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Improvement of Quality of Service Parameters in Dynamic and Heterogeneous WBAN

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Abstract

With growth in population and diseases, there is a need for monitoring and curing of patients with low cost for various health issues. Due to life threatening conditions, loss-free and timely sending of data is an essential factor for healthcare WBAN. Health data needs to transmit through reliable connection and with minimum delay, but designing a reliable, and congestion and delay free transport protocol is a challenging area in Wireless Body Area Networks (WBANs). Generally, transport layer is responsible for congestion control and reliable packet delivery. Congestion is a critical issue in the healthcare system. It not only increases loss and delay ratio but also raise a number of retransmissions and packet drop rates, which hampers Quality of Service (QoS). Thus, to meet the QoS requirements of healthcare WBANs, a reliable and fair transport protocol is mandatory. This motivates us to design a new protocol, which provides loss, delay and congestion free transmission of heterogeneous data. In this paper, we present a Dynamic priority based Quality of Service management protocol which not only controls the congestion in the network but also provides a reliable transmission with timely delivery of the packet.

Keywords*: congestion, delay, dynamic priority, packet drop rate, quality of service, reliability, wireless body area network*

1. Introduction

With the help of Wireless Body Area Network, monitoring of the patient is done remotely anytime from anywhere. WBAN consists of tiny and intelligent sensors. The main job of WBAN is to continuously monitor health data and send it to healthcare server. Dynamic and heterogeneous nature of healthcare WBAN makes Quality of Service (QoS) provisioning very inspiring and essential research facet [1-2]. In healthcare WBAN system reliable data transmission [10-11] with low delay [15] is very important, to improve the quality of life and to reduce treatment cost. The main motive of the proposed protocol is to offer reliable transmission of heterogeneous packets [3-6] within the time bound. It is also deals with duplicate packets along with performing congestion control by adjusting data sending rate dynamically. In addition to the challenges for reliable data transmission, there exist additional challenges due to the unique requirements of the healthcare system such as bounded delay and delay variation [16-17], fair resource allocation, drop rate [7-10] and retransmission control [12-14]. As argued earlier, the traditional transport protocols cannot be directly implemented for WBAN, and the already existing protocols are not considered all issues up to mark. Hence, it motivates us to develop a new transport protocol for WBAN, which ensures QoS requirements of healthcare systems.

This paper has been organized as follows: Section I signifies a brief introduction to the subject matter. Section II illustrates the related work. Section III provides proposed protocol with new techniques. Section IV provides the experimental results. Section V scrutinizes the conclusion part.

2. Related Work

Rate-Controlled Reliable Transport (RCRT) [7] is a new transport protocol for wireless sensor networks. RCRT consists of four major components including: congestion detection, rate adaptation, rate allocation and end-to-end retransmission. RCRT uses the length of retransmission list as the congestion indicator. When there are too many packets in retransmission list, it means that the congestion density is high. In this case, the RCRT tries to

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adapt the transmission rate of each sensor node, using an AIMD rate control mechanism. RCRT implements a NACK-based end-to-end loss recovery scheme. The sink detects packet losses and repairs them by requesting end-to-end retransmissions from source nodes.

The Congestion Detection and Avoidance (CODA) protocol [8] uses both a hop-by-hop and an end-to-end congestion control scheme. It avoids the congestion by simply dropping packets at the node preceding the congestion area and employing additive increase and multiplicative decrease (AIMD) scheme to control data rate. It uses a static threshold value for detecting the onset of congestion even though it is normally difficult to determine a suitable threshold value that works in dynamic channel environments. In CODA, nodes use a broadcast message to inform their neighboring nodes the onset of congestion though this message is not guaranteed to reach the sources. The CODA only partially minimizes the effects of congestion, and as a result retransmissions and consumption of resources still occur.

