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LIST OF PUBLICATIONS

1. Vanitha.G,Amudha.P,"Quality of Service Aware Dynamic Bandwidth Allocation for Rate Control in WSN", International Journal on Recent and Innovation Trends in Computing and Communication, Vol.11, Issue 11s, ISSN: 2321-8169, pp.166-176, Oct 2023.(Scopus indexed)
2. Vanitha.G,Amudha.P,Sivakumari.S,"Smart Bandwidth Prediction, Power Management and Adaptive Network Coding for WSN ", International Journal of Intelligent Engineering and Systems,Vol.16, No.3, pp.105-114, June 2023.(Scopus indexed)



Avinashilingam Institute for Home Science and Higher Education for Women

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Coimbatore - 641 043, Tamil Nadu, India

Appendix L2

(Item No 5 of Check List)

Details of Research Publications

S.No	Article	Journal	Other Details Vol/No/Page No/ Year	Published in UGC-CARE / Scopus Indexed/ Web of Science
1.	Smart Bandwidth Prediction, Power Management and Adaptive Network Coding for WSN.	International Journal of Intelligent Engineering and Systems	Vol.16, No.3, pp.105-114, June 2023.	Scopus Indexed.
2.	Quality of Service Aware Dynamic Bandwidth Allocation for Rate Control in WSN.	International Journal on Recent and Innovation Trends in Computing and Communication.	Volume: 11 Issue: 11s, ISSN: 2321- 8169, Oct 2023.	Scopus Indexed.

*Proof of list of Journals from Internet to be attached along with copies of reprints.

Scholar : *G. Vanitha*

Supervisor : *Dr. P. Amudha*
8/11/2023

(Dr. P. Amudha)

Checked By: *S. J. J. J.*
8/11/23
HoD/Dean of Respective School

The scholar Mrs. G. Vanitha (19PHEOF004)

has published her paper in the following journals:

① International Journal of Intelligent Engineering and systems -
is indexed & active in Scopus from 2008 to present and

② International Journal on Recent and Innovation Trends in
computing and communication - indexed & active in Scopus from 2021 to
present. This may be considered.

J. J. J. J.
08.11.2023



Smart Bandwidth Prediction, Power Management and Adaptive Network Coding for WSN

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Abstract: WSN has been widely used in many sensitive applications and it also has novel possibilities for laying the groundwork for using ubiquitous and pervasive computing, but it has also presented a number of issues and challenges, such as a dynamic network topology and a congestion problem that hinders not only network bandwidth utilisation but also performance. Proficient rate control and fair bandwidth allocation (PRC-FBA) was one of the schemes in the literature to solve issues of WSN by combining the ideas of traffic class priority and bandwidth fairness. However, because of the nature of WSN, the energy of nodes near the sink node is diminished when packets move from lowly congested nodes to highly congested nodes. This paper proposes a proficient rate control with data aggregation and fair bandwidth allocation (PRCDA-FBA) to address this problem by using an effective data aggregation approach for reducing the number of transmissions. In the proposed method, fair bandwidth allocation is simplified by an artificial intelligence-based bandwidth prediction method. Thus, PRCDA-FBA increases the network's durability. Despite having lower bandwidth utilizations, energy-critical sensor nodes require careful power management to avoid being eavesdropped upon. Along with data aggregation and fair bandwidth allocation, the effects of overhearing packets by energy-critical nodes are mitigated through network-wide route adjustments based on the energy level of nodes. Thus, in the proposed method, data aggregation is scheduled based on the availability of bandwidth, energy, queue size and packet priority. The proposed method is named as energy-aware proficient rate control with data aggregation and fair bandwidth allocation (EPRCDA-FBA). The proposed algorithms have been deployed on the Network Simulator 2.35 platform, and a comparative analysis has been performed using several metrics, including throughput, packet loss, End-to-End (E2E) delay and energy utilization. The EPRCDA-FBA method archives highest throughput which is 9.17%, 5.48%, 4.68% and 2.45% higher than congestion control strategies like discrete-time sliding mode congestion controller (DSMC), weighted priority based fair queue gradient rate control (WPFQGR), PRC-FBA and rate adjustment-based congestion control (RACC).

Keywords: Wireless Sensor networks, Congestion control, PRCDA-FBA, EPRCDA-FBA.

