TRP_{i,j}$) is the total number successfully transmitted packets via the link between node S_i and node S_j. Similarly, *Total number of packets forwarded* ($TPF_{i,j}$) is total number of *attempts* for both transmission as well as retransmission of all packets and γ is the average weighting factor [25], [27] as described in Equation (6). The link having maximum value of $linkR_{i,j}$ will be considered in route cast function.

$$linkR_{i,j} = (1-\gamma)\, linkR_{i,j} + \gamma \times \left(\frac{TPR_{i,j}}{TPT_{i,j}}\right) \tag{6}$$

The nodes upon receiving hello packet appends its related information e.g. Link delay (LD) and rebroadcast the received hello packet to their subsequent neighbors in the network. This process is continued until every node in the network receives the updated information of their neighborhoods. LDE is computed on basis of link delay between nodes. Whereas, LDE is derived from the Equation (7) that is estimated amount of time for the hello packet which is exchanged between the nodes on the same link and its acknowledgement received. ω is the constant weighted factor whose value is 0.2 [27]. The link having least delay is considered in route cast function.

$$Link\_Delay_{i,j} = (1-\omega) \times Link_{Delay}{}^{t-1}_{i,j} + \omega \times Link_{Delay_{i,j}} \tag{7}$$

A link is assigned a value on the basis of their packet forwarding ratio and link estimation delay that lies between 0 and 1.

Such that $0 \leq LRF \leq 1$. A link is considered as reliable if the value of $LRF_{i,j}$ is nearby to 1. Similarly, a link is considered as unreliable if the value of $LRF_{i,j}$ is nearby to 0.

The link status prediction (probable behavior of link) is a crucial design factor for routing protocols, as it enables them to determine whether a link is connected or disconnected. The *Link Prediction Factor (LPF)* of the proposed routing protocol employs the Beta Probability Density Function (PDF) [38], [39] to model the probability of link connectivity. This continuous probability distribution is defined on the interval [0, 1], with $Beta(\alpha, \beta)$ representing the number of successes and failures, respectively. In the context of link behavior prediction, a successful measurement indicates a connected link, whereas a failed measurement indicates a disconnected one. Equations (8a) and (8b) can estimate the likelihood of connected and disconnected links, respectively. Equation (8a) represents the connected status of link between two nodes, it uses the Exponential Weighted Moving Average (EWMA) optimizer technique to check the current connected status of link. Equation (8b) represents the disconnected status of link between two nodes. The use of the Beta distribution for link prediction factor offers several benefits. First, it is a versatile distribution that can be adapted to a wide range of data. Second, it can provide a probabilistic forecast of link status, which can be beneficial in routing protocol design. Finally, it can be updated as new data becomes available, improving the prediction over time.

$$linkR_{i,j}^{connected} = (1-\alpha)\, linkR_{i,j} + \alpha \times \left(\frac{TPR_{i,j}}{TPT_{i,j}}\right) \quad \text{if } LinkR_{i,j} \text{ is connected} \tag{8a}$$

$$linkR_{i,j}^{disconnected} = \alpha \times \left(\frac{TPR_{i,j}}{TPT_{i,j}}\right) \quad \text{if } LinkR_{i,j} \text{ is disconnected} \tag{8b}$$

The value of the α used in Equation (8a) and (8b) is taken from Equation (9) where window size is considered as 15 seconds. Moreover, the window size is a tunable parameter and can be changed according to the requirement.

$$\alpha_{i,j}^{curr} = \sum_{t}^{t-Window} LinkR_{i,j} \Big/ Window \tag{9}$$

$$Beta(\alpha, \beta) = \frac{\alpha}{\alpha+\beta} \tag{10}$$

Based on the standard Beta probability function (in Equation 10), the Link Prediction Factor is derived as shown in the Equation 11.

$$LPF = \frac{LRF_{Connected} + 1}{(LRF_{Connected} + 1) + (LRF_{disconnected} + 1)} \tag{11}$$

Finally, the Route Cost Function (RCF) on the basis of LRF and LPF(t) makes optimized decision regarding the link behavior. Accurate link status prediction enables routing protocols to efficiently route data through the network, resulting in better performance and improved route stability.

The route selection process of the proposed scheme is further elaborated in the following flowchart.

