International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 10 • Issue 1 pp. 64-69 Jan 2018-June 2018 www.csjournals.com

Recent trends in state-of-art QoS-Based Routing Protocols for Wireless Body Area Networks (WBANs)

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Abstract: WBAN is an emerging technology widely used for healthcare applications. It is a boon for countries that have acute shortage of medical infrastructure. It is a potentially vast research area garnering attention from academicians and researchers. QoS along with energy efficiency is a critical requirement in WBANs where delayed or unreliable information might cost a human life. Routing protocol design and development for WBANs is one of the major areas requiring attention as protocols designed for WSNs are not suited owing to different requirements. This paper provides an exhaustive survey of state-of-the-art protocols proposed in literature during the last decade in terms of the improvements provided and the shortfalls thereof.

Keywords: WBAN, QoS, Routing, Energy Efficiency, Reliability.

Introduction

Recent concentrated efforts- of researchers, system designers and application developers- are towards development of a new architecture commonly known as Wireless Body Area Network (WBAN) which is a sub-class of wireless sensor networks (WSNs). This new class of healthcare monitoring system owes its development to the merging of wireless technologies, bio-sensors and computing communication protocols. The concept of WBAN is realized by innovative advances on smart, light weight, small size, ultra low power and intelligent devices. In WBANs, special class of medical, smart and tiny sensors are located in, on or near the human body to sense, measure, store and transmit patients physiological data for analysis, investigation, treatment and real time applications.

A Body Area Network is formally defined by IEEE 802.15 Task Group 6 as, "a communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics / personal entertainment and other".[1]

WBAN architecture as shown in figure 1 is divided into three tiers: Intra-WBAN, Inter WBAN and Beyond WBAN. Some existing wireless communication protocols that are used for medical sensor networks include Bluetooth (802.15.1), Bluetooth Low Energy (BLE), ZigBee (802.15.4) and WBAN standard (802.15.6). Quality of Service (QoS) definition is mostly related to application. It encompasses the requirements such as reliability, timeliness etc. that must be attained during the packet transmission from the source to the destination. Quality of Service (QoS) is a mechanism for achieving desired performance by optimizing resource allocation, affirming reliability and enhancing usability of WBANs.

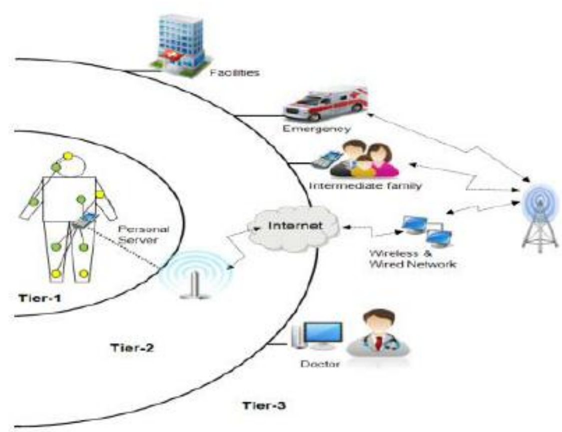

Figure 1: 3-Tier Architecture of WBAN

Academicians are working to identify and correlate QoS parameters and suggest design of new protocols for WBANs. Timeliness, reliability, energy consumption, bandwidth, delay, throughput, latency etc. are some critical attention seeking objectives for QoS protocols. WBAN applications require real-time QoS. The resource constraints limit the scope of supporting these requirements.

Section II of the paper discusses the roadblocks in regards to QoS provisioning in WBANs. The QoS metrics to be kept in mind while designing a QoS-based routing protocol are detailed in section III. An exhaustive discussion of protocols that are QoS based that have been proposed in literature for use in WBANs is provided in Section IV. Section V concludes the paper.