1. Introduction

WSNs are developed by connecting a large number of sensor nodes where each sensor can collect information from its neighbours and transmit it to them over a wireless network within its distribution centre. WSN is extensively used in a variety of applications, including medical practises, agricultural modelling, disaster monitoring, and so on, and it relies on a set of efficacious measures to preserve stability.

Every sensor node is equipped with all of the necessary data transmission capabilities [1]. But, due to continuous transmission congestion occurred which causes high delay, low throughput, high energy consumption, more data loss, poorer integrity and performance degradation even if such nodes employ the maximum capacity.

Over the last ten years, in the literature, many researchers focussed on developing several tailored Networking protocols [2]. An effective methods are required in WSN to handle massive amounts of frequently sensed data with limited bandwidth and

energy utilization. It's critical to get the signal from the originator node to the sink node with as little loss as possible. Congestion in the network is among the most important factors in data loss, and avoiding congestion has piqued the interest of many academics [3, 4].

In the literature, a variety of traffic delay tactics has been identified, with rate control being one of them. It has been discovered that real time (RT) traffic necessitates minimal latency and excellent consistency, and hence must be prioritised. In RT applications, WSNs can generate a wide range of data packets [5]. Due to bandwidth constraints in WSNs, such a wide range of data must be handled with different levels of priority, which helps to keep the network from becoming congested [6]. Various algorithms have been developed over the years to control congestion based on the traffic priorities of RT packets. Weighted Priority Difference of Differential Rate Control (WPDDRC) algorithm [7] has been developed which combines the DDR of a particular node with the WP of traffic class. Variations in next hops across routing paths between the transmitter and the receiver in the WPDDRC algorithm can lead to an increase in the WSN's unintended energy consumption.

For dealing with congestion and buffer overflow in WSNs, a PRC-FBA congestion control algorithm was proposed [8] in previous study. In this method, two different virtual queues are used on a single physical queue to collect incoming packets from all child nodes based on the priority. This technique prioritise different kinds of traffic and distributing bandwidth fairly. This approach first analyses the problem of bandwidth assignment in WSN using the Signal to Interference and Noise Ratio (SINR) model, which aims to find a balance between neutrality and network efficiency. Packets flow from low-congested nodes to highly-congested nodes in a WSN network, reducing the energy of nodes near sink nodes in the PRC-FBA.

To address the above problem, PRCDA-FBA is proposed in this paper that uses a well-organized aggregation mechanism to reduce the battery power across all participating nodes and leading to higher total network throughput. Aggregation mechanism just a form of adaptive network coding built on top of random linear network coding (RLNC). An adaptive network combines data for transmission to the next hop which increases channel usage and reducing packet redundancy in the network. An adaptive methodology is triggered only when congestion occurs Based on packet priority, residual energy, and latency, the parent node decides whether or not to activate networking coding, as per the

adaptive network coding approach. Long Short-term Memory (LSTM) based neural network is also used to anticipate the required bandwidth for nodes by learning from previous data, which includes packet drop rate, energy, priority of packets, latency of packets, and bandwidth use. Even though data aggregation mechanism reduce the unnecessary transmission and energy consumption, the energy management additionally required to improve the network performance further. As a result energy saving criteria also include in PRCDA-FBA and named as EPRCDA-FBA. The path selection is considered along with residual energy of nodes. The major purpose of this proposed method is ensure to meet QoS standards in terms of fast data delivery, reduced energy consumption of energy-intensive nodes and increased network durability. The excess power of the node is taken into account in this protocol's primary concern rate control approach.

Leftover paper units are made as follows: related works in section 2. PRCDA-FBA and EPRCDA-FBA are explained in section 3. Simulated findings are in section 4. Section 5 summarises the article and suggests future work.

2. Related works

There is a proposal for congestion control [9] that uses fuzzy heuristic and metaheuristic search to balance a variety of objectives, including travel time, energy consumption, and network density. Multiple goals are taken into account when controlling the cluster leader's queue. The reduced power usage from this technology increases the longevity of the network. However, as the simulation time increases, the delay and throughput progressively worsen. Cooperation game theory [10] is used to describe data transfer priorities. The level of congestion and the quality of service (QoS) requirements of each type of data inform the ant-based routing algorithm that is integrated with game theory to construct the path. Due to the lack of queue control, significant packet loss happens while employing this technique. To achieve this, a DSMC is developed, which successfully adjust queues at bottleneck nodes to the appropriate value [11]. In terms of latency and packet loss, this strategy is superior. However, the congestion issue will get more severe, resulting in greater delays, as the simulation time increases.

