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An Optimized Service Differentiated Congestion Management protocol for delay constrained traffic in Healthcare WSN's

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***Abstract-* This paper proposes a novel congestion management protocol for constrained delay traffic and optimized rate control for HWSNs. The proposed protocol consists of congestion avoidance and control phases. We distinguish between high and low priority traffics. For high priority traffic, we control end-to-end delay constrains with node output scheduling weights. For low priority traffics, we first avoid congestion using a new Active Queue Management (AQM) algorithm that uses a distinct virtual queue's situation to decide about accepting or dropping the received packets from child nodes. If acceptance occurs for the incoming packet, congestion is detected by the proposed protocol using a three state machine and a virtual queue status. Afterward, the child's sending rate is adjusted using an optimization function. The results of the simulation indicate goal achievement for the protocol proposed.**

Index Terms- Wireless sensor networks (WSN), congestion avoidance, Optimization, congestion control, differentiated service,

I. INTRODUCTION

The growth of the elderly population is a significant challenge of the past decade, leading to increased healthcare expenses. In [1] the authors suggested that more than 20% of the overall population in developed societies will be aged over 65 by the next decade. Therefore, the idea of using Wireless Sensor Networks in patients' home permits healthcare providers to monitor their patients distantly and provide well-timed health information and support. It expands the reach of health care available anywhere and anytime and improves life quality by enhancing the doctor-patient relationship's efficiency by reducing healthcare costs.

Recent developments in telecommunication technology have made it possible to send data over the wireless systems and design low-cost, small size, lightweight, and intelligent wearable sensor nodes that can be utilized in critical healthcare applications to improve human life [2][3][4]. For instance, in

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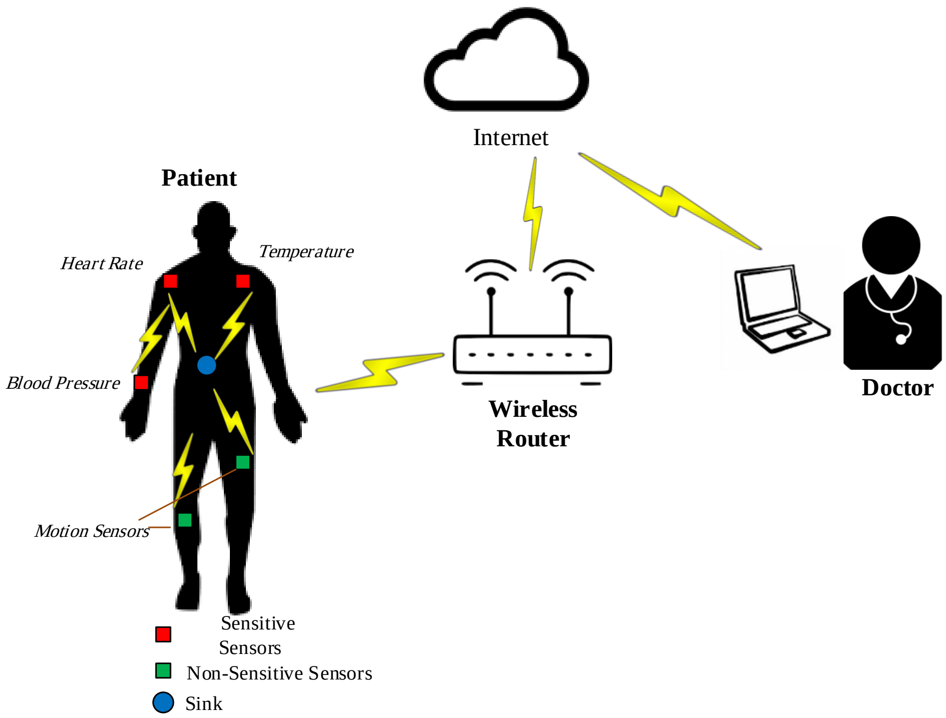


Fig. 1. Different sensors for human body.

identifying emergencies such as heart attacks or sudden changes in blood sugar and blood pressure, a few seconds or even minutes are vital to saving the elderly. Considering this situation, their health conditions will not be diagnosed on time without the use of sensors. Tiny attached sensors implanted in the body can collect, process, and generate various data related to vital signs or motion detectors in real-time and periodically deliver them to the medical facility, hospital staff and doctors. The sensed data are sensitive, such as vital signs, (blood pressure or heart rate) or not sensitive like the motion sensors. Sensitive data may need constrained delay while non-sensitive data tolerates much more to the delay while requiring a low packet drop. For this paper's purpose, sensor nodes are restricted to begin stationary, indicating no location change for at least a few days. This is shown in Fig. 1.

Based on the importance of the issue, several other health care applications are used today [3][5][6][7]. In one application, patients can be monitored remotely in their homes or other places outside of a clinical facility by physicians and nurses. This removes the necessity of physical presence in order to examine patients. The monitoring system collects patients' data (e.g. constant observing for Parkinson’s or Alzheimer’s illness) and transmits data to a remote server for storage where they are later analyzed by healthcare professionals, clinicians and physicians [8]. In another application, parents working outside the home can remotely control home appliances via environmental sensors to identify patients’ health status to react effectively in emergency situations, particularly when there are children or elderly patients at home [9]. Remote monitoring reduces the time of detection in

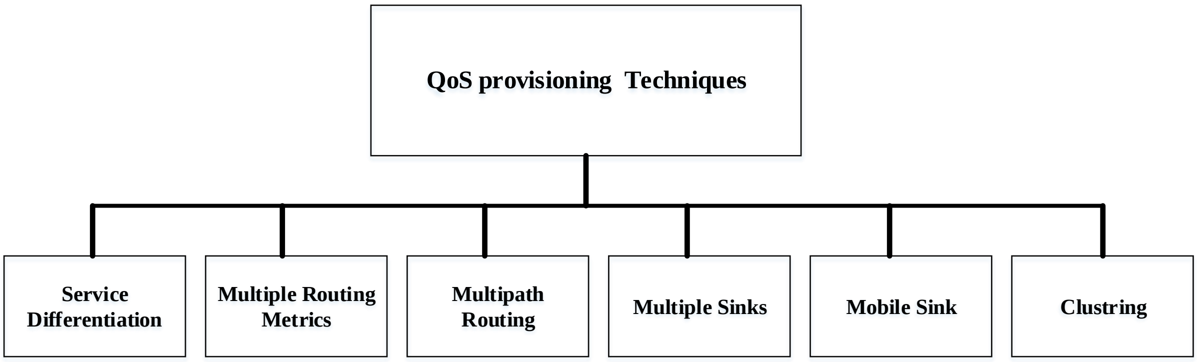


Fig. 2. QoS provisioning techniques at network layer.

emergencies and disorders for special care patients. It also provides an extensive collection of healthcare facilities for people with several mental and physical incapability grades.

In healthcare applications, various sensors can be attached to a patient's body, which generates different kinds of data traffic. These traffics may differ in quality of service (QOS) requirements, rate of data loss, data generation rate, and may differ in delay tolerances. Particular traffics may need low delay constrained and must be delivered to sink in a bounded end-to-end delay. This might happen in emergencies, which only a reasonable delay is accepted in order to assure the delivery of critical data. Some other signals may tolerate a certain percentage of queuing delay, but require a low packet drop rate. Therefore, certain signs are extra vital and further significant than other signs. Generally, the sensors used in these applications have common characteristics such as dynamic network topology, low power, limited energy, unstable mixture traffic, and resource limitations. Thus, QOS which is the network's ability to satisfy the user's certain requirements or application, is a challenging issue in healthcare applications [9].

There are several mechanisms at the network layer to meet the QoS requirements, including Service differentiation, Clustering, Multiple routing metrics, Multiple sinks and Multipath routing [41]. Figure 2 shows the QoS provisioning mechanism at the network layer.

Among existing provision QoS methods, in this paper, we will focus on the Service differentiation mechanism. Service differentiation is a widely used method to provide QOS guarantees [7][10]. This method aims to classify the packets based on their priorities and provide required service quality by sharing sensors' limited resources among classes.

Since different types of sensors may generate data with different rates and characteristics simultaneously requiring other QOS requirements (e.g. Delay and packet drop) [10], it is quite likely that this leads to a greater possibility of congestion the network near sink sensor nodes. Congestion may lead to packet loss, increased energy consumption, and decline of the throughput in the system. In the case of critical life applications, this congestion will be tremendously unwanted as it may lead to patient’s death.

A. Types of Congestion

There are two different kinds of congestion in WSNs. Congestion at the node level is the first kind and is common in conventional networks. The details about these two level can be found in [10][11].