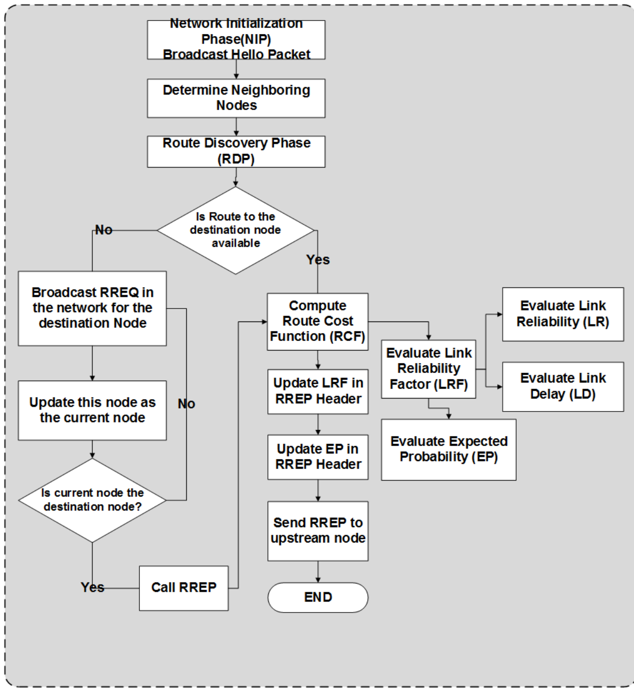

FIGURE 1. Flow chart for proposed routing protocol.

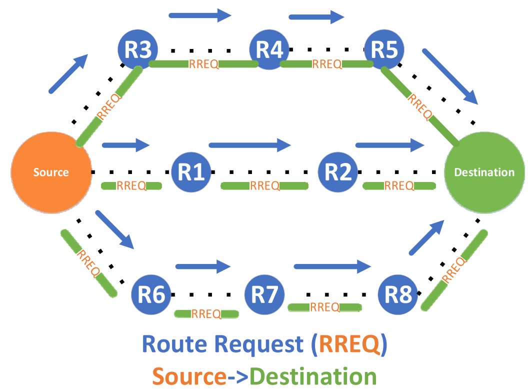

FIGURE 2. Hello packet (Route request packet).

The proposed scheme is composed of a network initialization phase (NIP) and a route discovery phase (RDP). Each of these phases are discussed in the following subsections.

Network Initialization Phase (NIP): In NIP phase, a hello packet is broadcasted by each node to inform its neighboring node, where hello packet contains the information regarding node-ID and the Hop count from the sink node.

Route Discovery Phase (RDP): The route discovery phase is responsible for finding optimized routes for forwarding packets to the destination node. PLQE enhances the route selection process of famous on-demand AODV routing protocol by customizing the RREQ and RREP control functions to incorporate RCF to evaluate link status, as shown in Figure 2 and 3, respectively.

In route discovery phase, biomedical sensor node forwards the sensed data to the destination node by searching for the

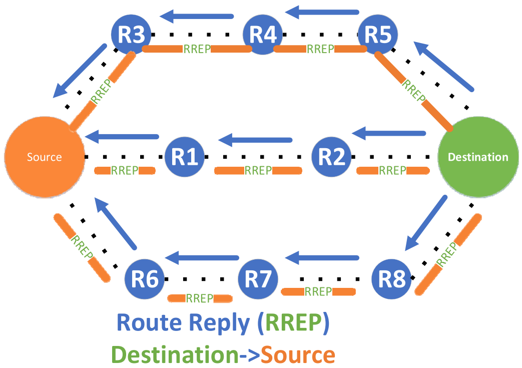

FIGURE 3. Hello packet (Route reply packet).