Wang et al. [9] proposed "A Prioritization Based Congestion Control Protocol for Healthcare Monitoring Application in Wireless Sensor Networks" for sensing and categorizing physiological signals into different classes. In this architecture, the node with high priority and low congestion get more network bandwidth than the others. When the central node detects any abnormal changes in any signal, it assigns high priority to the correspondence node and sends an alert message to the medical server. It considers a fixed service time for all and adjusts the sending rate according to node's priority without considering the conditions of the system.

The Event to sink reliable transport (ESRT) [10] protocol is transport protocol that achieves reliable event detection with minimum energy consumption. The features provided by ESRT are self-configuration, energy awareness, congestion control, collective identification, biased implementation. In self-configuration, ESRT adjusts the reporting rate according to required condition. If the reliability is higher than required then, sink reports to the sensor to reduce reporting rate which leads to energy awareness. ESRT uses the congestion control mechanism that conserves energy of nodes and simultaneously maintains desirable reliability. The collective identification in ESRT means sink refers only collective information provided by a number of nodes. In the biased implementation, ESRT runs on the sink which is high powered compare to the sensor node. ESRT algorithm runs in different reliability and congestion condition they are as NCHR (No Congestion High Reliability), NCLR (No Congestion Low Reliability), CHR (Congestion High Reliability), CLR (Congestion Low Reliability), and OOR (Optimal Operating Region). In NCHR, sink decreases frequency to achieve required reliability. In NCLR, sink increases frequency rate of sensor nodes. In CHR, sink decreases frequency aggressively which leads to NCHR condition and then it performs action in NCHR to achieve required reliability. In CLR, sink decreases frequency exponentially. In OOR, frequency remains unchanged. Applications of ESRT are bounded to Signal Estimation and Signal Tracking Event Detection only.

In Real Time Reliable Transport Protocol (RT2) [11], Wireless Sensor Actor Network (WSAN) consists of sensors and actors. Actors are resource rich and having better processing capabilities than sensors. RT2 protocol achieves congestion control and also transport event reliably. RT2 protocol mainly works in 2 stages, Sensor-Actor communication, and Actor-Actor communication. Here the sensor nodes sense the information about the environment and deliver this information to the actor nodes in Sensor-Actor communication. RT2 has different reliability and congestion conditions in the Sensor-Actor communication like ERNCC (Early Reliability No Congestion Condition), ERCC (Early Reliability Condition Condition), LRNCC (Low Reliability No Congestion Condition), LRCC (Low Reliability Congestion Condition), Adequate Reliability and No Congestion Condition. In ERNCC, actor node decreases the reporting rate of sensor nodes to conserve unnecessary wastage of energy of the sensor nodes and to maintain reliability. In ERCC, actor node decreases reporting rate of sensors more aggressively to avoid congestion as soon as possible. In LRNCC, actor nodes increase the reporting rate of sensors by using multiplicative strategy to achieve required reliability. In LRCC, actor node decreases reporting rate of sensors until required reliability is achieved. In Adequate Reliability and No Congestion Condition, reporting rate of sensors remains as it is. In the Actor-Actor Communication actor nodes communicate with other actors in the network to take a decision and send this decision to the sink node which acts as the base station.

The Learning Automata-Based Congestion Avoidance Scheme for Healthcare Wireless Sensor Networks (LACAS) [12], tries to make packet arrival rate and packet service rate equal, by avoiding queuing at the nodes for a longer period. Although it focuses to choose better data rates, but these rates are defined randomly and will not change during simulation, hence resulting inefficient channel utilization. Here the source nodes are not provided with feedback by the intermediate nodes to slow down their rates, this leads to increase the drop rate. It does not consider different types of vital signal and treats all nodes as same.