B. General types of Congestion control methods

Congestion is controlled via two main methods: 1) traffic control and 2) managing network resources [12][13]. The First method tries to control congestion by adjusting traffic rates for intermediate or source nodes. This approach is appropriate once it is difficult to fine-tune the network resources. The second method attempts to raise network resources to mitigate in the event of congestion. In this method, it is essential to ensure precise network resource adjustments for avoiding underprovided or over provided resources, which is difficult in wireless environments. In this work, congestion control in wireless sensor networks is investigated through data traffic control.

C. Contribution

In most of the literature, once congestion occurs, the packet sending rate is reduced, and attempts are made to retrieve lost packets. This requires an additional buffer in the former node to keep the packets while waiting for acknowledgment delivery, which comes costly. Contrary to that, some sensitive traffic reduction in the rate of data transmission is not permitted.

Congestion control generally consists of three mechanisms: congestion detection, congestion notification, and rate adjustment. There are several existing congestion detection mechanisms in WSNs, including single buffer threshold [16][10][11][13][14][15], dual buffer thresholds as well as weighted buffer difference approach [17], packet service time [18], the ratio of packet service time over packet inter-arrival time at the intermediate nodes [11] or packet service ratio [15]. After the congestion detection step, the transport protocol propagates the information regarding the congestion from the congested node to the sensor nodes through source nodes. This is completed clearly by transferring a separate control packet to all other sensors, or indirectly by inserting congestion in the header of each data packet using piggybacking techniques. Congestion information can be as minor as a binary Congestion Notification (CN) bit [16][19][20] or include further details such as the rate of send data [10] or degree of congestion as stated in [11]. When an intermediate or source node gets a CN message, it should regulate its data sending rates via a rate adjustment algorithm like the Additive Increase Multiplicative Decrease (AIMD) technique. However, more accurate data rate regulating can be prepared if additional, comprehensive congestion facts are accessible.

Most of the literature used the First Come First Serve (FCFS) approach, pre-emptive, and non-pre-emptive priority scheduling methods which cause more data transmission delay and big processing overhead. In this paper by considering our previous work FCCPAQM[26] and mentioned limitations, we will control end-to-end delay constrains with node output scheduling weights for high priority traffic. We proposed a novel optimized congestion management protocol consisting of congestion avoidance and congestion control. The proposed model supports two traffic classes: the high-priority (HP) class and the low priority (LP) class. The HP class is used for sensitive traffic such as emergency conditions. The emergency data must be assured to be transported within a sensible delay (critical signs, such as blood pressure and heartbeat rate). Since constrained delay bound is a significant matter for HP traffic, the suggested model guarantees the constrained delay bound to this particular sort of traffic. The LP class is also used for non-sensitive traffic (emotional signs such as leg sensors). All HP and LP traffic are buffered in two separate queues. The HP traffic is managed by the weighted fair queuing (WFQ) scheduler at the output of the intermediate nodes, while LP traffic can be controlled via active queue management algorithm (AQM) [21][22][23]. The AQM algorithm is used to evade congestion as much as possible due to the probability of packet drop. If the data transfer rate increases and congestion avoidance is not possible, the protocol controls the congestion by an optimization function.

The rest of this paper is prepared as follows: In section 2, current related Works in congestion control are stated. Under section 3 the proposed congestion management protocol is argued. In section 4, we explain performance evaluations that highlight our paper's efficiency by using computer simulation. We finally conclude in section 5.

II. RELATED WORKS

In this section, the existing congestion control approaches are investigated and divided into Congestion Control Protocol in WSNs and Healthcare WSN, respectively.

A. Congestion Control in WSN

Different congestion control techniques have been proposed for WSNs from 2003 onwards, such as [16][11][24][25][26].

In [11] a hop-by-hop upstream congestion control protocol (PCCP) wireless sensor networks was suggested. This protocol employs a cross-layer optimization and enacts a hop-by-hop tactic to control the congestion grounded on the presented degree of congestion and the node's priority index. It also establishes that PCCP attains energy effectiveness and flexible weighted fair-mindedness for together multipath and single-path routing. Nevertheless, PCCP does not use a method for controlling arranged traffic originating from a single node using multiple sensors.

Enhanced Congestion Detection and Avoidance (ECODA) [17] suggests an innovative energy-efficient system for congestion control in sensor networks. It utilizes a flexible scheduler for the queue, while scheduling packets are done based on priority. Transient congestion and persistent congestion are well thought-out by ECODA. It implements a hop-by-hop scheme for controlling congestion in the case of transient congestion where it regulates the bottleneck node, based on send control rate of source data for persistent congestion. ECODA accomplishes effective congestion control as well as flexible weighted fair-mindedness for various classes of traffic. The result is lesser packet loss, upper energy effectiveness, and improved QOS in the case of throughput as well as delays.

The distributed congestion control algorithm [13] was offered for tree-based communications in WSNs. It assigns a reasonable and effective transmission rate for every node. This algorithm distributes the entire change in a control interval into separate flows to accomplish fair-mindedness.
A content-aware cross layer congestion control protocol (WCCP) was proposed using the properties of multimedia content [25]. This protocol uses a congestion avoidance protocol in the source nodes, and a receiver congestion control protocol in the intermediate nodes. At the source, it uses a group of picture size prediction algorithms to detect congestion in the network and avoids congestion by adjusting the sending rate of source nodes. In addition, in recover monitors, it uses the queue length of the intermediate nodes to detect congestion in monitoring and event-driven data.

In [27] a hierarchy-based congestion control method is used. Firstly, the network model is considered a hierarchical topology. Each node's neighbour nodes are divided into three classes; the hierarchical nodes, the upstream nodes, and the downstream nodes. Afterward, in the congestion avoidance method, the nodes use other lower hierarchy neighbour nodes to forward data when the child nodes are congested. Finally, the congestion control mechanism will detect the congestion via the queue length, forwarding and receiving rate, and inform its upstream nodes to find other next hop and release the congestion.

In [28], a novel mobile node as a charger is proposed to increase sensor nodes' lifetime. Also an algorithm called initial constant congestion window (ICCW) is proposed in order to handle the congestion of the bottleneck links. The ICCW method manages new sending rate for effective utilization of the link capacity by injecting two different threshold values in the TCP procedure.

In [29], a framework is proposed to ensure higher dependability levels and lower delays in emergency messages. The presentation results indicate that the message's trustworthy delivery and small delays for monitoring are obtained via broadcast or multicast-based routing algorithms in wireless ad hoc networks. The [30] proposes a Queue management system as well as an energy effective congestion control protocol for the WSN. The suggested protocol emphasizes effective management of queue to offer the dependability and decrease loss of packets. It can support several applications in the same network via utilizing a whole packet sequence number.

The Prioritized Heterogeneous Traffic-Oriented Congestion Control Protocol for WSNs (PHTCCP) [15] implements hop-by-hop rate adjustment in order to control congestion and ensure effective rate for the prioritized diverse traffic. It uses an inter-queue and intra-queue priorities and weighted fair queuing for feasible transmission rates insurance in the case of heterogeneous data.

It has been proven that most of the current MAC protocols propose early channel access to traffic with high priority, but these protocols do not offer the true pre-emptive priority. Actually, there is no mechanism to interrupt or pause the low priority traffic ongoing transmission in order to simplify the immediate channel access for data with high priority. As a result, in [40] a taxonomy has been proposed based on the classification of lately proposed traffic prioritization MAC protocols (‘Duty-Cycle Adaptation’(DcA), ‘Adaptive Contention’ (AC), ‘Hybrid’ (HY) and ‘Queue Management’ (QM)).

In [42] an effective algorithm (DACC) for multiple traffic in WSNs is proposed to overcome the disadvantage of First In First Out (FIFO) depend on sensor nodes at gateways. DACC algorithm consists of two phases. The first phase is applied at the initial step at the gateway that detect congestion and the second one changes the duty cycle which is dependent on packet marking field. The result of examining this algorithm indicates reducing congestion and the improvement in distinguishing stability between non-pre-emptive and pre-emptive information.

Authors in [45] proposed a multi-objective congestion control optimization algorithm called PSO GSA to optimize and regulate the rate and arrival data rate from every child node to the parent node, respectively. The energy of each node is an important factor that is considered in the fitness function. In this method, the transmission is done by regarding priority as the optimization method regulates the data arrival rate based on output available bandwidth, each child node's energy.

In [46] free traffic management is proposed in WSNs. Authors in [46] have introduced the packet priority intimation (PPI) to control the congestion. The PPI bit in added in each packet to show its importance. As a result, packets with higher priority are transmitted by lower delay. This is because of the reduction of different packets priority comparison time. The PPI is used in the current standard AODV routing protocol and converts it into a congestion aware routing protocol.

