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A Comprehensive Survey of QoS-Aware Routing Protocols in Wireless Body Area Networks

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Abstract: Recent developments in wireless communications, MicroElectroMechanical Systems (MEMS) technology and integrated circuits have enabled low-power, intelligent, miniaturized, invasive/non-invasive micro sensor nodes strategically placed in or around the human body which forms Wireless Body Area Networks (WBANS) to be used in various applications including remote health monitoring. Due to inherent issues and specific challenges, routing protocols designed for Mobile Adhoc Networks (MANETs) and Wireless Sensor Networks (WSNs) are not applicable to WBANs. QoS-Aware Routing protocols mainly provide a modular approach by presenting separate modules for different QoS metrics that operate in coordination with each other. These approaches aim at providing higher reliability, lower end-to-end delay and higher packet delivery ratio. In this paper various issues and challenges in pursuit of effective QoS-Aware routing are identified and detailed literature survey of the various existing QoS-aware routing protocols, their strengths and weaknesses are discussed.

Keywords: Wireless Body Area Networks, Wireless Sensor Networks, Mobile Adhoc Networks, Quality-of-Service (QoS)-Aware Routing Protocols, Bio-Medical Sensors (BMSs).

I. INTRODUCTION

Wireless Body Area Networks (WBANs) have been receiving more and more attention in academia and industry in recent years, especially under the impending healthcare crisis and due to the availability of much less expensive biomedical sensors (BMSs) with certain computation and communication capabilities. The primary target applications of BSN research, so far, are medical healthcare services, addressing the weaknesses of traditional patient data collection system, such as imprecision (qualitative observation) and undersampling (infrequent assessment) [1, 2]. BSNs can offer a paradigm shift from managing illness to proactively managing wellness by focusing on prevention and early detection/treatment of diseases, thereby reducing healthcare costs. They can capture accurate and quantitative data from a variety of sensors (e.g., temperature, blood pressure, heart rate, electrocardiogram (ECG), etc.) for longer time periods. BSNs with real-time sensing capability would also help in protecting those exposed to potentially life-threatening environments, including soldiers, first responders, and deep-sea and space explorers [3]. Therefore, on-time and reliable data delivery to the control center is very important for BSN applications.

Numerous routing protocols have been designed for Adhoc networks [4] and WSNs [5]. WBANs are similar to MANETs in terms of the moving topology with group-based movement rather than node-based movement [6]. However, WBANs have more strict energy constraints in terms of transmit power compared to traditional sensor and Ad Hoc networks as node replacements particularly for implant nodes can be quite uncomfortable and might require surgery in some scenarios. Therefore, it is crucial for WBANs to have a longer network lifetime to avoid constant recharging and replacement of nodes attached to a person. Additionally, a WBAN has more frequent topology changes and a higher moving speed, whilst a WSN has static or low mobility scenarios [6]. Due to the aforementioned issues and specific WBANs challenges, the routing protocols designed for MANETs and WSNs are not applicable to WBANs [7].

The Quality-of-Service (QoS) provisioning in WBANs is a challenging task, mainly due to two reasons. First, the dynamic network topology, time-varying wireless channel and scarcity of node energy, computation power and channel bandwidth pose challenges on the design of QoS support schemes in BSNs. Second, there exist wide variations in data generation rate and delay- and loss-tolerances amongst the data packets generated by different types of BMSs [2]. For example, some low data rate BMSs (e.g., heartbeat, blood pressure, electroencephalogram (EEG) sensors) may generate very time-critical data packets, which must be delivered at the destination sink within a guaranteed end-to-end delay deadline and data packets from some of these sensors might also require high reliability. In contrast, some high data rate BMSs (e.g., streaming of ECG signals) may allow a certain percentage of packet losses. Therefore, a scalable solution with QoS-aware routing that can provide a clear differentiation in route selection between data packets with QoS requirements is greatly required for WBANs.

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II. ARCHITECTURE OF WIRELESS BODY AREA NETWORKS

The architecture of WBANs can divided into following three different tiers [8], as shown in Fig. 1:

Tier 1 - Intra-WBAN: In Intra-WBAN, the on-body and/or implanted bio-medical sensor nodes send the sensed data to the coordinator or base station. In Tier-1, variable sensors are used to forward body signals to a Personal Server (PS), located in Tier-1. The processed physiological data is then transmitted to an access point in Tier-2.