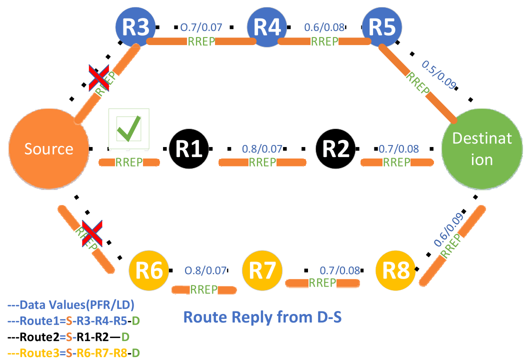

FIGURE 4. Route Selection using PLQE.

existing route in their routing table, if such route exists and satisfying the QoS constraint such as link reliability, link delay, and probability of link connectivity then the packets are forwarded on that route. Otherwise, the source node broadcast the customized RREQ to their neighboring node as shown in the Figure 2. Similarly, the intermediate relay node also looks for the route in their routing table and acknowledges the request if such route to the destination node exists. Otherwise, the request is rebroadcasted to the downstream until it reaches the destination node. Finally, the destination node unicast the RREP packet along the reverse route, where each intermediate relay node updates the RREP packet. The source node at the end receives multiple route reply packet (RREP) and compute the cost function. However, the route satisfying all the constraints is selected for forwarding the data packets as shown in the Figure 4.

The Algorithm describes the reliable route selection procedure of the PLQE scheme.

PLQE-Route Discovery Phase

1: *Input:* $LinkDelay_{i,j}$, $LRF_{i,j}$, $LPF(t)_{i,j}$

2: *Output: Linki,j, Relibale QoS – aware optimal link meets requirements of cost function*

3: *Begin:*

Initialize Route Discovery Phase

/Whether this is route meets the requirements to destination

4: *If (such route exists) then*

Forward data packets

5: *Else*

6: *Call procedure Relibale_RREQ_Proc*

7: *end if*

8: *end proc*

9: *procedure Relibale_RREQ_Proc*

10: *initialize RREQ packets*

11: *RREQ ←– – – – – – – – – – Network Diameter*

12: *Set Nodecurr ←– – – – – – This Node*

13: *Set Nodeprev ←– – – – – – &*

14: *Broadcast RREQ packets to next node/downstream nodes*

15: *Nodeprev ←– – – – – – – – Nodecurr*

16: *Nodecurr ←– – – – – – – – – Current Node*

17: *If Node this – node = Destination_Node then*

18: *Call procedure Reliable _RREP_Proc*

19: *end if*

20: *end proc*

21: *Procedure Reliable_RREP_Proc*

22: *Initialize RREP Packet*

23: *Set LRFthreshhold ←– – – – – – –*

24: *Set PFR ←– – – – – Packet Forwarding Ratio*

25: *Set* $LinkDelay_{i,j}$ *←– – – – – Delay for each link*

26: *Set Link_Reliability ←– – – – Link Reliability*

27: *RREPlink_delay ←– – –&, RREPpfr ←– – – – –&*

28: *Unicast RREP packet to upstream nodes*

29: *Nodeprev ← – Nodecurr*

30: *Nodecurr ← – This Node*

31: *Compute the* $Link_{Delay}$, $Link_{Reliability}$ *and LRF in the Network Diameter at time t*

32: *Link_Reliability*

33: $linkR_{i,j} = (1-\gamma)\, linkR_{i,j} + \gamma \times \left(\frac{TPR_{i,j}}{TPT_{i,j}}\right)$

34: *Link_Delay*

35: $Link\_Delay_{i,j} = (1-\omega) \times Link\_Delay_{i,j}^{t-1} + \omega \times Link\_Delay_{i,j}$

36: *Compute The* $LRF_{i,j}$

37: $LRF_{i,j} = linkR_{i,j} \times \left(\frac{1}{Link_{Delay_{i,j}}}\right)$

38: *If* $LRF_{i,j} \geq LRFthreshhold$ *then*

39: *Compute the Probability of the link connection Reliability*

40: $linkR_{i,j}^{connected} = (1-\alpha)\, linkR_{i,j} + \alpha \times \left(\frac{TPR_{i,j}}{TPT_{i,j}}\right)$

41: *if link* $R_{i,j}$ *is connected*

42: $linkR_{i,j}^{disconnected} = \alpha \times \left(\frac{TPR_{i,j}}{TPT_{i,j}}\right)$

43: *if* $linkR_{i,j}$ *is disconnected*

44: $\alpha_{i,j}^{curr} = \sum_{t}^{t-Window} LinkR_{i,j} \Big/ Window$

45: $LPF = \frac{LRF_{Connected}+1}{(LRF_{Connected}+1)+(LRF_{disconnected}+1)}$

46: *else call Relibale_RREQ_Proc*

47: *elseif Nodecurr = SourceNode then*

48: *Compute the route cost function from the* $LRF_{i,j}$, $LPF(t)$

49: $RCF = LRF_{i,j} + LPF(t)_{i,j}$

50: *If RCFcurr < RCFprev then*

TABLE 2. Simulation parameters.