II. Major Challenges to QoS support in WBAN

Meeting QoS requirements in wireless body sensor networks is a difficult task. The major technical challenges for supporting QoS requirements with respect to WBAN applications are:

- Resource limitations: The sensor nodes in WBAN have limited energy, storage and computational capability. Replacing or recharging batteries of sensors is a more difficult task in implanted sensors compared to wearable ones.
- Unpredictable traffic patterns: The real-time data pattern in WBAN depends on the criticality of the patient being monitored.
- Network dynamics: The body postural movements and energy constraint of nodes may cause a change in the network topology.
- Heterogeneous traffic types: Multimedia traffic generation with different data rate and bandwidth is obtained from different sensors but utilize the same link for transmission.
- Packet criticality
- Unbalanced traffic: The protocol must be designed to select alternate nodes from source to destination to prevent depletion of total energy of any particular node thereby enhancing network lifetime.

III. QoS evaluation metrics

Analysis of the various factors affecting QoS, yields the following metrics for consideration while developing the routing protocols for WBAN:

1. Packet delivery ratio (PDR) is determined by the ratio of number packets delivered to the sink and number of packets transmitted and re-transmitted from the source. The value ranges between 0 and 1 and a higher value of PDR is desired.

2. End-to-end delay (E2ED) is the sum of serialization delay (which depends on packet size) plus queueing delay (depends on the load and other parameters) plus processing delay. It is a measure of the average time taken by a data packet to reach the sink from the source node. It should be less than 125 milliseconds in medical applications.

Latency = propagation delay + serialization delay where,

Propagation delay = distance of link (m)/ transmission medium speed (m/s)

Serialization delay= packet size (bits)/data rate (bps)

3. Residual energy: Energy consumption in nodes takes place majorly during data transmission and reception. Some amount of energy is also consumed during data processing, storage and retrieval, which is usually neglected or assumed constant. Residual energy refers to the energy difference between initial energy and consumed energy during the operation of the network.

For node N_i, Residual Energy is:

$E_{res,i}=E_{init,i}- (A_i* (E_{TxElec}+ E_{amp}*D^2)+B_i* E_{RxElec})$ where,

$E_{init,i}$= Initial Energy of nodes N_i

A_i = No. of bits transmitted by node N_i

B_i = No. of bits Received by node N_i

E_{TxElec} = Energy consumed in transmitter antenna

E_{RxElec} = Energy consumed in receiver antenna

E_{amp} = Energy consumed in Amplifier section

D = Distance between nodes N_i and N_j

4. Stability period is the time till all nodes in the network are 'alive'. In other words, it refers to the time before first node is completely drained of power.

5. Network lifetime defines the total operation time of the network until the last node is dead.

6. Path loss is the power difference between the transmitted power at the source node and received power at sink node.

7. Link Utilization function could consist of various parameters as per the requirement metric of the network. Here we consider the Residual energy, queue size and link reliability functions to evaluate the link Utilization function and based on these maximum link Utilization in desired because if it is higher the network will offer high quality of services in terms of parameters like stability, throughput, latency, delay etc. [2]

Link Utilization function will be calculated as:

$C_{ij} = C_E \times (E_{res,} /E_{init,}) + C_Q \times (Q_{empty,} /Q_{total,}) + C_L \times R_{ij}$ where,

C_{ij} = link Utilization value of link between node N_i and N_j

$Q_{empty,}$ = Available Queue size of node N_j

$Q_{total,}$ = total Queue size of node N_j

C_Q &C_E & C_L = constants

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IV. Routing Protocols in WBANs

Routing protocol refers to a set of rules that provide for identification and maintenance of route ensuring reliable and efficient communication between nodes in the network. In [36], authors classify routing protocols in wireless sensor networks into flat, hierarchical and location-based in accordance to the underlying network structure. On protocol operation basis, the classification includes the following categories: multipath-based, query-based, negotiation-based, QoS-based, and coherent-based. Similarly in [9-11, 17, 23-24, 26-27, 32] different classification strategies for routing protocols are proposed. In this paper we provide a survey of state-of-art QoS aware routing protocols for WBANs that exist in literature. The motivation lies in the fact that protocols designed for WSNs are primarily based on energy efficiency. In WBANs however, unlike WSNs, QoS is an important design consideration keeping in view the prioritization of data from varying sources in terms of criticality and delay and loss tolerance in accordance to application i.e., Protocols proposed must be QoS aware. An efficient protocol design that can address the energy efficiency and QoS requirements in WBAN simultaneously is a challenging task [10]. In QoS-based routing protocols, an equilibrium between consumed energy and data quality in terms of QoS metrics such as E2ED, RE, bandwidth, throughput, PDR etc is maintained. QoS Aware Routing Protocols encompass different modules for each metric thereby making it a challenging task to provide correlation between various modules. These protocols optimize performance in terms of high reliability, lower end-to-end delay and high packet delivery ratio. This paper provides a comparison of some recent QoS Aware Protocols in terms of Throughput, Delay, PDR and Energy Consumption of state-of-the-art QoS based routing protocols propounded in literature that are in use in medical applications.