An improved ACO based QoS-aware routing protocol (EAQHSeN) is proposed in [48] for heterogeneous WSNs. This protocol can satisfy the various Qos constraints of heterogeneous traffic load, which has a lot to do with scalar and multimedia sensor nodes. The independent routing path for each kind of data traffic load should be explored to meet the divers QoS requirements. The residual bandwidth and E2E delay are considered as the heuristic factor by EAQHSeN protocol to select the next-hop node for multimedia data traffic. The results show the enhancement in E2E delay, residual energy, and data delivery ratio compared to standard protocols (EEABR, AODV).

B. Healthcare WSN and Congestion

In vital health applications, congestion is exceptionally undesirable. In this situation, a critical packet of a dying patient may be dropped in a node, and it may lead to a human's death. Also, in some healthcare applications like vital sign constant monitoring, we need a constrained delay bound.

The [31] is a prioritization grounded congestion control protocol in HWSNs. This protocol allocates dissimilar priorities for physiological signals while offering an improved QOS to transition extremely critical signs. Congestion control is achieved by considering congestion at the parent node along with priority on the child nodes when passing on network bandwidth to signals after several patients.

In [10] (HOCA) we designed a congestion management protocol consisting of congestion avoidance and congestion control stages. The congestion avoidance stage used a novel multipath and priority-based routing algorithm to avoid congestion. If the network's data traffic rate increases, the congestion control stage solves a cost function and calculates new send rates.

The priority-based congestion control method based on queue length is proposed in [32] for WBAN. This protocol has two key phases; Quick Start and Congestion control module. The quick-start method works till the congestion control module comes into action. The quick start phase starts with more packets initially, while the initial rate of sending one packet to sink by each sender node in the network is slow. The congestion control module has three stages. It first detects the congestion level by measuring the queue length, then sink sends a congestion notification bit to the sender node in the ACK packet. Finally, after receiving the notification of congestion, the packet send rate is adjusted in Additive Increase and Multiplicative Decrease (AIMD) manner by sender nodes according to each sender node priority.

In [35] a new rate control mechanism has been proposed by providing a unified method for both congestion and hotspot avoidance in WBAN. This work presents a scheduling rate allocation mechanism regarding the relative priority of sensors. The paper improves the performance of healthcare applications in terms of throughput, reliability, latency, and energy consumption.

In [43] a Priority-based Congestion-avoidance Routing Protocol (PCRP) is proposed for the energy efficiency of IoT-based medical sensors in multi-hop WBANs. Data packets are divided into two categories: normal and emergency data packets. The fitness function for normal data packet is calculated using three parameters, including, residual energy (RE), signal-to-noise ratio (SNR which is used for selection of better path between sender and receiver) and node congestion level (NCL which is applied for seeing the forwarder node status). For vital data, a priority bit is added to the data packet. Their priority label schedules data packets in each node and the packet which have a label is scheduled first before the normal data packet.

A Priority-Based Energy-Efficient Routing Algorithm (PERA) is provided in [44] for WBANs. Packet data are divided into normal, on-demand, and emergency data. The shortest-hop routing and direct path are used to send normal data and vital data to the sink, respectively. The highest, medium, and lowest priority are assigned to the emergency, on-demand, and normal data, respectively.

In [47] a scheduling and differentiated traffic method for HWSNs is proposed. The patient's transmission of vital data between sensor and coordinator nodes is done in a single hop. The coordinator keep path using communicating echo messages for the transmission between gateway and coordinator. The data's importance is determined based on the threshold values and are divided into three priority levels: Normal, Moderate and Urgent.

In [49] authors proposed a congestion protocol for WBANs, in which a method similar to the random early detection (RED) active queue management (AQM) to avoid congestion. A two-input-single-output fuzzy logic system is applied to adjust the RED algorithm's maximum drop probability (max_p) parameter. Two adaptive values the minimum threshold (min_{th}) and the maximum threshold (max_{th}) are used to predict the congestion level of each sensor node. The parent node's send rate is also adjusted using a fuzzy logic controller (FLC) based on the child's node traffic load. This proposed protocol obtains high performance in terms of packet loss, end-to-end delay, and energy.

In [50] authors work on a real sensor application in a congested IoT network. They try to maximize energy in IoT by minimizing the average packet transmission delay. In this paper, a healthcare data identifier is added to the IP packet header at the sensor level. Then the QoS software is altered at the network router level. The highest priority to healthcare data packet is provided using the healthcare data identifier. The result illustrates that doctors can receive data packets equipped with an identifier with 80% less latency than those transmitted packets without an identifier to save the human lives.

A distributed congestion routing protocol for IoT-base WSN is proposed in [51] to ease smart healthcare applications' congestion. The authors decrease and control the congestion using a priority-based data routing approach. They provide a priority queue based scheduling scheme to guarantee reliability. They take advantage of their proposed method to detect most arrhythmia events categorized by the Holter monitor.

The majority of existing research studies took advantage of the First Come First Serve (FCFS) approach, pre-emptive and non-pre-emptive priority scheduling, respectively. Using these methods leads to more data transmission delay and big processing overhead. In this paper, we control end-to-end delay constrains with node output scheduling weights for high priority traffic. For low priority traffics, we first avoid congestion by using a new Active Queue Management (AQM) algorithm that uses a distinct virtual queue's situation for a single physical queue to decide to accept or drop the received packets from child nodes.

III. THE PROPOSED PROTOCOL

In this section suggested congestion management protocol for HWSNs is proposed. This protocol's core objective is to evade, or if not likely, control congestion in HWSNs. This protocol's motivation is due to the restrictions of two current methods, FCCPAQM [26] and FCFS.

In [26] we introduced a Fuzzy Congestion Control Protocol Based on Active Queue Management for Healthcare WSNs when the patients are stationary in bed. Here we managed congestion in two stages. In the first stage, a novel Active Queue Management (AQM) scheme is proposed in order to avoid congestion and provide quality of service (QOS). We used separate virtual queues on a single physical queue to store the input packets from each child node based on the importance and priority of the source's traffic. In the second stage, the congestion is detected by a three-state machine and virtual queue status; it adjusts the child's sending rate by an optimization function. In some situations, we have constraints on end-to-end delay from patient to doctor (source to sink node) and quality of service parameters are very sensitive to delay. The challenges of using FCFS approach is the more delay of data transmission and big processing overhead.

The scenario for the proposed protocol can be employed for stationary patients who are not able to move in the clinics or hospital in which sensor nodes placing on specific parts of the patient's body, detect the patient's vital signs, and transmit sensing data to a medical center or doctor.

Our proposed mechanism solves the problems by a new rate adjustment optimized algorithm. The optimization function regulates only the sending rate of low priority packets coming from every child node grounded on parent available bandwidth, packet drop probability, and dynamic priority regarding every child node. The architecture for the suggested protocol is illustrated in Fig 3. It involves two phases; the first phase attempts to avoid congestion via AQM algorithm. It chooses either to drop or a received packet, based on the probability of packet drop. If the received packet is accepted, then second phase occurs where three different techniques are employed to control potential congestion. Methods include Automata-based Congestion Detection (ACD), implicit Congestion Notification (ICN), as well as optimized Rate Adjustment (ORA).

Congestion detection by ACD is done through a three-phase machine and virtual queue status. ACD output is the congestion level ($0 \leq CL \leq 1$). If CL goes higher than the specified threshold, an optimized rate adjustment (ORA) process is done. This process will solve the problem of optimization and will acquire new share rates for child nodes. Meanwhile, in healthcare applications, every patient node may be installed with several sensors having diverse priorities; priority is a significant parameter in our proposed model. Child priority (*CHP*) is used as well as Available Bandwidth (*AB*) as input parameters regarding the function of optimization ($AB=1-CL$). ORA process computes the new share rates for local source traffic and every child node.

The suggested protocol makes use of implicit Congestion Notification (ICN) that piggybacks information related to congestion in the header section of data packets and prevents transferring extra control messages that will subsequently cause progress for energy efficiency.

Before describing suggested model in detail, some definitions associated with the priority are provided as follows:

Definition 1: Static Priority for node *i* (SP^i) is defined as:

$$SP^i = PI^i . \sum_k SP_k^i \tag{1}$$

Where, the importance of a Patient ($0 \leq PI^i \leq 1$) for node *i* is the degree of importance for that patient.