Tier 2—Inter-WBANs: In Inter-WBAN, coordinators or base stations send the received data to the sink(s) after required data processing and data aggregation. Tier-2 communication aims to interconnect WBANs with various networks, which can easily be accessed in daily life as well as cellular networks and the Internet. The more technologies supported by a WBAN the easier for them to be integrated within applications.

Tier 3—Extra-WBAN: In this tier the sink(s) send the collected data to the remote medical center and/or any other destination via regular infrastructure such as internet. The design of this communication tier is for use in metropolitan areas. A gateway such as a PDA can be used to bridge the connection between Tier-2 and this tier; in essence from the Internet to the Medical Server (MS) in a specific application.

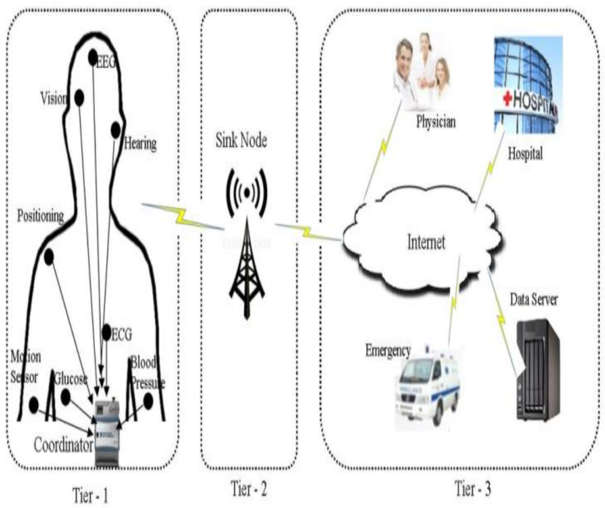

Fig. 1. Architecture of Wireless Body Area Networks

III. ISSUES AND CHALLENGES FOR ROUTING IN WBANS

Design and development of efficient routing protocols for WBANs is a challenging job due to their unique requirements and specific characteristics [8]. In the following sections, we discuss the routing issues and challenges of WBANs.

A. Network Topology

Network topology describes the logical way in which the different communicating devices communicate with each other. Efficient routing protocol development requires a proper network topology as it effects the overall performance of the communication system [7]. Proper network topology is very important for WBANs because of the energy constraint, body postural movements, heterogeneous nature of the sensors and short transmission range. Some researchers use single hop communication, where each node communicates directly with the destination, while others use cluster based multi-hop routing.

B. Topological Partitioning

The network topology of WBANs often faces the problem of disconnection or partitioning because of body postural movements and short range transmissions. Different researchers have tried to solve the problem of disconnection and partitioning in different ways. For example, the authors of [9] use Line-of-Sight (LoS) and None-Line-of-Sight (NLoS) communication, while the authors of [10-12] use store-and-forward routing to solve this problem. Therefore, the proposed routing protocols should take care of the different topological changes.

C. Energy Efficiency

Energy efficiency covers both the local energy consumption of nodes and the overall network lifetime. For implanted bio-medical sensors, it is not possible to replace the power source, while for wearable bio-medical sensors replacing the batteries might lead to discomfort of patients. Therefore, both energy consumption and network lifetime are major challenges in wireless body sensor networks. Communication among the sensor nodes consumes more energy as compared to sensing and processing [13]. Any proposed algorithm should be able to use different paths and/or nodes to send the data instead of depending on a single path and/or node preventing the consumption of total energy of that specific node(s). In [11], the authors define the network life as the time from which the network starts till the time when the first node of the network expires. The network life is very much important in WBANs because of energy constraints and the impossibility of replacing the energy source for implanted sensors.

D. Limited Resources

Along with limited energy source, WBANs also have short Radio Frequency (RF) transmission range, poor computation capabilities, limited storage capacity, as well as low bandwidth—which may keep on changing due to noise and other interferences [7]. Researchers must be aware of the limited resources when designing routing protocols for WBANs.

E. Quality of Service (QoS)

In WBANs different types of data require different quality of services as it deals with vital signs of the human body.

The authors in [14, 15] have classified the patient data into critical data (like EEG, ECG etc.), delay sensitive data (for example video streaming), reliability-sensitive data (like vital signals monitoring respiration monitor, and PH monitor) and ordinary data (for example temperature, heartbeat, etc.). The other data-centric applications of WSNs also cannot tolerate latency and/or any loss of packets [16]. The proposed protocols need to be aware of the different types of quality of service required for different types of patients' vital sign- related data.

