I-RP: Interference Aware Routing Protocol for WBAN

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Abstract. The Wireless Body Sensor Networks (WBSN) have witnessed tremendous research interest because of their wide range of applications (medical and non-medical) in order to improve the quality of life. The healthcare applications of WBSN demands dissemination of patient's data, reliably and in a timely manner. For this purpose, medical teams may use real-time applications for disseminating critical data such as blood pressure, ECG, and EEG. The critical data packets are highly delay sensitive that must reach intended destination within time constraints. Due to the exchange of real-time and multi-media data, some nodes or links may experience the significant level of interference in the network. Consequently, it results in transmission disruption, random number of packet drops, insufficient buffer space and lack of availability of bandwidth. Moreover, interference in the network strains the communication links, reduces the information delivery capacity of the network and leads to high collisions, packet losses, retransmission and energy consumption. Therefore, incorporating interference-awareness in routing decisions is desirable to enhance the performance of WBSN. In this paper, we present an Interference-aware Routing Protocol (I-RP) that makes use of composite routing metric incorporating link quality (in terms of link delay and interference level) and path length. This multi-facet routing strategy makes more informed routing decision regarding route selection in a way that, a route with the minimum level of interference and path length is selected. Moreover, it also increases the link reliability and minimizes the packet losses and retransmission. The simulation results demonstrate the improved performance of proposed scheme when compared to existing routing scheme in WBSN.

Keywords: Interference · Wireless Body Area Network · Routing · Delay
MAC layer · QoS

1 Introduction

The constant monitoring of patients, suffering from chronic diseases, encourages the researchers to develop special-purpose wireless sensor network's technology, called

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Wireless Body Area Network (WBAN), that provide continuous health monitoring system. WBAN is comprised of several biomedical sensor nodes, either placed on the body or implanted in a body to collect physiological parameters such as temperature, Glucose, blood pressure, blood oxygen, Electrocardiogram (ECG) and Electroencephalography (EEG). The sensed data is transmitted to base station/medical server through coordinator nodes (via efficient routing protocols), where medical experts take adequate decisions in providing treatment. WBAN can be envisioned as a cost-effective and reliable solution in providing real-time healthcare services to the patients requiring emergency medical assistance [1].

The growing concerns in providing real-time health monitoring services requires adequate link quality to be maintained. However, the distinguished characteristics of WBAN raise various challenges in designing efficient routing protocol owing to limited resources, transmission range, data rate, frequency, operating environment, postural body movement and unreliability of low-power wireless links that lack in terms of QoS requirements, as low-power radios are very sensitive to noise and interference [2]. Most of the existing routing schemes for WBSN [3, 4] have traditionally focused on selecting routes by incorporating single routing metric (either hop count or temperature). The research has revealed that hop count may not always represent the optimal route selection. Moreover, the wireless links may exhibit variations in terms of link's interference level, capacity, path loss and delay [5–7]. Moreover, most of the routing schemes [8–10] incorporates composite routing metric (hop count, temperature and energy) to disseminate data packets. However, optimized route selection by keeping in view important design characteristics of WBSN such as QoS (in pursuit of link quality) have been overlooked in most of the previous studies. The timely and efficiently dissemination of critical data packets in healthcare applications require more realistic routing metric that keeps in view important aspects pertaining to link quality such as interference and delay. To best of our knowledge, incorporating interference awareness in routing decision has gained little attention in WBAN. The interference is one of the most significant performance bottleneck for wireless ad-hoc networks. Therefore, in this paper, an Interference-aware Routing Protocol (I-RP) has been proposed for WBAN that makes more informed decision regarding the actual link status. The proposed scheme estimates the channel contention by using the information available on MAC layer (channel interference) and conveys that information to the network layer. Based on the acquired information the route cost is evaluated, and the link having least cost (satisfies QoS requirements) is selected for packet forwarding. This multi-facet strategy optimizes the route selection in a way that the routes with minimum interference level and delay are selected which vital for timely delivery of critical data packets in healthcare applications. The simulation results prove the efficacy of proposed scheme when compared with existing routing schemes in WBAN. The rest of paper is organized as follows. The Sect. 2 presents the related literature review. The Sect. 3 demonstrate the proposed routing protocol. The Sect. 4 presents the simulation results and finally, the Sect. 5 concludes the paper with future directions.