An adaptive access control is developed for more efficient traffic management and lower power usage [12]. To determine which nodes should be allowed access to the wireless channel first, second, or third, a fuzzy technique is utilised. In high-traffic settings, however, dynamic time-slot management is

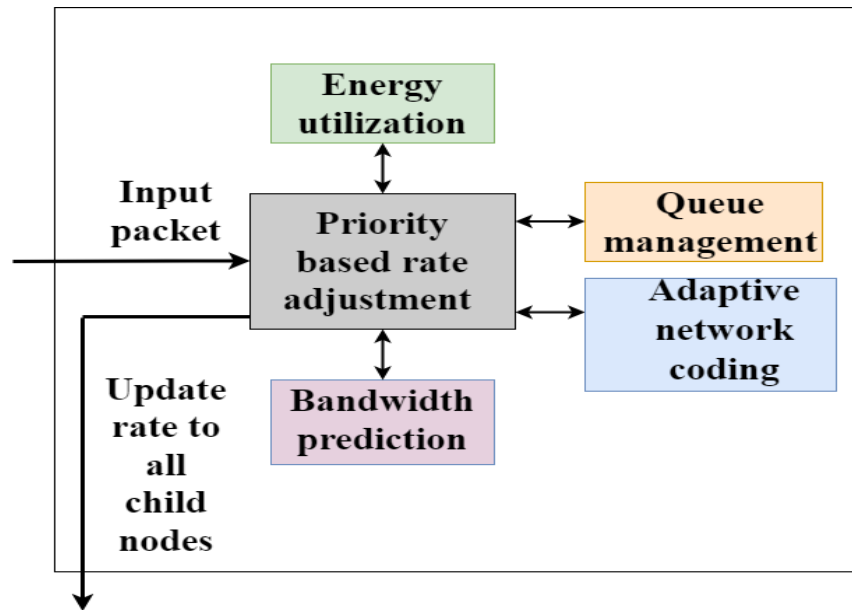


Figure. 1 The proposed method is depicted in a block diagram

challenging and will impair network throughput. To boost network functionality, an effective congestion avoidance strategy [13] is presented based on Huffman coding algorithm and ant colony optimization. This strategy is an amalgam of resource-based and traffic-based optimization strategies. Although effective initially perform well, this strategy has higher delay and low throughput as the duration of the simulation time increases.

By calculating the retransmission likelihood of packet arrival and the average energy usage, we may avoid transmission collision [14]. As energy consumption at individual nodes climbed above 50%, however, throughput began to degrade. Weighted priority based fair queue gradient rate control (WPFQGR) [15] ensures that available bandwidth is shared equitably by considering traffic class priorities, average queue sizes, and a node's connected loads. Every efficiency metric is improved upon by this technique. As the simulation period increases, however, key metrics like energy and throughput inevitably drop.

Artificial intelligence algorithms are employed for awakening scheduling of active nodes [16], while the Spatial Spider Optimization algorithm and K-means clustering enhancement are used to pick cluster heads. Provides improved delay and throughput at first, but both degrade with time. A system called RACC [17] has been developed to alleviate traffic congestion. Node buffer occupancy is monitored and used to dynamically alter the transmission rate. Additionally, a variety of modulation algorithms were used to lessen the load

on the available bandwidth. However, delays and reduced throughput become more common once a certain amount of time has passed during transmission.

3. Energy-aware proficient rate control with data aggregation and fair bandwidth location algorithm (PRCDA-FBA)

The model of the system is illustrated as a graph $G(V, E)$. Here, V represent sensor nodes and E is connections among them. $e(a, b) \in E$ defines the communication relationship between different nodes $a \in V$ and $b \in V$, and sink node is the ultimate receiving node. The connection $e(a, b) \in E$ also symbolises the nodes a and b at the transmitter (T_r) and reception (R_r) ends, respectively. Connections are established between nodes in a network when the space between them is less than the maximum range of the transmission medium. The sensor node communicated the collected data to the subsequent node after returning from the application field.