The Optimized Congestion Management Protocol for Healthcare Wireless Sensor Networks (OCMP) [13], designed with serviced prioritization policy. It employs a single physical queue which is divided into several virtual queues and assigns dynamic weights to each child node. If any child node's queue is likely to be full, then it can use the free space of other child node's queue. It minimizes the packet loss rate for high priority traffic classes, reduces starvation for low priority traffic, provides fair scheduling by applying weighted fair scheduling. It does not provide up to mark performance in unusual critical situations and does not focus on heterogeneous traffic flow handling.

3. Proposed Protocol

The proposed DWBAN [18] architecture is consists of three units: i) Wireless Body Area Network Unit (WBANU), ii) Controller Unit (CU), and iii) Medical Server Unit (MSU). The WBANU consists of sensor nodes that sense vital signals and sends them to CU. The CU aggregates and classifies the packets accordingly in packet handling unit using Dynamic Priority based Packet Handling protocol (DPPH). The other job of CU is to improve QoS parameters i.e. Reliability, Delay, and Congestion in its QoS management unit. The MSU receives packets from CU and diagnosed the health condition accordingly.

QoS management Unit:

The purpose of QoS management unit in dynamic and heterogeneous WBAN applications like healthcare system is to achieve high reliability and to reduce delay. The main motive of the proposed QoS management protocol is to reduce loss and drop, avoid unnecessary retransmission, minimize duplicate transmission and make an effort to reduce transmission delay and its variance. To improve the QoS parameters in WBAN, heterogeneous packet delivery, packet loss, packet transmission delay and congestion degree are considered as the key parameters.

3.1. Reliability Unit

Reliability is measured using the packet loss rate (PLR). The main reason for packet loss or drop includes congestion, bad channel conditions, and link breakage. The main functionality of reliability unit is given below:

a. Flow Control: The proposed protocol follows a quick start based flow control policy. According to the sensor priority, the data sending rate is calculated and notifies to the controller unit at the time of three-way handshake connection establishment phase. The initial *Data Sending Rate (DSR)* is calculated exponentially by considering the sensor node priority as given in equation (1) in the beginning phase. The subsequent data sending rate of a sensor node is increased or decreased only by a fractional amount as given in equation (2), depending on the degree of congestion (CD), hence called Fractional Increased and Fractional Decreased (FIFD).

$$DSR_{Sn} = 2^{(N-n)} \tag{1}$$

$$DSR_{Sni} = \begin{cases} DSR_{Sni}\text{-}^{1+\,2floor(k*(N-n))}, \text{ if } CD <= Th_{min} \\ Ceil\ (DSR_{Sn}{}^{i-1} / 2^{k*n}), \text{ if } Th_{min}<CD<Th_{max} \\ 1, \text{ if } CD>=Th_{max} \end{cases} \tag{2}$$

where N=total number of sensors, n= priority of the sensor.

b. Loss Minimization: Minimization of loss is an essential factor for reduction of unnecessary retransmission and wastage of limited resources.
   1. Loss detection: The gap in sequence number of packets is the indicator of packet loss. In the first two steps of the three-way handshake, both source and sink exchange the initial sequence number along with the maximum sequence number.
   2. Loss ratio calculation: Proposed protocol calculates the packet loss ratio. The packet loss ratio is denoted as the ratio of the total number of lost packets in an interval with respect to the total number of packets transmitted in that interval.
   3. Loss Notification: Unlike ACK/NACK, a novel Duplicate Selective Negative Acknowledgment (DSNACK) based loss notification policy is introduced here. It provides the benefits of multiple loss notifications with the help of two consecutive SNACKs. Here the SNACK packet is having three index fields in its header i.e. Current Sequence Index (CSI), Previous Sequence Index (PSI) and Successive Sequence Index (SSI). The CSI provides the sequence number of very first lost packets in the current SNACK packet, PSI provides the sequence number of very first lost packets in the previous SNACK packet and the SSI provides the total number of consecutive lost packets in current SNACK packet. The CSI of previous SNACK and PSI of current SNACK are used to detect loss of SNACK packets. The SNACK based protocol consumes fewer network resources.
   4. Loss Recovery: The sensor node discovers packet loss after analyzing the DSNACK packet or expiration of the timer. Recovery of loss packets are done in the proposed selective and topical Fast retransmit and Fast recovery phase. The sensor nodes are allowed to select the number of packets it needs to retransmit and are permitted to retransmit latest loss packets according to their dynamic priority. By doing so, it reduces the number of unnecessary retransmission.