F. Radiation Absorption and Overheating
The two sources of temperature rise of a node are antenna radiation absorption and power consumption of node circuitry [17], which will affect the heat sensitive organs of the human body [17] and may damage some tissues [18]. Researchers should carefully develop the routing protocols for WBANs to keep human tissues safe from any overheating caused by radiation absorption and operation of the implanted bio-medical sensor nodes.

G. Heterogeneous Environment
Different types of sensor nodes are required to sense and monitor the different health parameters of human beings, which may also differ in computation, storage capabilities and energy consumption [7]. Thus the heterogeneous nature of WBANs also imposes some more challenges.

H. Path Loss
Path loss or path attenuation is a measure of the decline in power density of an electromagnetic wave as it propagates through the wireless medium. It is the ratio of the power of transmitted to received signals [19]. The wireless communication between the implanted sensor nodes is through the human body, where the path loss exponent varies from four to seven [20], which are very high as compared to the free space, where it is two. The researcher must consider the path loss while designing routing protocols for wireless body sensor networks.

I. Security and Privacy
Like other applications of WSNs, security and privacy are among the basic requirements of WBANs. It is impossible to apply the conventional techniques of security and privacy because of the low energy availability, limited resources and other constraints [21]. Researchers should take care of the privacy and security of the patient's data while designing routing protocols for WBANs.

IV. ARCHITECTURE OF QOS-AWARE ROUTING SERVICE FRAMEWORK

A cross-layered modular based QoS-aware routing service framework proposed in [22] aims to provide priority-based routing services and user specific QoS support. The QoS metrics used to determine the routes are: user specific QoS requirements, wireless channel status, priority level of the data packets and willingness of the sensor nodes to behave as a router. The main functions of this framework are: QoS-aware route establishment and maintenance, prioritized packet routing, Application Programming Interfaces (APIs), feedback on network condition to the user application(s) and finally adaptive network traffic balancing. As shown in Fig. 2, redrawn from [22], the architecture of this routing service framework has four modules: Application Programming Interfaces (APIs) module, routing service module, packet queuing and schedule module and system information repository module.

The APIs module of [22] acts as an interface between the user application and the routing service module. The four sub-modules of the APIs module are: QoS metrics selection, packet sending/receiving, packet priority level setting and admission control and service level control. The QoS metrics selection sub-module includes end-to-end delay, delivery ratio and power consumption. The packet sending/receiving sub-module is responsible for receiving the sensed data from the user application and sending it to sink node or any other node. The packet priority level setting sub-module is responsible for setting the priority level of the received data packets. Finally, the admission control and service level sub-module control returns feedback on the network conditions to the user application.

The second module (routing service module) is responsible for constructing and maintaining the routing table with the help of the receiving neighbour's status information. All data packets, including both the control and data packets, are categorized into eight different priority levels, where the control packets have more priority as compared to the data packets. The node's buffer will reach a pre-assigned threshold value if the sensor node is not able to access the wireless channel due to network congestion.

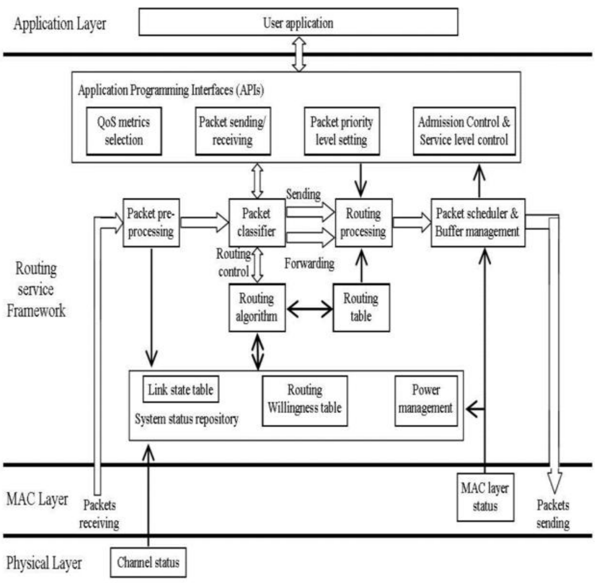

Fig. 2. Architecture of QoS-aware routing service framework [22]

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In such cases the packet queuing and scheduling module will inform the user application to reduce service level and willingness level to be a router. The System Information Repository module maintains two tables: link state table and willingness table. The link state table provides the link state of each node, including link quality, end-to-end delay, communication bandwidth, and average packet delivery ratio, while the willingness table contains the information for each node to behave as a router [23].