Parameters	Values
Simulation time	1000s
Area	2m x 2m
Window length W(t)	15s
γ	0.4
ω	0.2
Transport layer protocol	UDP
MAC protocol	IEEE 802.15.4
Routing protocols	PLQE, MCARMR, ERRS
No. of sensor nodes	5
No. of relay nodes	10
No. of the sink node	1
Packet size	100 bytes
Traffic type	CBR
Traffic load	50 Kbps – 250 Kbps

51: *Update the routing table RCFcurr for the route in the cache*
52: *End if*
53: *Update RREPlinkdelay, RREPlr, RREPlrf*
54: *End procedure Reliable_RREP_Proc*
55: *end*

IV. SIMULATION AND RESULTS DISCUSSIONS

The performance of the scheme is evaluated under different network configuration such as varying data rates in terms of various performance metric against well-known QoS Aware Routing protocols e.g., MCARMR, ERRS. The network nodes in our scheme are classified as normal sensor nodes and relay nodes. The sensor nodes continuously record human physiological attributes and forward this recorded information via intermediate relay nodes to the sink. Relay node perform dedicated task of Packet forwarding received from normal sensing node.

The network simulator NS-2 has been used to evaluate the performance of the proposed scheme. Table-2 describes the different simulation parameters which have been used in the simulation.

To analyze the effects of network partitioning, we made a network of 16 nodes placed at different position on the human body and a pre-determined sequence of body movement such as standing, sitting, sleeping, running and walking has been carried out and the time for each body posture is set to 200ms. Whereas, the results are evaluated in terms of network partitioning and packet delivery, delay as shown in Figures 4 and 5, respectively.

It can be observed that each body posture significantly affects the overall performance of the network in terms of average number of route breakages. Consequently, a high number of control packets are required to be forwarded for reestablishing the route. Similarly, average delay per packet is also increased due to, frequent route maintenance calls, interferences and excessive number of retransmissions that also increase/affecting the network routing load.

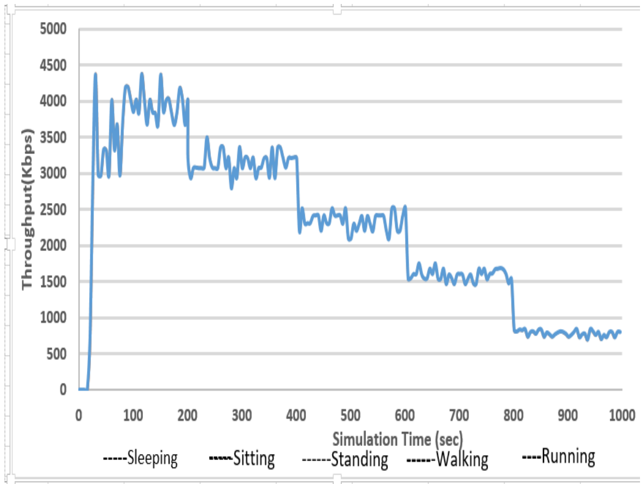

FIGURE 5. Instantaneous throughput at different body positions.

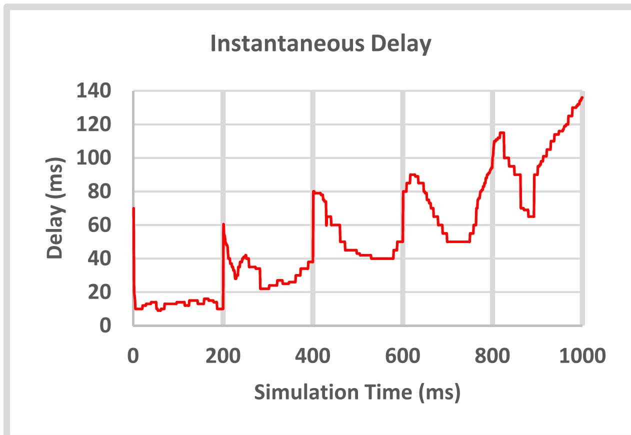

FIGURE 6. Instantaneous delay at different body positions.