c. Reordering: Unlike single ended priority queue, here Double Ended Priority Queue(DEPQ) is used. It is made up of min_max heap-based data structure. A min-max heap is a complete binary tree containing alternating min and max levels to store packets according to their priority and sequence number. This heap structure implicitly reorders the packets.

d. Mitigation of Duplicate transmission: Here the packet sequence number will help to identify and remove duplicate packets. In the proposed protocol, controller unit (CU) maintains a packet loss table (i.e. cuckoo hash table) to store lost packet's sequence numbers. When sink received an out of order packet, it stores the lost packet's sequence number in this loss table. When CU receive a retransmitted lost packet, it first searches the entry of the incoming packet's sequence number in its loss table, if the sequence number is found, then it marks it as a duplicate packet and drops it, otherwise, it inserts this packet into the appropriate queue. Here Cuckoo hashing determines two places for the loss packet by applying hash functions on some header fields of incoming packet P_i^{Sn}. The working principle of this technique given below.
   i. Calculate two places $h1(P_i^{Sn})$ and $h2(P_i^{Sn})$.
   ii. Then it checks both these places for their vacancy.
   iii. If both or any one place is empty, then it inserts packet's sequence number to the empty place.
   Else if neither of these places is empty, then
      a. it selects one of the candidate places,
      b. kicks out the existing sequence number (i.e. re-inserts the victim sequence number to its own alternate place or follows step (ii) until it gets its right place)
      c. insert PiSn's sequence number into this empty place.

Unlike traditional and existing reliability protocols the proposed protocol transmit selected and latest loss packets, which reduce retransmission rate, increase packet delivery ratio, and improves bandwidth utilization. Duplicate packet detection and rejection utilizes buffer or memory in a more efficient way.

3.2. Delay Unit

In a healthcare system, health data recognized after lapsed time, does not reflect the actual condition of the patient and may cause serious problems. Hence, one of the most important metrics for QoS is delay in these kinds of time critical applications. The delay and delay variance is highly dependent on the communication link, topology, and resource used in the network. In this unit, the total transmission delay is evaluated by summing all types of delay, i.e., Total Elapsed Time (T_{EL}), Total delay variance (T_{VA}), and Total Loss Time (T_{LE}). The Following equations are used to calculate total transmission delay from source to destination.

a. Total Elapse time (TEL): It calculates the total elapsed time due to the late arrival of packet Pi at the receiver end.

$$T_{EL}^{P}i = \begin{cases} T_{AD}^{Pi} - T_{ED}^{Pi}, & \text{if } T_{AD}^{Pi} > T_{ED}^{Pi} \\ 0, & \text{if } T_{AD}^{Pi} <= T_{ED}^{Pi} \end{cases} \quad (3)$$

$$T_{EL}^{Sn} = \sum_{Ii=1} T_{EL}^{Pi} \quad (4)$$

$$T_{EL}^{Total} = \sum_{n=1}^{N} T_{EL}^{Sn} \quad (5)$$

where TELSn denotes the total elapsed time for a particular sensor node or for one link, TELTotal denotes the total elapsed time for all sensors or all links, TAD denotes the time when packet Pi actually arrived at the receiver, TED denotes the expected deliver time of a packet Pi of sensor node Sn at the receiver end and calculated as:

$$T_{ED}^{P}i = T_{ED}^{Pi-1} + TTG^{Sn} \quad (6)$$

where TTG^{Sn} denotes the transmission time gap between two consecutive packets.