V. MAJOR QOS-AWARE ROUTING PROTOCOLS

During last decade, researchers have proposed different QoS-Aware routing protocols. Major QoS-Aware routing algorithms are shown in Fig. 3. The QoS-aware routing protocols are modular-based protocols and use different modules for different types of QoS metrics. The design of these protocols is a challenging job, due to the complexity of considering different modules for different QoS metrics and coordination between these modules. In the following sections different QoS-aware routing protocols for WBANs are discussed.

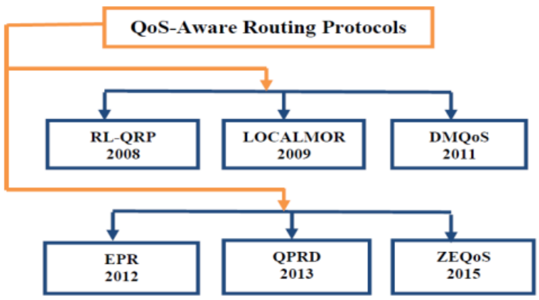

Fig. 3. Major QoS-Aware Routing Protocols

A. Reinforcement Learning based Routing Protocol with QoS Support (RL-QRP)

In [24], the authors proposed a reinforcement learning-based routing protocol with QoS support, using geographic information and a distributed Q-learning algorithm where the optimal routes can be found through experiences and rewards. The tiny bio-medical sensor nodes, implanted inside the body or attached with the body, forward the sensed data to sink nodes deployed at fixed positions. After collecting the data packets from the bio-medical sensor nodes, the sink node(s) forward them to the medical server for further real-time monitoring and diagnosis.

In this scheme the packet delivery ratio and end-to-end delay are the main QoS metrics. In the Q-learning algorithm, each sensor node receives a reward, either positive or negative, after forwarding a data packet to its neighbour. The reward along with the expected future reward, updates the Q-value of the sensor node, which will be used for the future decisions. Sensor nodes exchange the Q-values with its one-hop neighbours to learn about their optimal routes. The sensor nodes can use the neighbour sensor nodes Q-value information to predict the expected future reward. Each sensor node considers its Q-values list as its routing table.

The authors of this scheme use Random Waypoint Mobility Model (RWMM) for the mobile sensor nodes, where the sensor nodes can only move to the chosen random destinations and will stay there for a predefined time. RL-QRP uses the neighbour nodes' Q-values and geographic information to find out the optimal routes while energy which is one of the major constraints of wireless sensor networks, is not considered at all [23].

B. New QoS and Geographic Routing (LOCALMOR)

A distributed QoS-aware module-based protocol is proposed in [14], to help the system to meet different QoS requirements based on the nature of data (energy efficiency, reliability and latency). The proposed mechanism divides the patient's data into: Regular Traffic, Reliability-Sensitive Traffic, Delay-Sensitive Traffic, and Critical Traffic. The coordinator, which they called a body sensor mote collects the raw data from the bio-medical sensor nodes and after required data processing, and data aggregation, sends it to the sink node(s). Each (fixed) sink node may cover more than one patient (fixed and/or mobile). The proposed protocol has two kinds of sink nodes for every patient: Primary Sink and Secondary Sink and each sink receive a separate copy of each message.

In their scheme, they use four different modules: power efficiency module, reliability-sensitive module, delay-sensitive module, and neighbour manager module. The power efficiency module is responsible for the regular traffic data packets and may be used by other modules to optimize the data-related metrics.