– Reinforcement Learning based Routing Protocol, RL-QRP with QoS support for Biomedical Sensor Networks proposed in [35] uses two dominant QoS metrics: end-to-end delay and packet delivery ratio to find optimal routing policy without maintaining precise network state information. The route is independently evaluated by the sensor node in adherence to the QoS requisites of the data packet using distributed Q-learning algorithm with location information support. At the initialization step, RL-QRP may yield insufficient results owing to exploration and approximation of all available routes and link qualities thereof, but overtime superior results are attained. RL-QRP is well suited for dynamic network but does not achieve comprehensive optimization in large scale networks and does not emphasize on the energy metric.

– In [34], authors propose LOCALMOR- a Localized multi-objective routing for biomedical networks. The data traffic is classified into four brackets: regular traffic, reliability-sensitive traffic, delay-sensitive traffic and critical traffic, on the basis of the required QoS metrics. Four different modules are responsible for handling data according to traffic diversity. In addition, a neighbor manager maintains neighboring table and packet classification. The QoS metrics improved by the proposed protocol are end-to-end delay and packet reception ratio. However, the protocol is unscalable due to blind duplication of all packets towards two sinks which also increases the overhead in transmitting duplicate packets.

– In [33], a Data-Centric Multi-objective QoS-based Routing Protocol, DMQoS aimed to provide a route selection differentiation between four categories of data packets-ordinary, critical, delay driven and reliability driven packets-is proposed. DMQoS tends to improve the overall network performance for WBANs in delay and reliability realms by considering QoS-based routing while maintaining energy cost optimality of the routing path. The DMQoS architecture consisting of five modules, cooperatively rendering enhanced QoS services, implements a localization based routing. The proposed protocol diminishes the operational energy overloads and presents enhanced results for delay-driven packets in respect of E2ED and for reliability-driven packets in respect of the PDR. Confined decisions at each intermediate node without end-to-end path discovery and maintenance allow appropriateness to multiple traffic classes, provide self-adaptation to network dynamics and facilitate scalability to large-scale sensor networks. However, this approach assumes knowledge of node locations which is considerably difficult. Further, the protocol fails to guarantee the required end-to-end latency or the reliability in case of traffic congestion.

– An extension of Energy aware peer routing (EPR) protocol [25] named QoS-aware Peering Routing Protocol for delay sensitive Data, QPRD is proposed in [28]. The seven modules: MAC receiver, delay, packet classifier, Hello protocol, routing service, QoS-aware queuing and MAC transmitter, in the protocol provide a QoS considerate mechanism for best route determination to two data types-ordinary packets and delay-sensitive packets. QPRD provides enhanced transmission rates and diminished comprehensive network traffic load but provides no mechanism for reliability of transmission.

– In [29], authors propose a modified OLSR (Optimized Link State Routing) protocol for WBAN in hospital environment, wherein the selection of Multipoint Relay nodes (MPR) is executed using the delay metric. The modified OLSR outperforms the primary model of OLSR in terms of delay but fails to ensure reliability, an indispensable QoS metric in WBANs.