2 Literature Review

This section presents the related review of the routing protocols proposed for WBAN. An Adaptive Transmit Power Mechanism (ATPM) scheme [11] is presented for e-health application of WBAN to improve QoS and energy conservation. ATPM based on Signal to Interference and Noise Ratio (SINR) and make use of few threshold values to make a decision. Moreover, to minimize the energy consumption ATMP also tune the parameter related to transmission power. A link quality aware with load balancing scheme namely, DSCA [12], is presented for WBAN with the aim to balance the load among the deployed body sensor nodes and maintain the quality of service. The proposed scheme consists of two phases: temporal link quality measurement and sub-channel allocation. The temporal link quality measure phase employs a probabilistic approach to measure the radio link quality between a sensor node and access point. The sub-channel allocation phase divides the available bandwidth in sub-channel to maintain QoS. A priority based routing protocol [3] is proposed for WBAN which is based on traditional AODV protocol. The proposed routing protocol places the data packets in the queue that is based on the defined priorities. The packets with the highest priority are placed in L1 queue whereas normal data packets are placed in L2 queue. A Link-Aware and Energy Efficient scheme for Body Area networks (LAEEBA) [13] is proposed for WBAN with the objective to minimize energy consumption and improve throughput. The proposed scheme comprised of four phases such as initialization, next-hop selection, routing and path loss selection phases. The proposed scheme incorporates a cost function that is based on distance to sink node, node's remaining energy and path loss model. The path loss model ensures the fewer packet losses. A Priority-based Cross-layer Routing Protocol (PCRP) [14] is proposed for healthcare application of WBAN that ensures reliable data dissemination for inter and intra-body communication. In order to provide channel access, the proposed PCRP scheme combines TDMA and CSMA/CA approaches to avoid idle listening, data losses and collisions. Furthermore, the PCRP scheme defines three classes of traffic to compliance heterogeneous QoS requirements such as general monitoring traffic, delay sensitive packets and emergency packets. A reliable and temperature aware routing protocol [15] is proposed for WBAN, which incorporates security primitives and temperature awareness to address the reliable dissemination of critical data packets and solve hotspot issue. Similarly, a Thermal-Aware Routing Algorithm (TARA) [4] is proposed to overcome the issue of temperature rise for implanted biomedical sensor nodes. A biosensor node estimates the temperature of its neighboring nodes by overhearing the packets sent and received. If the temperature rise is above the specified threshold, that specified node is considered as hotspot node thereby isolated from routing paths.

Based on the presented literature review it is observed that most of the proposed routing protocols for WBAN do not incorporate dynamic/changing network conditions such as channel interference in their routing decisions. Consequently, it leads to the selection of links that do not meet QoS requirements. Furthermore, most of the routing protocols require a special set of resources for their network operations such as tight synchronization, channel allocation requirements and asymmetric authentication. Moreover, most of the routing protocols either hop count and energy or hop count and temperature as a composite metric for route selection. However, these routing metrics does not adapt to varying traffic and channel conditions. The interference on links causes significant variations in the performance of throughput, delay and reliability. By keeping these issues in mind, Interference-aware Routing Protocol (I-RP) has been proposed that satisfy QoS requirements for critical healthcare application of WBAN. I-RP incorporates link's delay [16] and interference in routing decision and provide optimized route selection. The details of the proposed I-RP scheme are presented in the upcoming section.

3 Proposed Routing Protocol

The proposed I-RP routing scheme extends the routing mechanism of traditional AODV routing protocol where the control packets for route discovery, route request and route reply, are customized to keep information about the link's delay, interference and length. The proposed scheme comprises of two major phases: network initialization phase and QoS aware routing phase. The following sub-sections provide the details of each phase.

3.1 Network Initialization Phase

During this phase, sensor nodes identify the number of neighbor nodes in their transmission range and compute the hop-count, delay and link interference by exchanging hello packets. Upon receiving the hello packets, the receiving nodes add the relevant information (hop count, delay and estimated interference values) and rebroadcast and share with a neighbor in their transmission range. This process continues till all the nodes compute relevant information and exchange with their neighbor nodes. The process of computing the delay and link interference is discussed below.