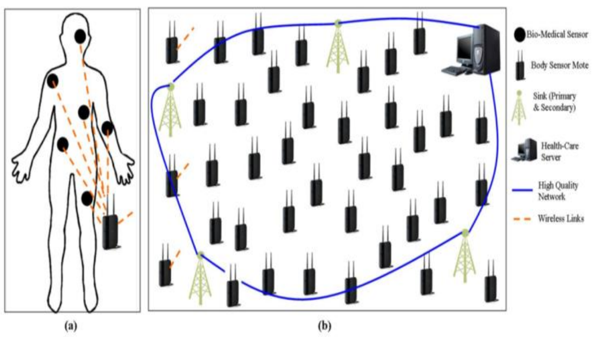

Fig. 4. System architecture of LOCALMOR, (a) On-body network, (b) In-hospital network [23]

Power efficiency can be achieved by considering both the transmission power and residual energy using Min-Max Approach discussed in [25]. The reliability drawn data packets use the reliability-sensitive module to achieve the required reliability by sending a copy of each data packet to both the primary and secondary sinks. The delay-sensitive module is used to route the latency sensitive data packets by using Pocket Velocity Approach given in [26]. The neighbour manager module is responsible to send/receive the Hello packets and update neighbours'

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information. The system architecture of the proposed protocol is shown in Fig. 4.

C. Data-Centric Multi-Objectives QoS-Aware Routing (DMQoS)

DMQoS proposed in [15] is a module-based multi-objective QoS-aware routing protocol that focuses on meeting the QoS requirements for different categories of the generated data. In DMQoS, the data packets are divided into four classes: Ordinary Data Packets (ODs), Reliability-Driven Data Packets (RPs), Delay-Driven Data Packets (DPs) and Critical Data Packets (CPs). The bio-medical sensor nodes send the sensed data towards the coordinator, which they called as body sensor mote in raw form. The body sensor mote is a central node acting as a cluster head and having less constraint in terms of energy and computation capability as compared to bio-medical sensor nodes.

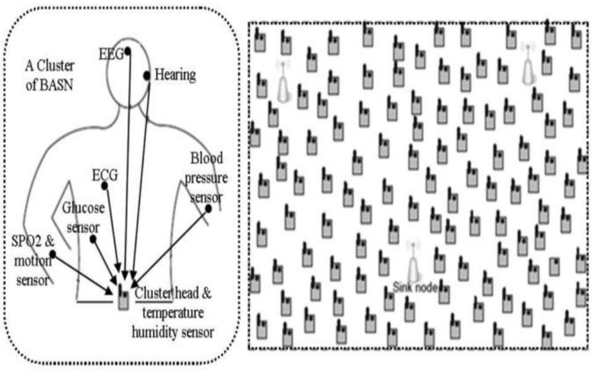

Fig. 5. Network architecture for DMQoS [15]

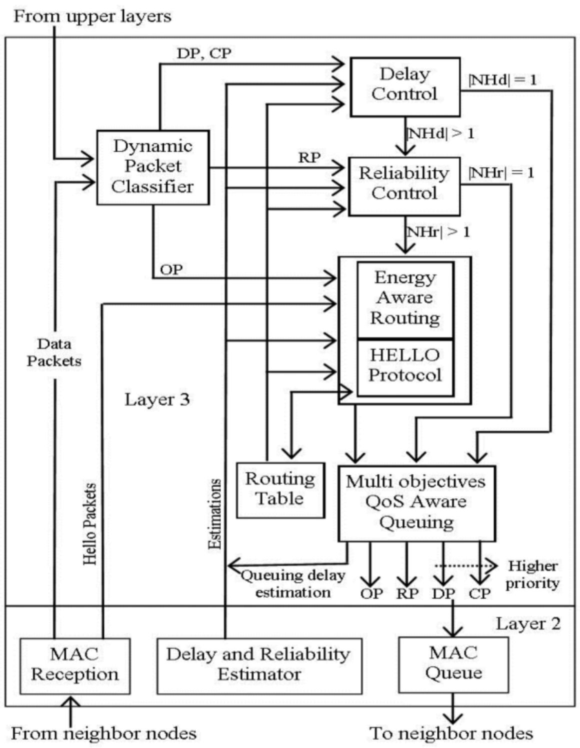

Fig. 6. Routing architecture for DMQoS [15]

The network architecture of the DMQoS is shown in Fig. 5, redrawn from [26]. After the required data processing and aggregation, the body sensor mote forwards the data towards the sink in multi-hop fashion using other body sensor motes. The routing architecture of DMQoS [15] consists of five modules: dynamic packet classifier, energy- ware geographic forwarding module, reliability control module, delay control module, and multi-objectives QoS-aware queuing module, as shown in Fig. 6, redrawn from [15]. The dynamic packet classifier receives the data packets from the neighbour node or the upper layers then classifies them into one of the four aforementioned categories, and forwards them to their respective module on a First-Come-First-Serve (FCFS) basis. The energy-aware geographic forwarding module decides the next hop node with least distance and comparatively high residual energy using multi-objective Lexicographic Optimization (LO) discussed in [27].