The proposed method aggregates data via network coding to lessen latencies in data transmission and power consumption while increasing network throughput. The transmission frequency is the average rate at which packets are sent from a single node during a single transmission round. Reduced transmission frequency, on the other hand, increased network channel capacity, which enhanced overall network throughput. The network coding path combines data for transmission to the next hop, increasing channel usage and reducing

packet redundancy in the network [18]. When congestion occurs, an adaptive methodology is given in which the packet dropping rate is increased and the node sends packets by aggregating them using network coding.

In a dynamic environment, network coding offers a few advantages in terms of performance and throughput. In contrast, network coding necessitates extensive computational complexity on both ends of the transmission link. As a result, the necessity to devise an algorithm that provides optimal performance while minimising operating cost. A new adaptive network coding method is developed based on [19] to enable the source node to switch back and forth between archiving and transmitting actual packets into networks and going to perform RLNC of data packets and trying to deliver them into system. Fig. 1 represents the proposed congestion control mechanism.

3.1 Energy-aware proficient rate control

Due to the use of battery power and energy consumption, lots of energy will be loss hence power management is required to overcome this difficulty. To establish a relationship between the strength of the transmission signal and the quality of the forward connection, researchers at EPRCDA-FBA developed a receiver-based prediction model. The EPRCDA-FBA algorithm is presented to handle power regulation and extend battery life.

In the proposed EPRCDA-FBA algorithm, energy aware Proficient Rate control scheme is proposed. The major purpose is to ensure that QoS standards are met in terms of delayed data delivery, reduced energy consumption of energy-intensive nodes, and increased network lifespan. The surplus power of the node is taken into account in this protocol's priority-based rate control method. Initially, a prediction model is used to determine the proportion of node transmit energy levels that can be reduced without drastically reducing the packet delivery ratio. Then, to avoid overhearing energy-critical nodes, a priority of nodes for delivering traffic classes of packets is determined using a combination of energy.

The nodes employ this prediction model for two objectives. First, a node can use this model to determine how much power it can lower in relation to a receiver while keeping a specific level of connection quality. Second, the node can determine how much overhearing is transmitted to energy essential neighbours at a given transmit power level. Since the broadcast power level of the broadcaster greatly affects the link quality between a pair of

nodes, it is important to build a prediction model at the receiver end that links the broadcast power level at the transmitter together with the lifetime at the receiver. Traffic load of node is calculated in Eq. (1)

$$TL = \frac{\sum_{j=1}^N q(j)}{N} \quad (1)$$

The number N here represents the number of packets, $q(j)$ represent the j^{th} packet in the queue. q_{max} is the maximum queue size. Traffic Load Intensity is calculated Eq. (2).

$$TLI_{(i)} = \frac{TL_{(i)}}{q_{max}^{(i)}} \quad (2)$$

The cost of the link is calculated based on the energy utilized for packets transmission Eq. (3).

$$LC_{i,n} = \frac{O_i}{E_{i,j}} \quad (3)$$

$E_{i,j}$ energy for transmitting j^{th} packet by i^{th} node. O Represent out coming packet from previous sensor nodes of current node. The network coding is applicable in the node whoever TLI and LC exceeds maximum limit.

Proficient rate control is followed by the previous work [8]. The primary goal of this algorithm is to deal with various kinds of non live time (NLT) packets, such as high preference NLT (HNLT), Middle preference NLT (MNLT), and Little preference NLT (LNLT). When these packets are sent out, they each have a different priority level. Therefore, the packets are identified by data rates of varying values. The live time (LT) traffic class is extremely important and receives the highest consideration.

Consider ptp_n^k and lp_n^k are packet type of preference and the location preference of packets in n^{th} queue of k^{th} intermediate sensor node. sp_i^{kn} is the source preference of n^{th} queue of k^{th} node, the packet types are $i \in \{LT, HNLT, MNLT, LNLT\}$.