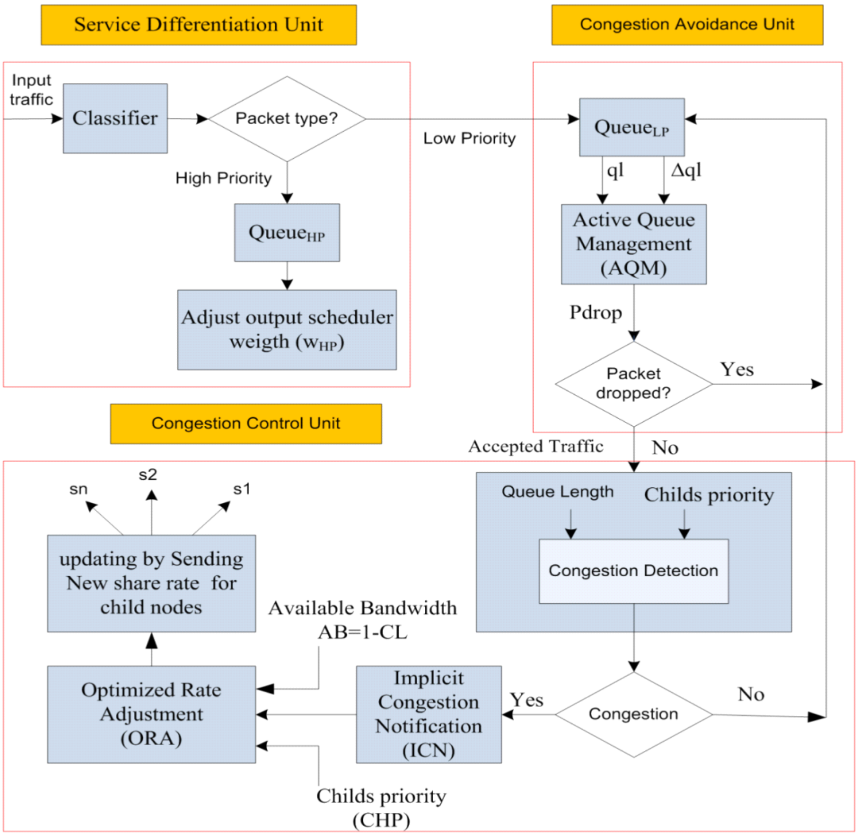


Fig. 3. Suggested congestion management protocol architecture.

For instance, a diabetic patient or patients with heart disease, differentiate when it comes to importance. Parameter represents the *kth* priority of source data for a sensor type for node *i*. The rate can be set by hand for service variation. *k* is the type of sensor on the body of patients.

Definition 2: (GLP^i) is Global Priority for node *i* and defined as:

$$GLP^i = TP^i + SP^i \tag{2}$$

Where, TP^i indicates Transit data Priority for node *i*. It indicates the relative importance of transit data traffic passed through node *i*.

Definition 3: Global Priority Ratio for every virtual queue *j* in node *i* are described as follows:

$$GPR_1^i = \frac{SP^i}{GLP^i}, \quad GPR_j^i = \frac{GLP^j}{GLP^i}, j = 2,3,\ldots,N_i+1, \tag{3}$$

Where N_i indicates count of child nodes for node *i*.

Definition 4: Normalized Child Priority *j* in node *i* (NCP_j^i) is defined as:

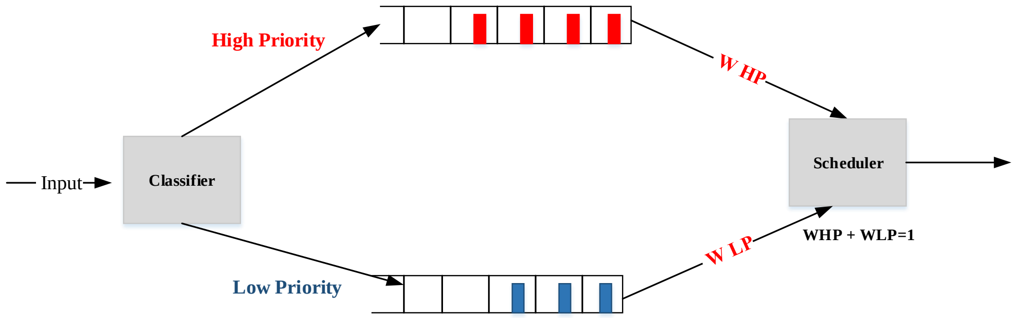


Fig. 4. Queuing model on a particular node.

$$NCP_j^i = \frac{GPR_j^i.(1-CL_j^i).\overline{D}_j^i}{\sum GPR_j^i.(1-CL_j^i).\overline{D}_j^i} \tag{4}$$

Where CL_j^i is the congestion level of virtual queue j in node i , and average delay $\overline{D}_j^i$ of each virtual queue *j* in node *i* is obtained as follows

$$\overline{D}_j^i = \frac{\sum_k \overline{D_k^j}(i).SP_k}{\sum_k SP_k} \tag{5}$$

The $\overline{D}_k^j(i)$ is the average delay of packet type *k* in virtual queue *j* at node *i*.

A. Service differentiation unit

The service differentiation unit establishes traffic in two traffic classes based on whether the traffic equals the required QOS principles [36]. The QOS criteria are constrained delay for HP class traffic and low packet drop rate (due to buffer overflow) for LP class traffic. HP class traffic belongs to the patient's vital signs sensors and needs constraining end-to-end delay bound, and their data generation rate cannot be reduced. LP class traffic comes from the patient's motion detector sensors and needs a low packet drop. The queuing idea of every node is illustrated in Fig 4. In this model a packet classifier selects packets from the input traffic stream cantered on the type of data packet and places them in the appropriate queue. A distinct queue is used for each traffic class and performance is evaluated under the weighted fair queue (WFQ) scheduler.

The (WFQ) algorithm at the output of the node schedules the traffic classes based on each queue weight (W_{HP} and W_{LP}). Since HP class traffics need a constrained end to end delay, its packets should be delivered to the sink within a guaranteed end-to-end delay deadline. Fig 4 demonstrates a single path route between a patient and doctor with *N* intermediate nodes and total allowed constrained delay. In this figure an HP class packet arrives at node *i* with a total constrained delay allowed (TD).

Table I. Basic notations used for calculating output scheduler weight.

Constrained delay from node *i* up to sink node	ND (Node Delay Constrained)
Total delay constrained from the source node up to sink node	TD (Total Delay Constrained)
Remained delay allowed from node *i* up to sink node	RD (Remained Delay Constrained)
Total number of hop counts from source node up to sink node	TH (Total Hop Count)
Number of hop counts remained from node *i* up to sink node	RH (Remained Hop Count)
Packet delay from source node up to node *i*.	PD (Packet Delay)

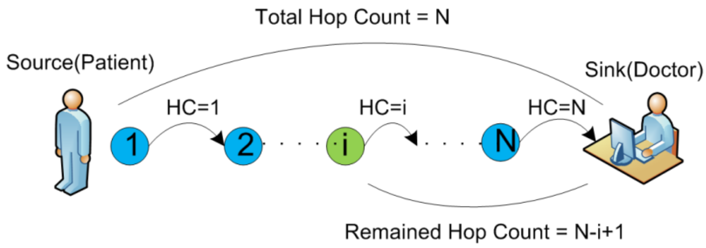


Fig. 5. Linear multihop path between the patient's source sensors and the Sink.

The scheduler weight for the high priority queue in node I (W^i_{HP}) should be recalculated to guarantee the total end-to-end delay deadline: (the basic notations are as in table 1)

$$w^i_{\mathrm{HP}} = w^i_{HP} + \alpha\left(\frac{\mathrm{ND}-\mathrm{RD}}{\mathrm{ND}}\right) \tag{6}$$

$$\mathrm{RD} = \mathrm{TD} - \mathrm{PD}$$

$$\mathrm{ND} = \frac{\mathrm{TD}}{\mathrm{TH}}.\mathrm{RH}$$

Where $0 \le \alpha \le 1$ is a flexible parameter.

Since low priority (LP) class traffic has lower priority and can tolerate loss rate, so after each new weight calculation for HP class traffic, the w_{LP} ($w_{LP}=1- w_{HP}$) is obtained as in Fig .5.