The reliability control module determines the next hop with highest reliability, while the delay control module finds the next hop having least delay. The QoS-aware queuing module is responsible for forwarding the received data packet to one of the four queues based on the assigned priorities, as shown in Fig. 6, redrawn from [15]. The use of the multi-objective LO approach to manage the trade-off between the geographic information and residual energy ensures a homogenous energy consumption rate for all nodes.

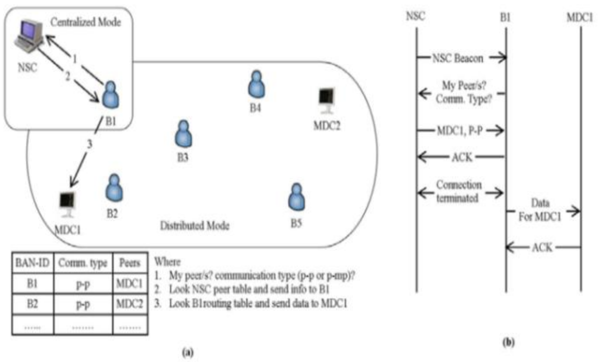

Fig. 7. (a) EPR framework, (b) Timing diagram [28]

D. Energy-Aware Peering Routing (EPR)

In [28] the authors presented an Energy-aware Peering Routing protocol aimed at reducing the network traffic and the energy consumption, based on both centralized and distributed approaches. It is designed to display the patients' real-time data inside a hospital. In this scheme, they have 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). NCS is a centralized device with continuous power supply, which keeps the peering and type of communication information of all BANCs. MDCs are display devices with replaceable power supplies while the BANCs with limited energy are responsible for collecting the data from the tiny bio-medical sensor nodes and forward it towards the corresponding MDC(s) after required processing. Initially, the BANC will try to access the NSC to get the peering and communication type (p-p or p-mp) information of MDC(s). After getting the required information, the BANC will discover the corresponding MDC(s) and display the data, as shown in Fig. 7, redrawn from [28]. The energy efficiency is achieved by controlling the broadcasting mechanism of the hello packets. At the same time the selection of next hop node is based on the aforementioned device types, geographic information and residual energy of the neighbour [23].

E. QoS-Aware Peering Routing for Delay-Sensitive Data (QPRD)

In [29] the authors proposed QPRD, which intends to improve the EPR discussed in [28] by classifying the patients' data packets into two categories: Ordinary Packets (OP) and Delay Sensitive Packets (DSP). It uses the same framework used by EPR [28]. As shown in Fig. 8, redrawn from [30], the routing architecture of the QPRD is divided into seven modules: MAC receiver, delay module, packet classifier, hello protocol module, routing service module, QoS-aware queuing module, and MAC transmitter. The data packets from the other nodes are received by the MAC receiver module, while their classification as hello packets and data packets is done at the packet classifier module.