First, the packet type of preference in n^{th} queue of k^{th} node is calculated as Eq. (4)

$$ptp_n^k = \sum_n \sum_i sp_i^{kn} \quad (4)$$

The overall preference of packets type in n^{th} queue of k^{th} node is computed as

$$Op_n^k = ptp_n^k \cdot lp_n^k + [O_{LT} - \delta(O_{HNLT} + O_{MNLT} + O_{LNLT})] \quad (5)$$

In Eq. (5), δ is the values ($0 \leq \delta \leq 1$) and $O_{LT}, O_{HNLT}, O_{MNLT}, O_{LNLT}$ are the preference assigned to LT and NLT packet types. Likewise, the packet type preference in n^{th} queue of l^{th} next level node is computed as Eq. (6).

$$ptpt_n^l = \sum_n \sum_i sp_i^{ln} \quad (6)$$

After the preference rate has been updated, the sensor node transmits the information to the subsequent node in the hierarchy. If priorities are set properly, network congestion, buffer overflow, and dropped packets can be avoided.

3.2 Adaptive RLNC for data aggregation

According to the adaptive RLNC technique, the origin node determines whether to switch networking coding ON or OFF based on number of factors including packet size, the estimated disconnection time among connected hubs, and the network's data flow or packet rate. In cases where the total amount of the content being sent by the nodes is less than the maximum transmitting capacity of the link, network coding should be disabled. When the amount of information to be transmitted grows beyond a certain threshold, network coding is used. [20]. Using encoding, the packets are constructed and sent as a concatenation of the actual packets. An encoded data packet received by a node is then decoded to reveal the original data. Parameters for establishing network coding are calculated from Eq. (7) to Eq. (10)

$$Packet(sizeinbits) = 8 \times Packet(size) \quad (7)$$

$$D = Data\ rates\ in\ bps \quad (8)$$

$$ET = Estimated\ link\ expiration\ Time \quad (9)$$

$$MDT = Max\ Data\ rate\ Transmit = D \times ET \quad (10)$$

For network coding to take place, it is necessary and sufficient that nodes satisfy certain conditions in order to establish optimal pathways with potential coding nodes. Before to look at the network coding situation, let's establish some notations. $a \in d_f$ denotes node a beside the data flow d_f , whereby the source nodes and sink node. The single-hop neighbour set of nodes a is referred as $Ns(a)$. $Forward(a, d_f)$ and $Backward(a, d_f)$ respectively represent nodes towards destination and nodes set from origin of data flow d_f . Fig. 2 represent the sample network coding from source to intermediate and destination node, As a result, the in-between

sensor node e where incoming flows meet, encrypt the obtained data and delivered by the intervening node if the network condition is met. The packet flow in the network is denoted by the letters O_1 and O_2 . The critical and adequate conditions under which system coding is performed should be expressed to uncover ways with possible coding chances. Unless the preceding condition is met when the flows d_{f1} and d_{f2} overlay at node e is network coding possible [20]. Due to the possibility of distinct flows interfering with each other, the issue of network coding collision has arisen.

Condition:

1: Existing node $n_1 \in Backward(a, d_{f1})$ while $n_1 \in N_s(m_2) \wedge m_2 \in Forward(e, d_{f2})$ or $n_1 \in Forward(e, d_{f2})$

2: Existing node $n_2 \in Backward(a, d_{f2})$ while $n_2 \in N_s(m_1) \wedge m_1 \in Forward(e, d_{f1})$ or $n_2 \in Forward(e, d_{f1})$

Here, n_1, n_2, m_1 and m_2 are neighbours of node a and e respectively. For a network with many flows, the one that best satisfies the coding criterion is the one along which the most possible codes can be transmitted. However, a native packet may not be decoded at the final node due to excessive coding at several contradicting nodes along the route. Flow d_{f3} does, however, connect to the network at a certain point. Node E_1 pleased aggregation with the d_{f1} and d_{f3} . Node E_2 perform the coding of d_{f2} and d_{f3} . Node E_1 gets $O_1 \delta O_3$ when it encodes packets $O_1 \delta O_3$ and delivers them along route d_{f3} . Furthermore, node E_2 is the coding node, which will again encode packets $O_1 \delta O_3$ and O_2 , i.e., $O_1 \delta O_2 \delta O_3$, and send them to D_3 and N_2 , correspondingly, through the paths d_{f3} and d_{f2} . Since that overhears packets O_1 and O_2 from source nodes $S1$ and $S2$, it may see that destination node D_3 decodes packets O_3 from $O_1 \delta O_2 \delta O_3$. If packets arrive at destination node D_2 , it is unable to decode original packets O_2 , but it can decode packet O_3 . However, node E_2 cannot be utilised as a coding node, as can be seen. Due to extensive coding along the path, d_{f3} has an impact on the coding collision problem in this situation. In order to avoid the code collision problem, extra limits should be imposed.