For example, suppose that there are $N=5$ intermediate nodes in a single path route from a patient's place up tom doctor station. If a patient goes to a critical state and sends a delay constrained (high priority) packet (TD=0. 3 second) from its vital sign sensors toward the doctor place and this packet arrives at node i= 3 with delay PD= 0.2 Sec then,

RD=TD-PD=0.3-0.2=0.1 Sec

This means that this packet has only 0.1 second deadline to reach the destination. At this moment our algorithm calculates new weight for the output scheduler weight so it can service the packet on time.

$$\mathrm{ND} = \frac{\mathrm{TD}}{\mathrm{TH}}.\mathrm{RH} = \frac{0.3}{5}.3 = 0.18\mathrm{Sec}$$

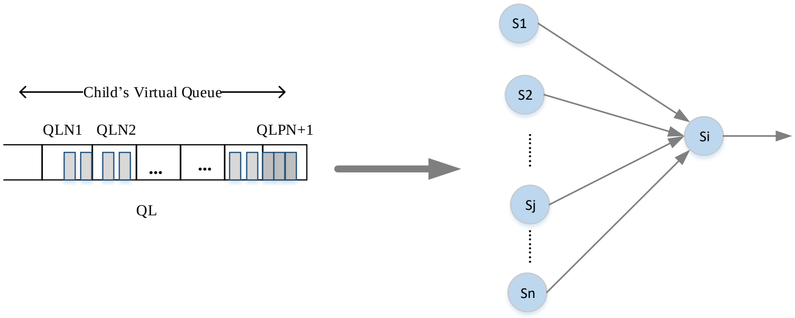


Fig. 6. The LP class queue is separated into *N+ 1* virtual queue.

It means that this high priority packet has arrived as late as (*ND-RD=0.18-0.1=0.08 Sec*) to node *i*. In this case the output scheduler weight should increase.

B. Congestion Avoidance Algorithm

Active Queue Management (AQM) structures are methods designed to escape the congestion and provide QoS by pro-actively dropping packets [21][37][23][38][39]. Using these structures, controlling congestion is obtainable, and improvements are gained for network performance performances such as network delay, link utilization, packet drop rate, and system fairness. The presented protocol utilizes a flexible process to complete queue management for LP class traffic. This process practices distinct virtual queues to store the input LP class packets from every child node. This indicates that the physical LP class queues with maximum size M*QL* are virtually shared amongst *N* child node's LP class traffics. One local source's LP class traffic centred on their importance and priority (Fig. 6). If a child node has extra priority, additional space can be used for its queue. Still, the boundaries amongst virtual queues are not constant; therefore, when a child node has open space in its virtual queue, others can use the unoccupied space if required.

When an LP class packet is obtained from a child node *j* by a parent node, packet drop $Pdrop_j$ is calculated for that packet. At start the primary value of packet drop possibility for child *j* ($\mathrm{Pdrop}_j^{\mathrm{pri}}$), is computed as below:

$$Pdrop_j^{pri} = \begin{cases} q_j < \alpha_1.QL.CP_j & 0 \\ \alpha_1.QL.CP_j < q_j < \alpha_2.QL.CP_j & \dfrac{q_j - \alpha_1.QL.CP_j}{\alpha_2.QL.CP_j - \alpha_1.QL.CP_j} \\ q_j > \alpha_2.QL.CP_j & 1 \end{cases} \tag{7}$$

Here q_j is the size of queue for the *j*th virtual queue belonging to the *jth* child, while *MQL* is the maximum size of the physical queue. a_1 are a_2 respectively lower and upper thresholds that can be attuned over simulations. NCP_j indicates normalized child node priority.

Remind that *MQL*.NCP_j denotes the virtual queue share for child *j* in the physical queue *MQL*. Once the primary value of packet drop possibility is calculated, AQM method computes packet drop P_j as below:

$$\mathrm{Pdrop}_j = \beta_1.\delta \mathrm{qv}_i - \beta_2.\left(1-\left(\sum q_m / \mathrm{MQL}\right)\right) + \mathrm{Pdrop}_j^{\mathrm{pri}} \tag{8}$$

The primary value for the drop probability $Pdrop^{pri}{}_j$, is adjusted based on the network condition. The second expression ($1-(\sum_{m=1}^{k} q_m / QL)$) determines the total free space percentage in the physical queue. In other words, the more the free space is, the less packet drop probability will be achieved. However, the effect of this value depends on the β_2 parameter.

δqv_j is the virtual queue length difference of the *j*th child and is calculated as:

$$\delta \mathrm{qv}_j = \frac{q_j^{\mathrm{new}} - q_j^{\mathrm{old}}}{\mathrm{MQL.NCP}_j} \tag{9}$$

The value of qv_j can be either negative or positive. qv_j is multiplied by coefficient $_{B1}$, as offered in equation (8). Keep in mind that parameters in equations (7) to (9) are defined in a periodic manner. Thus, the value of $q^{old}{}_j$ is the *j*th virtual queue size at the start of the last period, and the value of $q^{new}{}_j$ is the *j*th virtual queue size at the end of the last period and the beginning of the new period. If the differential of *j*th virtual queue size turns positive, qv_j will also turn positive, and still continue positive after multiplying by β_1 value resulting increment in P_j. This shows that if the variation in the virtual queue length is positive, therefore there is increment in packet drop possibility. According to the drop possibility P_j value,s If the packet does not drop and is accepted and places in its virtual queue in the parent node *I* then our protocol goes into the congestion control process.

C. Congestion Control Algorithm

1) Three state Automata: automata are used in order to decide congestion levels in each intermediate node. The fundamental philosophy of automata is that automation is self-operating machinery, or a method which replies to a sequence of commands in a specific way in order to obtain a certain goal. Suggested three state automata is mapped to the 5-tuple {Q, A, B, F (.,.), G (.)}, in [40]:

Q = {*Normal*, *Congestion Avoidance*, *Congested*} defines set of finite states.

A = {0<*congestion level*<*1*} is the output.

B = {q_1, q_2... q_k} is the inputs to the automaton, which signifies a queue portion of every child node in the physical queue at the time of t.

F (.): Q×B → Q is the function of transition (that is a function deciding state of the automaton at any ensuing time instant (t+1)) mapping for the state and input at the instant t, such that, q (t+1) = F (Q, B).

G (.): G: Q → A is the output function mapping that defines output of automaton (*congestion level*).

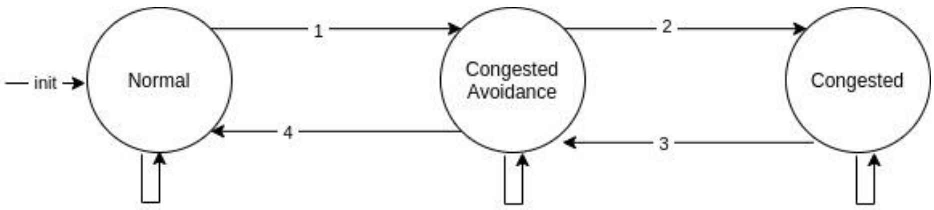


Fig. 7. State diagram for congestion-detection.

Suggested automaton is shown in Fig 7. Finite states are demonstrated via circles and transitions are symbolized by the shape of arrow. When automaton comes across a symbol of the condition, based on equation (9), transition happens to alternative state according to the function of transition. Once the packet is acknowledged and queued in a virtual queue in the parent node, three finite states of machine compute the level of congestion.

$$\begin{aligned}
&\text{I: if } \textstyle\sum_{m=1}^{k} q_m > MQL.\alpha_1 \text{ or } \exists\, j \mid q_j > MQL.NCP_j\\
&\text{II: if } \textstyle\sum_{m=1}^{k} q_m > MQL.\alpha_1 \text{ or } \forall j \in s,\, L_j > 0.95.\ MQL.NCP_j\\
&\text{III: if } \textstyle\sum_{m=1}^{k} q_m < MQL.\alpha_2\\
&\text{IV: if } \textstyle\sum_{m=1}^{k} q_m < MQL.\alpha_1\\
&0 \le \alpha_1 \le \alpha_2 \le 1
\end{aligned} \tag{10}$$

I. At beginning each node is in a Normal state. At this status, arrival rate from node neighbors is smaller or equivalent to service rate of the relative queue. Therefore congestion will not occur for nodes and the average length for virtual queue is less than their portions. Once the virtual queues total length turn out to be higher than $MQL.\alpha_1$, or at least one of the virtual queues surpasses its particular portion, the transmission rate of neighborhood will increase and the node will convert from the Normal state to the state of Congestion Avoidance.

II. In the state of Congestion Avoidance, once the arrival rate rises, the algorithm avoids congestion to a possible extend. More severities are used for avoiding congestion in comparison to Normal state. If the overall length of virtual queues goes above $MQL.\alpha_2$, or for every neighborhood set of s (s is half of neighborhood number k/2), the related size of the virtual queue is higher than ninety five percent of its portion, then state of the node will turn into the state of congestion.

III. A node in the Congested state has congestion. If the entire length of queues turns out to be lesser than $MQL.\alpha_2$, the node switches to the state of Congestion Avoidance. This aids the node to adjust itself in the condition of reduced congestion and this matter helps in measuring the congestion level.