The performance of the proposed scheme is evaluated with the state-of-the-art QoS-aware routing schemes MCARMR, ERRS in terms of end-to-end delay, throughput, route stability, and normalized routing load under varying data rates. Different data rate/traffic load are used to analyze the performance of the PLQE with respect to postural body movement and its impact on the route stability.

Figure 7: shows the comparative analysis of proposed scheme PLQE against MCARMR and ERRS in terms of average end to end delay.

The substantial increase in the end-to-end delay can be experienced in MCARMR, ERRS in the state of postural body movements due to frequent route breakages and increased number of route discovery calls.

Figure 8: shows that proposed scheme PLQE due to high route stability minimizes the packet retransmission and improves the transmission of routing packets, thereby

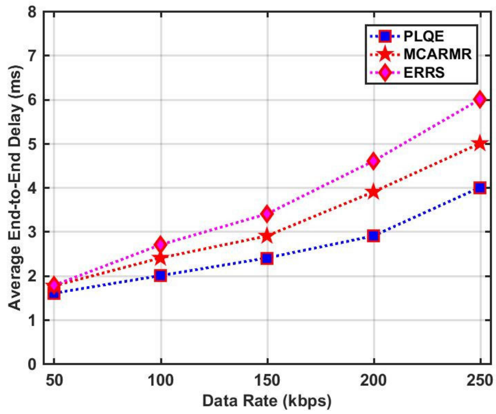

FIGURE 7. Analysis of average end-to-end delay.

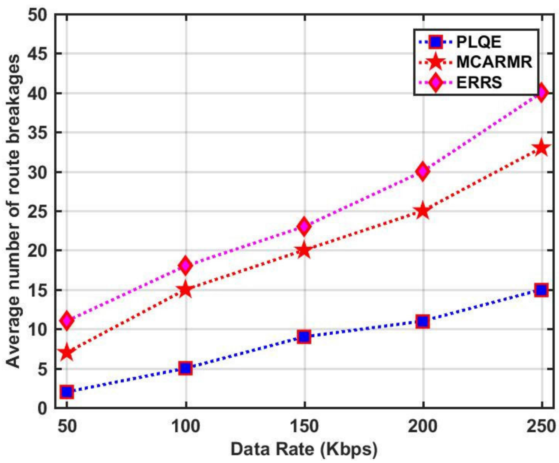

FIGURE 8. Analysis of average number of route breakages.

showing better performance in term of route stability which decreases the route breakages. As shown in figure 8, the proposed scheme generates a smaller number of route breakages as compared to its counterparts because PLQE makes more coherent decision while establishing link between source and destination.

Figure 9: exhibits the lifetime of a route established between source and destination at varying data rate. Route lifetime describes how long a link is connected between source and destination before the route breakage is called. As shown in figure 9: it is observed that the proposed scheme outperforms its existing compared schemes, due to incorporation of Link Prediction Factor in selection of efficient link which improves the overall lifetime/connectivity as compared to the existing schemes.

Figure 10: Describes the results for the throughput against compared schemes. The throughput performance of the PLQE is significantly better than the compared schemes due to the incorporation of link reliability factor, which helps in determining the most reliable and stable routes. On the contrary, the compared schemes highly rely on shortest hop count metric and available energy resources. Therefore, it can

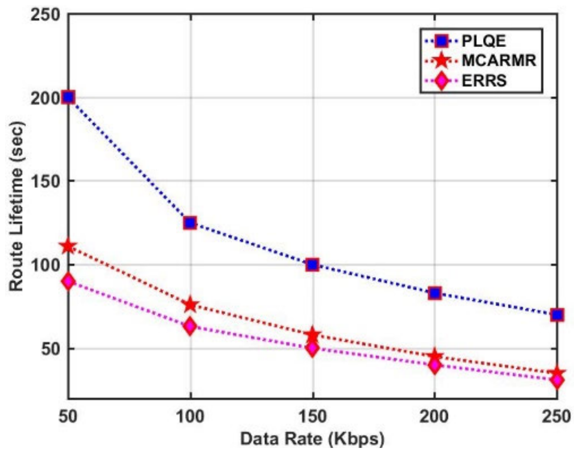

FIGURE 9. Analysis of route lifetime.