Link Delay Estimation (LDE): Each sensor node periodically exchanges hello packets with 1-hop neighbors in order to estimate the link delay. The delay is estimated, as shown in Eq. 1, by computing the difference between the times hello packet exchanged and its acknowledgment received. In this way, the inter-arrival time of the link formed between the two neighboring nodes is determined.

$$LDE = \frac{Hello\ Packet_{Ack} - Hello\ Packet_{sent}}{2} \quad (1)$$

Link Quality Indicator (LQI): The LQI refer to the QoS metric in term of channel interference. LQI primarily focus of interference at MAC layer mainly attributed by the MAC based CSMA/CA protocol which prevents the nodes from transmitting on the shared medium as the channel is occupied by the transmission from another node, within their carrier sensing range. In other words, it indicates that access to medium has been deferred (node is in the back-off state) due to on-going traffic within the carrier sensing range. The higher the traffic rate, the larger the accumulative LQI value and vice versa. The LQI can be a good indicator for estimating the channel interference.

$$LQE = \sum\nolimits_{link \in r} (HC + LDE + LQI) \tag{2}$$

The integrated outcome of Hop Count, LDE and LQI lead to the formation of new routing metric, termed as Link Quality Estimator (LQE), as shown in Eq. 2. The LQE of the route *r* is aggregated sum of HC, LDE and LQI values for all the links in that selected route.

3.2 QoS Aware Routing Phase

The interference-aware routing process is incorporated in QoS aware routing phase which extends the route discovery mechanism of classical on-demand routing protocol, AODV, by replacing conventional hop count metric with new LQE metric (interference aware metric). The RREQ and RREP packets are customized to include LDE and LQI fields in their packet headers. The link that satisfies the requirements in LQE metric, in a way that $Min(LQE)$ value, is chosen for packet forwarding. The route with high LQE indicates that cost of the route is high in terms of hop count, link delay and channel interference. The QoS aware route discovery mechanism is explained as follows:

The route discovery process is initiated by source node by generating and broadcasting RREQ packet to their neighboring nodes. The intermediate/neighboring nodes receive the RREQ packets sets the reverse path to the node that sends the RREQ packet and appends HC, LDE and LQI values in the packet header. Afterward, it rebroadcast the RREQ packet to their downstream neighbor nodes. The same process continues till the RREQ reaches the destination or to the node having a valid route to the destination. Such node generates the RREP packet and unicast it to upstream nodes and maintain an entry for a forward route to the node that sends-out RREP. During network initialization phase, each sensor node has already estimated the LDE and LQI values. The same values are appended to RREP packet header and forwarded to upstream nodes. Finally, the source node may receive multiple RREPs from several routes. It computes the cost for each route and selects the one with minimum cost. This multi-facet strategy of I-RP helps in selecting the route that satisfies the QoS requirements (pertaining to link delay and channel interference) consequently leads to more route stability, minimized average delay, loss ratio and retransmissions which is very crucial for delivering critical data packets in WBAN.

4 Results and Discussions

This section presents the simulation results of proposed scheme via simulation parameters listed in Table 1. The performance of the proposed scheme is compared with ATMP and TARA routing protocols in WBAN, by varying the traffic load so that a more realistic scenario having high traffic (interference on the channel) is chosen in order to fairly analyze the performance.

Table 1. Simulation parameters

Simulation area	10 m × 10 m
Relay nodes	20
Biomedical sensor nodes	5
Transport layer protocol	UDP
Propagation model	TwoRayGround
Network interface type	WirelessPhy
Traffic type	CBR
IEEE 802.15.4 standard	Default values
Simulation time	500 s
Routing protocols	I-RP, TARA, AODV
Packet size	50 bytes