IV. Similarly, if in the state of Congestion Avoidance, the overall queue length turns into lesser than $MQL.\alpha_2$, the node returns to the state of Normal.

The α_1 and α_2 is the thresholds of transferring from Normal to Congestion Avoidance state vice versa from Congestion Avoidance to Congestion state.

2) Automata based Congestion Detection (ACD): ncl_i which is the node congestion level can reveal current level of congestion in sensor node of i. At each node i with k child nodes shown in Fig. 3, the level of congestion in *j th* child (cl_j), is calculated grounded on current virtual queue and the automaton status. The assumption is made that every child node which is distributing traffic, buffers it in an individual virtual queue. Primarily, every queue is in the Normal state. So if a child node's traffic is located in a virtual queue in the state of Normal, and q_i (size) is greater than its share, level of congestion in the child node denoted via cl_j is computed as below:

$$\forall j, \text{if } \frac{q_j}{\text{MQL.NCP}_j} \geq 1 \text{ then } \quad \text{cl}_j = \frac{q_j}{\text{MQL.NCP}_j} - 1, \quad \text{else cl}_j = 0 \tag{11}$$

Where $MQL.NCP_j$ is the *jth* child node's portion of physical queue MQL in node *i*. If sent traffic from a child node is placed in a virtual queue with Congestion Avoidance state, the child node congestion level is obtained as:

$$\forall j, if \begin{cases} \frac{q_j}{MQL.NCP_j} < 1/3 \longrightarrow cl_j = 0 \\ 1/3 < \frac{q_j}{MQL.NCP_j} < 2/3 \longrightarrow cl_j = \frac{q_j}{MQL.NCP_j} \cdot \frac{L_j}{MQL.NCP_j} \\ \frac{q_j}{MQL.NCP_j} > 2/3 \longrightarrow cl_j = \frac{L_j}{MQL.NCP_j} \end{cases} \tag{12}$$

Where L_j denotes average length of the *jth* virtual queue, with the rate of input μ, and rate of service denoted via λ in a server system calculated as follows [41]:

$$\begin{gathered} L_j = \frac{\rho}{1-\rho} - \frac{(k+1).\rho^{k+1}}{1-\rho^{k+1}}, k = \text{QML.NCP}_j \\ \rho = \frac{\lambda.(1-P_k)}{\mu} \\ P_k = \frac{(1-\rho),\rho^k}{1-\rho^{k+1}} \end{gathered} \tag{13}$$

K is the total queue size and $P = (\lambda/\mu)$. If the sent traffic from a child node is placed in a virtual queue with Congestion state, the child node congestion level is calculated as:

$$\forall j, if \begin{cases} \frac{q_j}{MQL.NCP_j} < 1/3 \longrightarrow cl_j = \frac{q_j}{MQL.NCP_j} \cdot \frac{L_j}{MQL.NCP_j} \\ \frac{q_j}{MQL.NCP_j} > 1/3 \longrightarrow cl_j = \frac{q_j}{MQL.NCP_j} \end{cases} \tag{14}$$

The cl_j is used for the rate adjustment. Using equation (14) for congestion level, node congestion level ncl_i can be computed for every single *i* sensor node as follows:

$$ncl_i = \sum_{j=1}^{k} NCP_j.cl_j \quad (15)$$

The *node congestion level (ncl)* shows accessible bandwidth for a node *(AB = 1- ncl)*. In the condition that packet arrival rate stands bigger than the packet service rate (*ncl* >0), congestion happens for the node.

3) Implicit Congestion Notification (ICN): There are two approaches to notify information regarding congestion: First is Explicit Congestion Notification (ECN), and second is the Implicit Congestion Notification (ICN). ICN practices particular control messages, which result in added overhead. Meanwhile, wireless channels' broadcast nature aid child nodes to get acknowledgment and congestion statistics from the parent data packet header. Therefore, extra control messages are not transmitted.

4) Optimized Rate Adjustment (ORA): Assuming node *i* owns *k* child nodes which can send packets to parents and forwarding them towards the sink, by their initial rate. The maximum rate for every node is denoted by r_{max}. Congestion will occur in node *i* in the case that overall average rate of child nodes will be greater than the service rate. In this condition, an optimization problem can be utilized in order to calculate the new child nodes sending rate shown in Fig.4. Following, we suggest an optimization problem, in order to compute the new child nodes sending rate.

$$\text{Min}F_i = \sum NCP_j . Pdrop_j . \frac{AB_j.(1-w) - S_j}{\varepsilon . S_j} \quad (16)$$

S.t.

$$S_j \geq 0 \quad , \quad 0 \leq \alpha \leq 1 \quad (16\text{-}1)$$

Where

$$0 \leq CP_j \leq 1, \quad AB_i = 1 - ncl_i \quad (16\text{-}2)$$

Fig. 8 clarifies the equation (16). Equations (16-1) and (16-2) show the circumstances of optimization problem. The purpose of optimization is to reduce the cost function of equation (16). In present function, *N* denotes the number of child nodes of node *i* and CP_j is the *jth* child node's normalized priority. This function computes new share rates (*N)* for the child nodes' data traffic as well as one for the local source node's data traffic. AB_i is the accessible bandwidth regarding node *i*. The total level of congestion at node *I*, is shown via *nuclei*. If the level of node congestion upsurges, its offered bandwidth reduces. For node *i* with *N* number of child nodes, overall share for every child node is founded according to equation (16-1), s_j is the portion of child node *j* for sending data determined by node *i*. The share is relative to maximum permitted bandwidth of a child node. Consequently the new sending rate for every child node can be computed as shown in Fig.8 ($r_{new} = r_{max} \times s_i$). In equation (16-

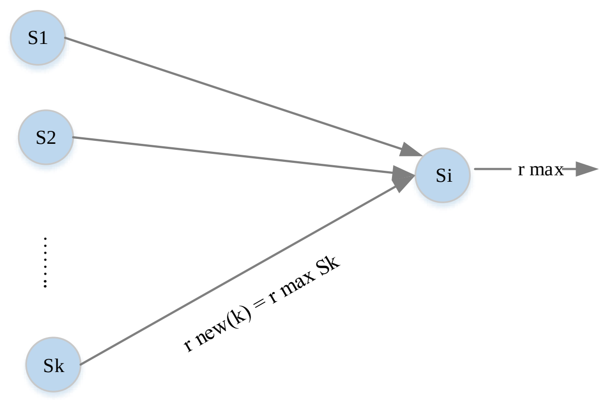


Fig. 8. The rate adjustment model utilized for intermediate nodes in low priority packets.

1), α is a constant value that has control over maximum rate of the overall share, relative with existing bandwidth.

IV. SIMULATION RESULTS

This section suggested protocol is simulated using MATLAB and OPNET software to evaluate its performance. The proposed protocol is compared to FCCPAQM and FCFS; hence, FCCPAQM is one of the latest and typical WSN congestion control protocols that can be applied for healthcare infrastructure. The optimization function in equation (16) is executed in MATLAB while the simulation is completed via OPNET. Ever since they are both programmed on C++ basis, links can be created between the two. So, simulation of the suggested protocol is done via linking MATLAB and OPNET software, both having a C++ compiler. During the simulation, MATLAB and OPNET software run concurrently. The optimization function equation and all other associated functions are executed via MATLAB software. OPNET is capable of calling functions in MATLAB at any time needed.

The topology of the network shown in Fig. 9 is utilized to measure efficiency for the suggested protocol in healthcare applications, and all simulation parameters are given in Table 2. We used the routing protocol in [10] for our scenario.

The parameters used for simulation are as follows:

- End to end delay: is source to destination transmission time for a packet.
- Packet drop: total number of dropped packets
- Source rate: total data packets created by a data source in each second.
- Arrival rate: number of arriving packets to a node
- Throughput: overall number of receiving packets by the sink per time.
- Queue Length: quantity of packets in a queue.