b. Delay variation time (TVA): Variation in the elapsed time (i.e difference between two consecutive elapsed time).

$$T_{VA}^{P}i = T_{EL}^{Pi} - T_{EL}^{Pi-1} \quad (7)$$

$$T_{VA}^{Sn} = \sum_{Ii=1} T_{VA}^{Pi} \quad (8)$$

$$T_{VA}^{Total} = \sum_{n=1}^{N} T_{VA}^{Sn} \quad (9)$$

where T_{VA}^{Sn} denotes the total delay variance time for a particular link, T_{VA}^{Total} denotes the total delay variance time for all links.

c. Loss error time (T_{LE}): Time interval between last delivered in-order packet (T^{AD}_{Pb}) and current delivered out-of-order packet (i.e. T_{AD}^{Pi}).

$$T_{LE}^{Pi} = T_{AD}^{Pi} - T_{AD}^{Pb} \quad (10)$$

$$T_{LE}^{Sn} = \sum_{Ii=1} T_{LE}^{Pi} \quad (11)$$

$$T_{LE}^{Total} = \sum_{n=1}^{N} T_{LE}^{Sn} \quad (12)$$

where T_{LE}^{Sn} denotes the total loss error time for a particular link, T_{LE}^{Total} denotes the total loss error time for all links.

d. Total transmission Delay (T_D): Total time is taken for delivery of all generated packets in a given time interval.

$$T_D = (\alpha * T_{EL}) + (\beta * T_{VA}) + (\gamma * T_{LE}) \quad (13)$$

where α, β, γ are small coefficient values with constraints

$0 < \gamma < = \beta < = \alpha < 1$.

This calculated transmission delay value lowers the end-to-end delay tremendously, as it used to calculate the congestion level of the network for next time interval.

3.3. Congestion Unit

Congestion means over-crowding, occurs mainly in many-to-one point topology, burst data rates, and low resources. In the healthcare system, having critical data for transmission, it is essential to avoid congestion as much as possible. Congestion occurs when offered load exceeds available capacity or the link bandwidth is reduced due to fading channels. Network congestion causes channel quality to degrade and loss rates rise. It leads to packets drops at the buffers, increased delays, wasted energy, and requires retransmissions.

So in the proposed protocol, a dynamic congestion mitigation protocol is designed. The proposed congestion unit is consisting of three sub-units: i) Congestion Detection and Notification (CDN) unit, ii) Congestion Control (CC) unit, iii) Congestion Avoidance (CA) unit. In the Congestion detection unit, it calculates congestion degree (CD) from various parameters like packet loss ratio, packet drop rate, transmission delay and current queue length. In the congestion notification unit, it activates CN bit in the header field of the control packet and notifies to all source. The congestion control unit employs the dynamic rate adjustment policy, which computes a new sending rate that is a reflection of the current sending rate and the dynamic priority of the sensor node as already mentioned in equation (2). The congestion avoidance unit is having an Active Queue Managements (AQM) policy. It finds and drops selected amount of low priority packets from the low priority queue.

a. Calculate Queue length (QL)

```
If (QL <=THmin), then
        Set Drop rate =0
   else if (THmin < QL  < THmax), then
        Drop rate: Ceil (QL/ i)
   else if (QL >= 1), then
        Drop rate: Ceil (QL/ 2*i)
```

The congestion unit tries to minimize the packet drop rate and resource consumption, and reduced retransmission rate.

4. Experimental Result

The protocol used for QoS management is the extension of our proposed DPPH protocol so termed as Modified DPPH (MDPPH) protocol. The experimental results show the comparison of MDPPH with DPPH and OCMP (i.e. existing protocol). The performance these protocols are implemented using the NS-2.35 simulator and graphs are generated using Matlab. It considers Packet Delivery Ratio (PDR), End-to-End Delay, and Throughput as the key performance metrics.