The efficacy of proposed I-RP scheme is measured in terms of throughput, average end-to-end delay and routing load. Figures 1, 2 and 3 present the performance analysis of I-RP, TARA and ATMP routing protocols in terms of throughput, average end-to-end delay and normalized routing load. As the ATMP and TARA routing protocols do not provide any mechanism to deal with channel interference, therefore, under heavy traffic loads they exhibit reduced performance. Initially, when more data packets are supplied, the throughput performance increases. However, when it reaches saturation point the performance of ATMP and TARA starts to decline due to high interference on links. Furthermore, TARA protocol makes use of hop count (other than temperature) for route selection, which is not an optimal choice under dynamic network conditions. As a result, both routing protocols (ATMP and TARA) exhibits increased packet losses due to significant congestion on the network. Moreover, it also results in a high number of retransmissions and route breakages under heavy network load. The high number of retransmissions and route breakages strain the communication links with control packets (new route discoveries and route maintenance). Thereby, limits the flow of data packets that affect the throughput of the network. Similarly, nodes have to suspend packet forwarding till the new routes are discovered, so it affects the end-to-end delay performance. Likewise, the flow of a higher number of control packets results in the increased normalized routing load. The proposed I-RP routing protocol outperforms the existing schemes as it makes more informed decision regarding the actual interference on the link by incorporating Link Quality Indicator (LQI). Moreover, Link Delay Estimation (LDE) also helps in selecting the routes with least communication delay, that is vital for the transmission of critical data packets in WBAN. The integrated outcome of LQI, LDE and HC leads to the formation of improved routing metric that performs optimized route selection which gives equal emphasis to all factors that are crucial for WBAN performance. Due to the adopted methodology of the proposed scheme, the selected routes remains more stable thereby the flow of packets remains consistent for an extended period of time. Consequently, it improves the overall throughput and end-to-end delay performances. Moreover, it also improves the routing load performance as fewer control packets flows in the network.

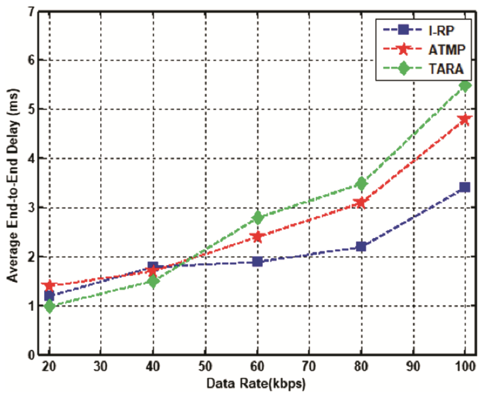

Fig. 1. Average End-to-End delay

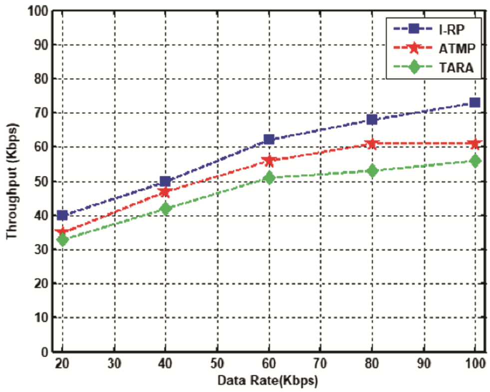

Fig. 2. Average throughput (kbps)

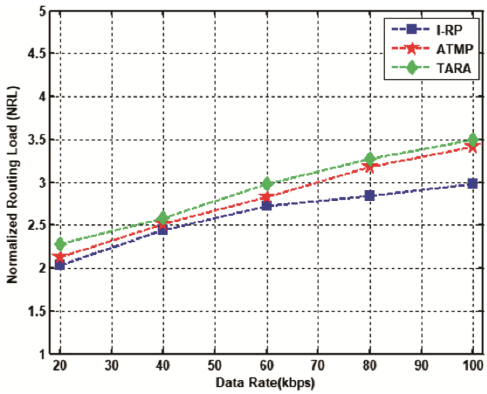

Fig. 3. Normalized routing load

5 Conclusion

The healthcare applications of WBAN are highly critical and delay sensitive, therefore, information must be disseminated reliably and within time constraints. The routing protocol responsible for delivering data packets must meet QoS requirements. The interference is one of the bottleneck factors that significantly affects the network performance. Therefore, this paper presented an interference-aware routing protocol for WBAN with the objective to make a more informed decision regarding the channel contention so that less congested links may be selected for data delivery. Moreover, link's delay and hop count parameters are also incorporated in routing decisions which ensures the selection of links with minimum delay and path length. The simulation results demonstrated the improved performance of proposed I-RP scheme as compared to existing routing protocols for WBAN. In future, we intended to propose more improved link quality metric for WBAN with its integration with security aspect so that critical patient's data should reach securely to its destination.

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