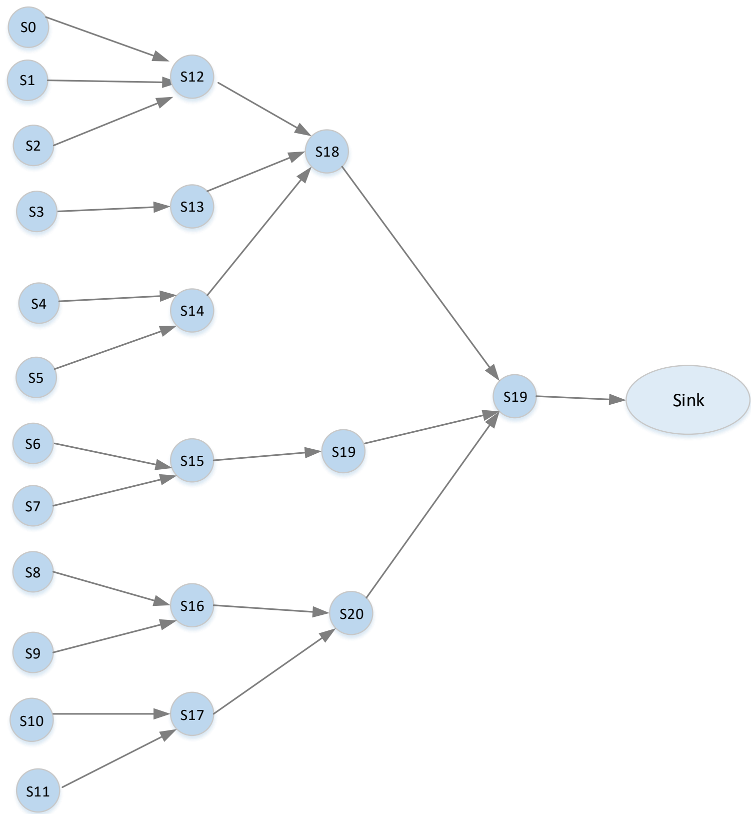


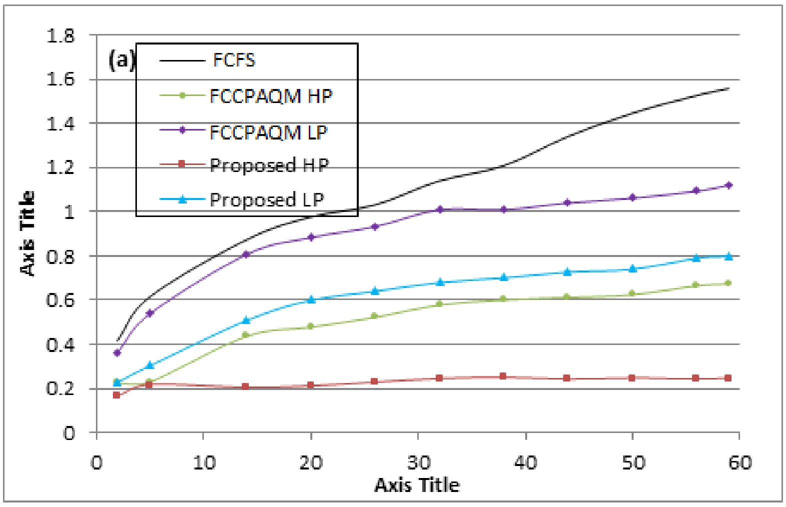
Fig. 9. The topology utilized for simulation.

Table 2. Parameters for Simulation

Radio range of a sensor node	40 meters
Initial node energy	50 joule
Type of traffics	High priority, Low priority
Network area	200×200 m^2
Packet send energy	12 MJ
Packet receive energy	10 MJ
Congestion detection epoch	Each 50 packet
Number of Sensor nodes	22
Number of Queues	2
Packet length	64 bytes
Transmit Power	0.660 W
Receive Power	0.395 W

A. Service Differentiation comparison

We evaluated the effect of service differentiation on end to end delay and packet drop. End to End delay is a parameter which is critically significant for the healthcare applications. It takes time for a packet to be transmitted from source to destination. There are different QOS requirements for the two classes. Class 1 (HP) is used for high priority sensitive data and requires a constrained delay, and their



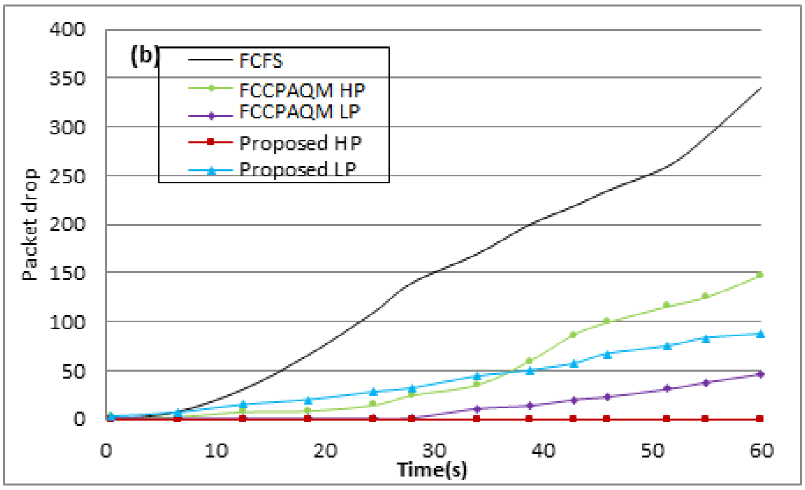


Fig. 10. The performance of the service differentiation unit using the WFQ scheduler: (a) End to end delay (b) Network total packet drop.

data generation rate cannot be reduced. Class 2 (LP) is used for low priority non-sensitive data and their data generation rates can be controlled and need low drop rate.

In this experiment we defined a constrained delay requirement (0.25 second) for the high priority class, and try to meet this delay bound by adjusting high priority queue scheduling weight periodically at the output WFQ scheduler at intermediate nodes in the source to sink path.

Fig. 10 dfiemonstrates end to end delay as well as packet drop for the two types of traffics in proposed protocol as well as FCCPAQM and FCFS protocols. From this Figure, Observations indicate suggested service differentiation unit can efficiently discriminate amongst traffic classes and meet QOS requirements. In the proposed protocol HP class, delay is nearby required constrained delay and in LP class a smaller packet drop rate can be seen rather than FCCPAQM and FCFS. In the proposed protocol, when HP traffic increases, W_{LP} and LP class service rate decrease. So, the

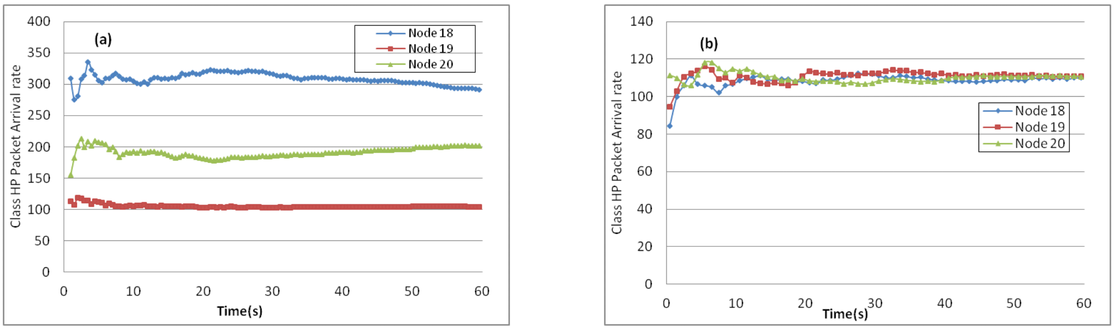


Fig. 11. Arrival rate of Class HP packet over time in node numbers 18, 19 and 20 (a) Proposed Protocol (b) FCCPAQM Protocol.

proposed protocol decreases child nodes send rates in order to meet the low packet drop rate for LP class traffic. This is obvious from Fig. 10 (b) after 40 second simulation.

B. Packet arrival rate comparison

Fig. 11 illustrates the arrival rate of class HP packets to node numbers 18, 19 and 20 for both proposed and FCCPAQM protocols. We assume only node numbers 0 to 11 are on and generating packets with initial source rate 50 packets per second for class HP. As it can be obtained from the topology in Fig 8, node numbers 18, 19 and 20 each have 6, 2 and 4 source nodes generating class HP packets in their sub trees respectively The results in Fig. 10 show that in proposed protocol the arrival rate of class HP packets in node 18, 19 and 20 are about 100, 200 and 300 packets per second respectively according to the number of source nodes in their sub trees, but FCCPAQM protocol reduces source send rates in a simple fair method.

C. Queue length comparison

Fig. 12 shows the variation in queue length of the nearest node to sink in the topology used for evaluation. Node 21 gets all traffic from its 3 child nodes and the classifier inside it put all the packets into two separate queues, one for high priority HP and one for low priority LP traffic. As displayed in Fig. 12, the presented protocol consequences a shorter queue length. The shorter the queue length, the more it can reduce queuing delay. This approves the lowest delay for the proposed HP traffic shown in Fig. 10. The packet drop due to buffer overflow is also reduced in case of low queuing delay and indirectly implies improving energy consumption since lost packets near sink node may have transitioned in more than a few hops while consuming certain energy.