3.3 LSTM based fair bandwidth allocation

A learning based bandwidth assignment takes into account high – bandwidth traffic patterns. Training and testing done by LSTM [21] which used to handle bandwidth and traffic of various levels of burstiness. Bandwidth allocation is initially assigned

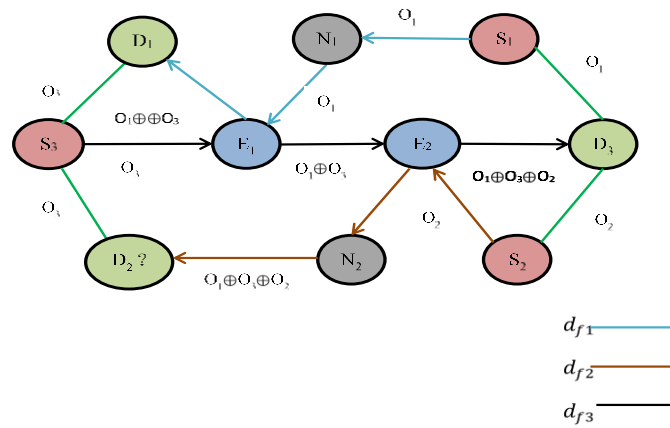


Figure. 2 An example network coding in network

based on the fair allocation scheme proposed in the previous study [8]. In this paper, the calculation of utility of bandwidth for links at every time is avoided by intelligent prediction model using LSTM. First LSTM is trained for higher and lower throughput for the parameters like packet transmit duration T_o , Packet size O_s , number of packets in the flow N_o , Bandwidth utilized BW_o and packet transmission rate O_R . The trained LSTM is used to predict required bandwidth for present packet transmission.

3.4 Algorithm for EPRCDA-FBA

Algorithm : EPRCDA-FBA

Input: Set of path

Output: Selected path

Step 1: Set the parameters: β, δ, μ are the priority values for traffic classes

Step 2: Service time (receiving packets) of sink node (ST_n^{sink})

Step 3: Compute the mean service time of available queues in sink node

$$\overline{ST}_n^{sink}(t+1) = (1 - \alpha)\overline{ST}_n^{sink}(t) + \alpha \cdot ST_n^{sink}$$

α is a fixed variable ranges 0 and 1

Step 4: Calculate the rate variance n^{th} queue in the sink node using the formula

$$\Delta r^{sink} = \beta \cdot r_{out}^{sink} - r_{in}^{sink}$$

where r_{out}^{sink} is the outage rate and the receiving rate of the sink node r_{in}^{sink} .

β is a fixed variable ranges 0 and 1.

Step 5: Compute k^{th} parent nodes using the following formula

$$\Delta r^k = \beta \cdot r_{out}^k - r_{in}^k$$

where, r_{out}^k is the outage rate of k^{th} node connected with sink. The receiving rate of the k^{th} parent node is r_{in}^k

Step 6: Calculate the updated outage rate of queue in the k^{th} node

Step 7: Calculate the updated outage rate of queue in the l^{th} child node

Step 9: Continue Steps 2 to Steps 7 for updating the rate of transmission for sensor nodes

Step 10: Check for active neighbouring nodes

Step 11: If Nodes has information to share

Step 12: if ($O_R > MDT$ or $TLI > max_{TLI}$ or $LC > max_{LC}$)

{

Execute adaptive network coding

$$O_1, O_2, O_3, \dots, O_n$$

$$P(n) = O_1 \oplus O_2 \oplus O_3 \oplus O_n \dots$$

$$P(n) = \sum_{k=1}^n A_k \times O_k$$

}

Step 13: Eliminate coding collision

When flow d_{f1} and d_{f1} overlap at the node e , network coding is possible only

if

{

Existing node $n_1 \in Backward(a, d_{f1})$

while $n_1 \in N_s(m_2) \wedge m_2 \in Forward(e, d_{f2})$ or $n_1 \in Forward(e, d_{f2})$.