4.1 Packet Delivery Ratio (PDR)

The PDR is defined as the total number of packets delivered to the CU. The graph in Figure 1 shows that the dynamic flow control along with data sending rate in MDPPH increases the number of packets delivery ratio.

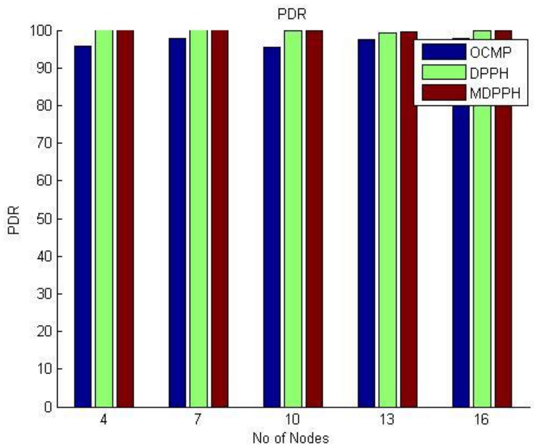

Figure 1. The impact of OCMP, DPPH, MDPPH on PDR.

4.2. Delay

It is defined as the total time required for transmitting a packet from source to destination. The Figure 3 shows that MDPPH protocol tries to minimize delay with an increase in a number of nodes.

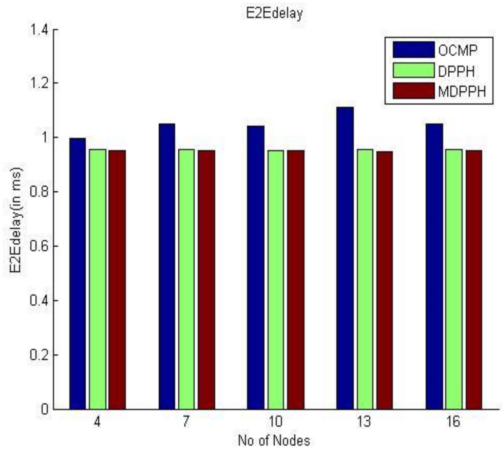

Figure 2. The impact of OCMP, DPPH, MDPPH on E2E Delay.

4.3. Throughput

It indicates the data rate. It denotes the speed of the received data in bits per seconds or data packets per second. The Figure 4 shows that the throughput for proposed MDPPH protocol is raised due to proposed loss recovery and congestion mitigation methods.

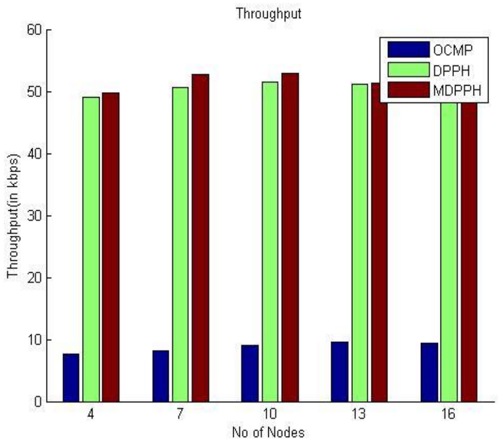

Figure 3. The impact of OCMP, DPPH, MDPPH on Throughput.

5. Conclusion

Congestion may occur due to limited resources in WBANs, which further hampers QoS parameters i.e. increases loss and delay and wastes energy. In this paper, we proposed a QoS provisioning transport protocol for WBANs. The proposed protocol enables QoS guarantees with end-to-end reliable data transmission within the critical time interval. Its main purposes are flow and congestion control, loss recovery, duplicate mitigation, loss, drop, retransmission and delay minimization. The proposed protocol uses the SNACK policy to decrease the number of ACK and NACK packet. It provides a dynamic rate adjustment method. It also overcomes the problem of critical time delivery of heterogeneous data flow. The experimental results validate the performance of the proposed protocol with respect to packet delivery ratio, delay, and throughput.

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