D. Throughput comparison

In Fig. 13 we demonstrated the normalized throughput for proposed and FCCPAQM protocols. The system bandwidth (1000 packets/second) is normalized to the value of one. Within 0 to 60 seconds, every node is active and node numbers 0 to 11 are generating HP and LP data traffic with initial rate 50 packets /second each.

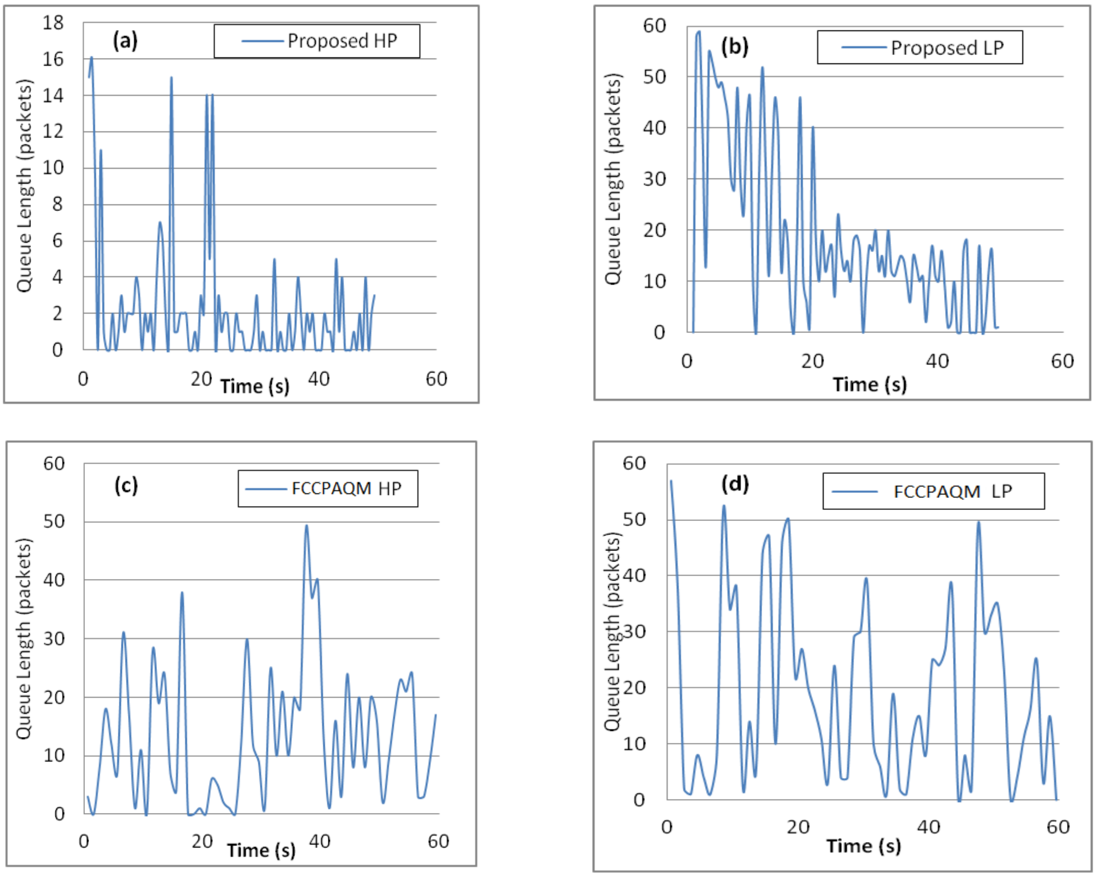


Fig. 12. Queue length at the node closest to the sink (node number 21). (a) Class HP of proposed protocol (b) Class LP of proposed protocol (c) Class HP of FCCPAQM protocol (d) Class LP of PH FCCPAQM protocol.

Since HP data traffic has a high priority with constrained delay and we are not allowed to reduce their rate, we should allocate proper bandwidth for them to meet the required QoS. As it is obvious in Fig. 13 HP data traffic gets near 0.6 throughputs in proposed protocol and near 0.65 in FCCPAQM protocol. This means that the proposed protocol does not change source data rates, and since there are 12 source nodes generating HP data traffic, so nearly all high priority data traffic is received in sink node. The FCCPAQM protocol increases the HP source data traffics and this leads to lower throughput (near 0.32) for LP data traffic. But this is not necessary. Results indicate that presented protocol can manage improved network resources to meet the required QOS.

E. Source Rate Comparison

The initial data sending rate of nodes for high priority class HP is assumed 50 and 150 packets/second correspondingly. The service rate of the near sink node that is node number 21 is 1000 packets/second. Moreover, all nodes have similar importance and priority. This can be happened to a part of the healthcare environment that involves patients with similar primary status. The Fig. 14 shows the source rate changing in the node number 0. As can be seen the proposed protocol does not reduce class HP traffic data send rate and instead it automatically adapts the class LP traffic data send

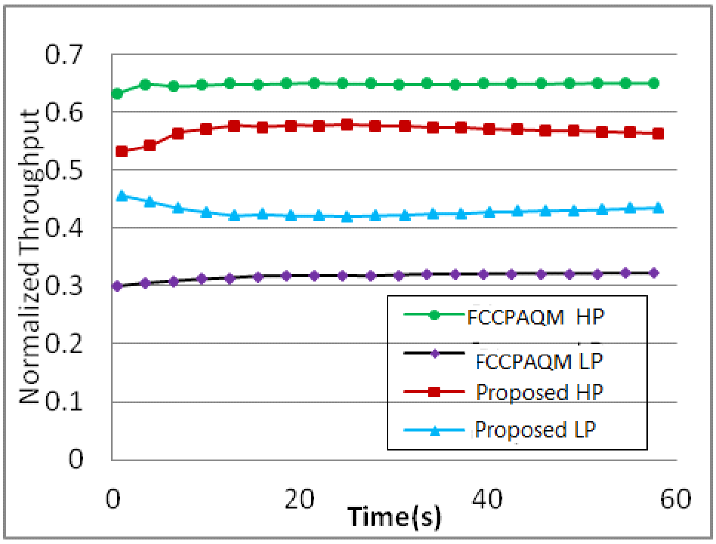


Fig. 13. Normalized throughput over time.

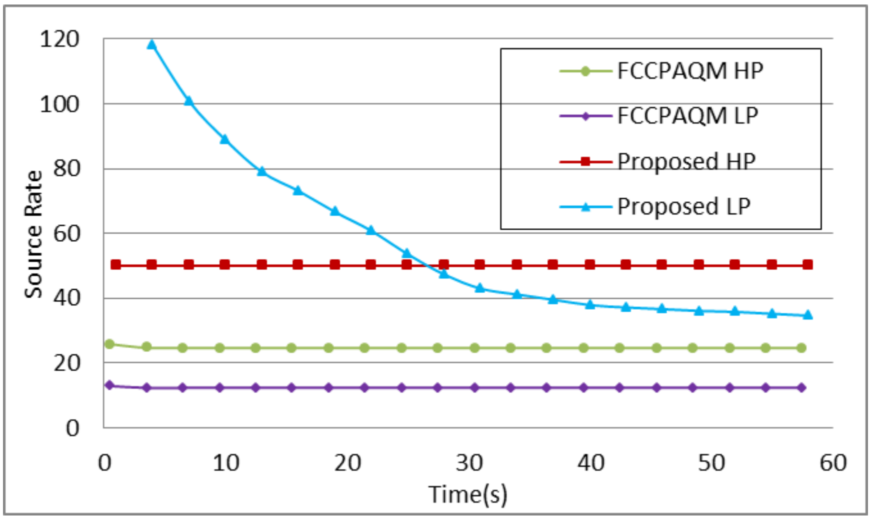


Fig. 14. Data source rate changing over time.

rate according to the network remaining bandwidth. But the FCCPAQM protocol changes the source rate based on the scheduling rate and the priority regarding every type of data.

V. CONCLUSION

This paper peovides a new congestion management protocol in healthcare WSN. The presented protocol supports two different traffic classes: high priority sensitive traffic class (HP class) and low priority non-sensitive traffic class (LP class). Since HP class traffics needs constrained delay bound, HP class queue's scheduling weight periodically changes at the output WFQ scheduler at intermediate nodes to meet the bounded delay requirements. For LP class traffics, an AQM method is used to avoid congestion with dropping or accepting the packet. If congestion cannot be avoided, the proposed protocol will mitigate congestion via an optimized rate adjustment algorithm in a hop-by-hop manner.

Outcomes of simulation indicate that the suggested protocol is more effective than FCCPAQM and FCFS protocols, and can achieve improved performance in terms of packet drop, constrained end to end delay, and throughput.

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