Existing node $n_2 \in Backward(a, d_{f2})$

while $n_2 \in N_s(m_1) \wedge m_1 \in Forward(e, d_{f1})$ or $n_2 \in Forward(e, d_{f1})$

}

Step 14: intelligent fair bandwidth allocation

Node parameters : $x_p = \{P_s, T_p, N_p, BW_p, P_R\}$

$x_{model} = Train(LSTM(x_p))$ // Training using LSTM

$$BW_{(p+1)} = Predict(LSTM, x_{model}) //$$

bandwidth prediction for next packet transmission

Step 15:

}
Step 16: Else GOTO step 2

The link cost conditions checked in the if conditions in step 12 of algorithm is removed in EPRCDA-FBA. This paper evaluate the performance of both PRCDA-FBA and EPRCDA-FBA under various network characteristics.

4. Simulation results

In this section, the PRCDA-FBA and EPRCDA-FBA technique is executed in network simulator version 2.35 (NS2.35) and its effectiveness is analysed compared to the DSMC [11], WPFQGR [15], PRC-FBA [8] and RACC [17] techniques. The analysis is conducted based on throughput, packet loss, end-to-end (e2e) delay and energy utilization. Table 1 gives the simulation parameters considered in this analysis.

4.1 Throughput

It's the total amount of information transmitted from sensors to sink in a certain amount of time Eq. (11).

$$\text{Throughput} = \frac{\text{Total amount of data accepted by the target}}{\text{Time}} \quad (11)$$

Fig. 3 shows the throughput (in Mbps) for the approaches compared to the DSMC, WPFQGR, PRC-FBA, RACC, PRCDA, and EPRCDA-FBA under different simulation times in network simulator 2.35 (NS2.35) (in sec). EPRCDA-FBA is shown to have the highest throughput of all the methods studied. Throughput for EPRCDA-FBA is 9.17% higher than DSMC, 5.48% higher than WPFQGR, 4.68% higher than PRC-FBA, 2.45% higher than RACC, and 0.41% higher than PRCDA-FBA if the simulation time is 120sec. This is made possible by allocating equal bandwidth to all network nodes and assigning different traffic classes different priority levels in each virtual queue.

4.2 Packet loss

It is the amount of data dropped or missed during transfer Eq. (12)

$$\text{packet loss} = \frac{\text{Amount of lost data}}{\text{amount of lost data} + \text{Amount of accepted data}} \quad (12)$$

Fig. 4 compares the packet loss (in %) across several different simulation times for the DSMC,

Table 1. Simulation parameters

Parameter	Range
Distance Covered by Nodes	300m
Data transfer rate	2Mbps
MAC layer type	IEEE802.11
Network Nodes	500
Traffic types	4
Operating frequency	5GHz
Packet size	200bytes
Routing protocol	AODV
Boundary of Simulation	1000×1000m ²
Duration of Simulation	120sec
Cause of Traffic	CBR
Transmission power	285.63mW

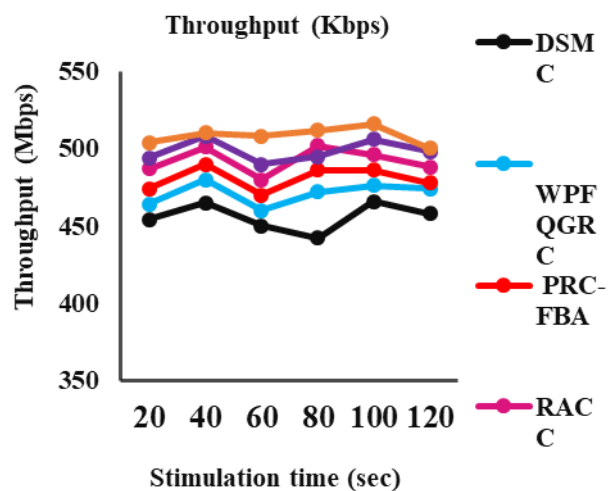


Figure. 3 Throughput vs. simulation time

WPFQGR, PRC-FBA, RACC, PRCDA, and EPRCDA-FBA methods (in sec). This finding suggests that EPRCDA-FBA achieves lower packet loss than competing methods. In a 120-second simulation, EPRCDA-FBA reduces packet loss by 57% compared to DSMC, 54% compared to WPFQGR, 49% compared to PRC-FBA, 42% compared to RACC, and 33% compared to PRC-FBA. EPRCDA-FBA uses virtual queues and fair bandwidth allocation at each node to mitigate the effects of WSN congestion, making it the most effective protocol in terms of packet loss.