– In [30], an energy efficient and delay tolerant routing protocol EDSR for WBAN is proposed. An extension of the Dynamic Source Routing (DSR) protocol for multi-patient healthcare monitoring, it aims to reduce the average E2ED and the number of packets lost. In this cluster topology based protocol route building is performed only on-demand by flooding route request packets. The initiating and the terminating time of the route request packet, path election time of the route and trust time for the route are control overheads which are reduced in this protocol. Route discovery process is faster in EDSR in contrast to DSR. The protocol is effective in terms of energy and delay but dependence on the complex clustering process may induce a considerable overhead.

– In [31], authors propose an Energy-Balanced Rate Assignment and Routing Protocol (EBRAR) which performs route selection based on depth and residual energy of sensor nodes. Adaptive resource allocation policy of EBRAR relentlessly conforms to the QoS requirements. Based on the estimated efficacy of different streams, calculated on stream priority along with the cardinality of flows via each sensor node, some streams are put offline thereby improving the overall utility. The EBRAR protocol operation involves four phases and employs a load balancing strategy to increase network lifetime. Periodic rotation of active sensor nodes ensures fairness of energy balance. The proposed protocol shows positive response in respect of energy balance and network lifetime. The mechanism used in EBRAR provides improved monitoring system and performs fairly well in regards to network lifetime and energy balance. However, it depends on continuous availability of sensor nodes and with large number of nodes, duration to achieve the optimal solution to rate assignment problem increases.

– Based on Dijkstra's algorithm, authors in [19], have suggested a global dynamic routing protocol incorporating energy harvesting mechanism from sources such as body heat, direct sunlight and ambient light and airflow. Obtainable energy at all sensor nodes post energy harvesting affects the proposed dynamic link cost function, which changes during each data accumulating round. The dynamic cost function ensures energy efficient routing. Energy harvesting methods permit longstanding operation of WBANs without requiring battery recharge. The protocol works well in respect of energy, but is computationally overloaded.

– In [20], Reliable Proactive Routing Protocol (RPRP) has been proposed which is a proactive, partial multi-hop protocol that selects intermediate nodes on the basis of hop-count parameters and Received Signal Strength Indicator (RSSI). A routing table is maintained at all sensor nodes with two logical multi-hop paths towards the sink. Delay and computation overhead due to multihop approach increase energy consumption and provide shorter network lifetime. Further, path quality assessment in terms of link reliability is not reviewed.

– In [21], the authors propose a stable, increased throughput, multi-hop protocol for link efficiency in WBANs, utilizing a cost function based on maximum residual energy of sensor nodes and the least distance from the sink to warrant energy balance and guaranteed packet delivery. Based on the cost function value computed centrally at the sink for all nodes, each sensor node confirms whether to be assigned as a forwarder node so as to aggregate neighbour's data and forward it to the sink using TDMA. Even though network stability time and PDR to sink are enhanced but path loss requiring packet retransmission is not considered.

– In [8], authors have proposed ZEQoS, a modular integrated energy and QoS-aware routing protocol taking energy consumption, end-to-end latency and reliability demand of WBAN systems into account. The proposed protocol combines two previously proposed protocols QPRD[28] and QPRR[18] by the authors. The framework is as in EPR [25] and routing architecture is of QPRR. The modular ZEQoS protocol renders a reliable solution for transmitting three categories of data packets- ordinary, delay-sensitive and reliability-sensitive - and exhibits real-time WBAN data. ZEQoS protocol preconceived to be utilized only for indoor-based applications, drains more energy than its master protocols- QPRD and QPRR.

– In [12], authors have proposed a thermal aware QoS-based routing protocol for heterogeneous WBANs named M2E2 which provisions energy management by supporting "multi-mode" of human body. Network reliability is increased by use of a combination of single-hop and multi-hop communication. The proposed protocol does not provide the details of metrics or nex-hop selection mechanism used to achieve a reliable and high throughput and reduced energy consumption.

– An improvement of the protocol ATTEMPT [22], the RE-ATTEMPT protocol proposed in [16] is an energy-efficient routing protocol for WBANs that aims energy efficient reliable data delivery. Operating in four phases, RE-ATTEMPT enhances the network lifetime. However, reliability-sensitive and delay-sensitive data are assigned the same priority and multihop process which may not be acceptable for delay intolerant data packets requiring time bound delivery.