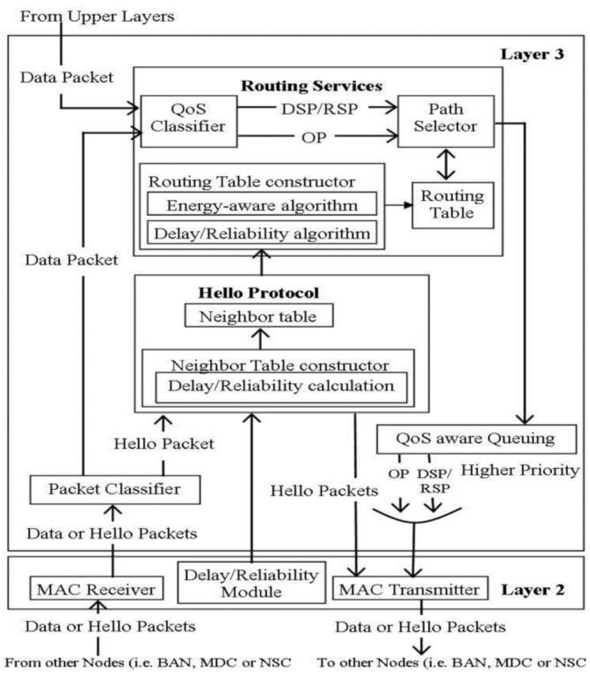

Fig. 8. Routing architecture for QPRD

The delay module monitors the different types of delays and forwards the results to the network layer to find out the node delay. The hello protocol module is responsible for sending/receiving the hello packets. The routing service module receives the data packets from the upper layers and packet classifier, categorizes them as ordinary packets or delay sensitive packets, and chooses the best path for each category. QoS-aware queuing module forwards the received data packets to their corresponding queue while the MAC transmitter module store the received data and hello packets in a queue on a First-Come-First-Serve (FCFS) manner and transmits them using the CSMA/CA approach.

F. A New Energy and QoS-Aware Routing Protocol (ZEQoS)

ZEQoS proposed in [31] introduces two main modules (MAC layer and network layer) and three algorithms (neighbour table constructor, routing table constructor, and path selector). To handle ordinary packets (OPs), delay-sensitive packets (DSPs), and reliability-sensitive packets (RSPs), the new mechanism first calculates the communication costs, end-to-end path delays, and end-to-end path reliabilities of all possible paths from a source to destination. The protocol then selects the best possible path(s) for OPs, RSPs, and DSPs by considering their QoS requirements. The ZEQoS also offers better performance in terms of higher throughput, less packets dropped on MAC and network layers, and lower network traffic than comparable protocols including DMQoS.

The proposed ZEQoS routing protocol provides a mechanism with the help of neighbor table constructor algorithm, routing table constructor algorithm, and path selector algorithm to calculate the communication costs, end-to-end path delays, and end-to-end path reliabilities of all possible paths from a source to destination and then decides on the best possible path(s) with the consideration of QoS requirement of the OPs, RSPs, and DSPs. The simulation results showed that the ZEQoS had in excess of 81% and 75% throughput for all classes of packets in fixed and variable cases, respectively, when offeredtraffic load of 9.5K to 95K packets was used. The simulation results showed that the ZEQoS had superior performance in excess of 84% throughput when compared with DMQoS and noRouting provides 36% and 65%, respectively.

VI. COMPARATIVE STUDY OF QOS-AWARE ROUTING PROTOCOLS

RL-QRP performance is bad at the start due to learning process but becoming better with the passage of time. In all data packets are blindly disseminated towards both the primary and secondary sinks. The network traffic increases due to sending too many duplicate data packets. In DMQoS performance decreases due to increase in the network throughput and use of the LO technique to optimize the trade-off between geographic information and residual energy is not an efficient way. EPR performance is better to reduce the energy consumption and network traffic as compared to DMQoS. QPRD performs well to decrease the packet delivery delay as compared to DMQoS at high network throughput. ZEQoS considers network of limited size and it concentrates more on MAC layer entities.

TABLE I COMPARISION OF QOS-AWARE ROUTING PROTOCOLS

Protocol	Goal	Network Size	Network Throughput	Mobility	Delay	PDR	Energy Req.
RL-QRP (2008)	To achieve high packet delivery ratio and low end-to-end delay	Small	Low	Yes	High	High	N/A
LOCALMOR (2009)	To provide QoS support based on nature of Data	Medium	N/A	Yes	Low	High	High
DMQoS (2011)	To provide Data Centric QoS support	Large	Very Low	Yes	Low	High	Medium
EPR (2012)	To reduce network traffic and energy consumption	Very Small	High	Yes	N/A	High	Low
QPRD (2013)	To reduce end-to-end delay	Very Small	High	Yes	Very Low	High	Low
ZEQoS (2015)	To achieve energy, end-to-end latency and reliability requirements	Large	Medium	Yes	Medium	High	Medium

VII. CONCLUSION

In this paper six major QoS-Aware routing protocols proposed in the last decade for WBANs are comprehensively studied and analyzed. It is observed that all the protocols perform well in limited domains and network sizes. No protocol considers optimal design of all the QoS requirements considered in the literature. The protocols aim at optimizing only a small subset of parameters, so any fully fledged WBAN application aiming to provide optimal services with all the QoS parameters cannot incorporate these protocols. These protocols can only be included in limited applications. These protocols are suitable for specific architectures of WBAN, not for general adhoc architectures. It is also observed that Intra-body communications which are more resource constrained are not effectively dealt so far. The paper provides future research directions in designing robust QoS provisions for WBANs.

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