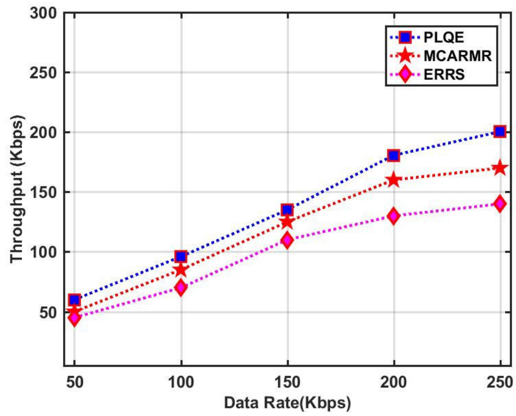

FIGURE 10. Analysis of throughput.

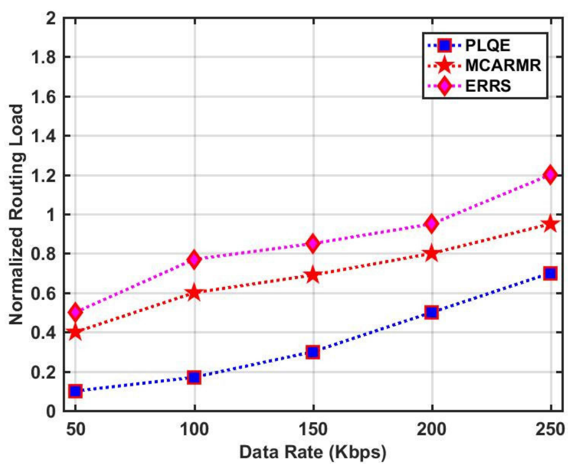

FIGURE 11. Analysis of normalized routing load.

be observed that at low data rate all the schemes depict similar performance. However, at higher data rate throughput performance of compared scheme starts declining while PLQE shows improved throughput.

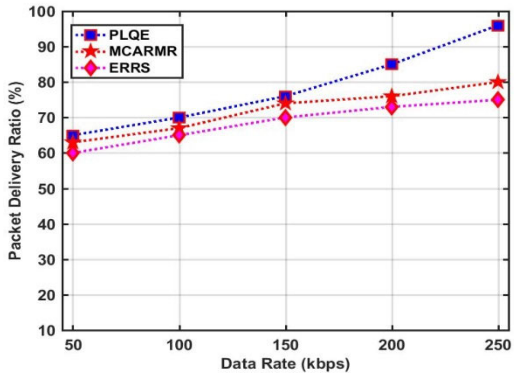

FIGURE 12. **Analysis of packet delivery ratio.**

Figure 11: shows the performance of routing load at varying data rate. The routing load of the proposed scheme is significantly lower than the compared schemes due to the fact that the prosed scheme incorporates link quality and link reliability while establishing end to end routes. Therefore, incurring less number of route breakages which ultimately require fewer number of control packets retransmissions. Whereas, the emphases of the compared schemes is only on energy efficiency and hop count. Therefore, these scheme leads into the selection of unstable routes which suffers high overhead due to excessive flow of control packets.

Figure 12: shows the packet delivery ratio at different data rates. It can be observed from the graph that PLQE and others performs similar at the lower data rates. However, when data rate is increased along with node mobility, the packet delivery ratio of the compared schemes MCARMR and ERRS significantly drops due to high congestions and frequent route breakages.

V. CONCLUSION

In this research work, we propose a Predicting Link Quality Estimation (PLQE) protocol for WBAN that addresses the challenges faced by the existing QoS-aware routing protocol for Wireless Body Area Network (WBANs), in pursuit of postural body movements. Due to postural body movements the link between the nodes frequently disconnects thereby results in poor network performance in terms of throughput, end-to-end delay and routing load. Incorporating link quality/link reliability (LRF) along with expected probability (EP) and link delay estimation (LDE) with QoS-aware routing protocol exhibits in the selection of optimal route which significantly improves the network performance. We compared the proposed PLQE against state of the art-routing schemes and it is observed that the proposed scheme significantly performs better than the compared schemes in terms of throughput, end-to-end delay and normalized routing load. In future, we aim to customize this work by incorporating energy to maximize the network lifetime along with packet classification.

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