– Energy Efficient Rate Selection (EERS) routing protocol based on Collection Tree Protocol (CTP) for WBANs is proposed in [14]. It is a minimal overhead protocol that reckons residual energy of sensor nodes along with link quality base transmission power adaptation to prolong network lifetime. The three modules included in EERS- used for selecting route, estimating link quality and forwarding data- support five mechanisms which are prompted by precise cases such as damaged link, channel conditions, poor link quality etc. The EERS protocol may provide a good barter between reliability, delay and energy consumption but does not examine diverse traffic classification and scheduling mechanisms to meet the QoS requirements.

– In [15], a mathematical mobility model for the postural movement of the human body in WBANs is proposed. The stability period, network lifetime and throughput increase using the forwarder based protocol compared to the multi-hop routing technique (both techniques presented in the paper) which escalates the delay making it unsuitable for emergency data. Moreover, the elected forwarder nodes expend much energy. Sensor nodes with energy below threshold are not a part of forwarder selection process and directly route their data straight to the sink thus overcoming delay.

– Authors in [4], propose a relay based energy solution for the communication of in-vivo WBANs concentrating on energy reduction by utilizing relays and one sink on the patient's clothes thereby reducing the communication distance and maximizing the network lifetime. The proposed protocol with linear programming based mathematical models boosts network lifetime and end-to-end-delay is minimized. However, it lacks a mechanism for packet retransmission and deploys on body sink which might not be always suitable.

– Critical Data Routing (CDR) for intra-WBAN proposed in [5] is a modular architecture based protocol that aims to categorize data packets as critical and non-critical and provide the best routes for latency intolerant critical data requiring highest possible reliability. Dynamic path loss prompted by postural movement and electromagnetic wave absorption leading to temperature rise issues of the human body, have been taken into account. Both objectives- highly reliable and on time critical data packet forwarding and reduction of in-body sensor node temperature rise-are achieved. However, in terms of the average temperature rise the protocol is slightly under performing.

– The routing protocol proposed in [6], for Balanced Energy Consumption (BEC) utilizes a residual energy based cost function mechanism for data collection from far distant nodes, aggregation and routing it to the sink. The nodes send their data to their nearest relay nodes- selected on the basis of minimum cost- for onward routing to the sink. In the event of node energy dropping below threshold, the protocol forwards only critical data demanding immediate medical intervention. Energy consumption by the selected forwarder nodes is increased but the network stability period time and network lifetime are improved by the protocol.

– In [3], authors have proposed a multihop routing protocol for WBAN. Fixed nodes are added to WBAN that are used as forwarder nodes, as sensor nodes on body provide partial mobility owing to postural changes. Transmission power, velocity vector of the receiver, residual energy and the instantaneous node position relative the coordinator are used as metrics for cost function calculation to identify nodes to be utilized for forwarding. In the proposed protocol, every node's energy is homogeneously utilized and direct communication between coordinator and relay node or body sensor nodes is done only when it is within the transmission range, thereby preventing hot-spot formation. Transmission power and network lifetime is improved compared to ATTEMPT [30] but there is no mechanism for transmission reliability or data packet retransmission in event of path loss.

V Conclusion

WBAN application in healthcare domain owes its roots to advances in sensing, networking and miniaturization. There are various open design issues in WBAN. Routing protocol design has maximum potential to simultaneously address energy efficiency and QoS constraints. The in-body and on-body constraints however make the routing protocol design in WBANs a challenging task. In this paper the WBAN architecture and challenges to QoS attainment are discussed. The QoS metrics that are used in designing of various routing protocols are summarized. A detailed survey of state-of-the-art QoS based protocols proposed in literature during the last decade in terms of metrics improved and drawbacks thereof is presented. This survey can be used by researchers involved in contributing to the field of remote healthcare provisioning by designing protocols suited for the application. As clear from the discussion, each protocol performs well only for some QoS metrics but none is designed to simultaneously address the issues of energy efficiency along with all identified metrics such as latency, reliability, mobility, thermal-effects, energy consumption etc.

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