4.3 End-to-end delay

The amount of time it takes for information to travel from its source to its destination (sink)

$$E2E \text{ Delay} = \text{Time}_{\text{sink}} - \text{Time}_{\text{origin}} \quad (13)$$

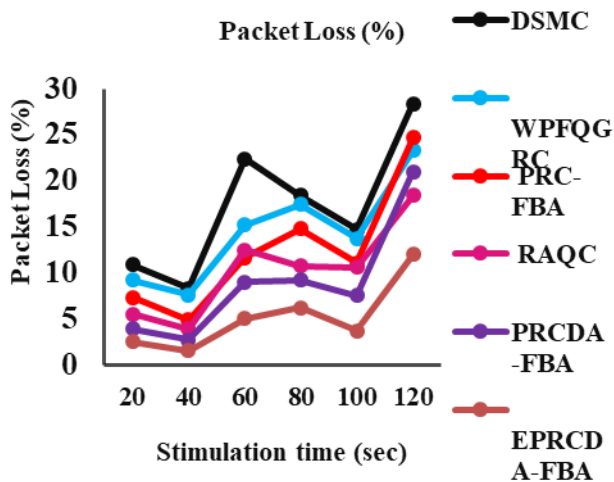


Figure. 4 Packet loss vs. simulation time

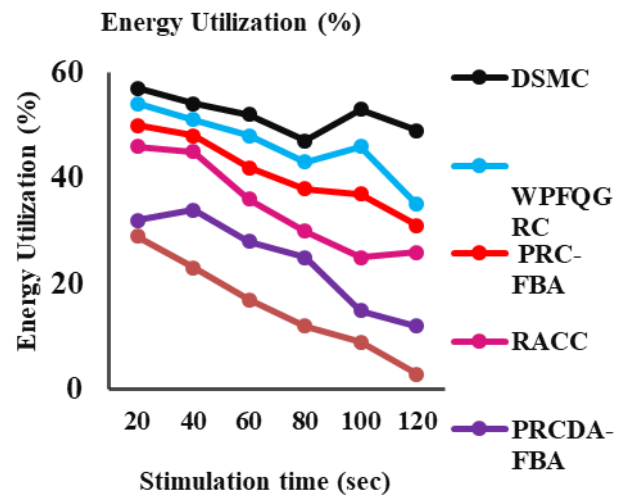


Figure. 6 Energy utilization (%) vs. simulation time

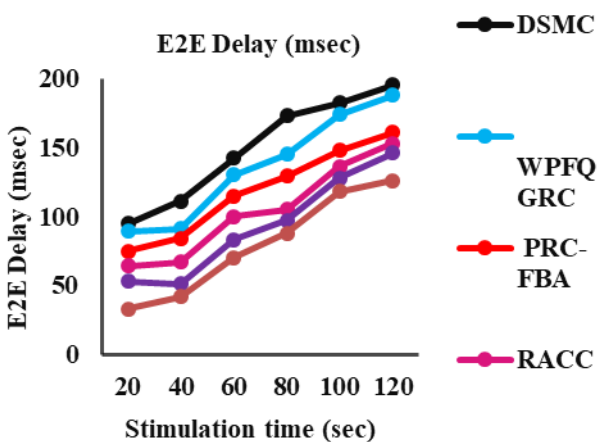


Figure. 5 E2E delay vs. simulation time

In this Eq. (13) $Time_{sink}$ is the time at the sink while accepting the data and $Time_{origin}$ is the time at the origin while forwarding that data.

The E2E delay (in ms) for different simulation times (in sec) is shown in Fig. 5 for the DSMC, WPFQGR, PRC-FBA, RACC, PRCDA and EPRCDA methods. When compared to the other approaches, the EPRCDA-FBA is found to have the shortest E2E delay. EPRCDA-FBA has a 35.38% lower E2E delay than DSMC, 32.97% lower than WPFQGR, 21.74% lower than PRC-FBA, 17.64% lower than RACC, and 13.69% lower than PRCDA-FBA when the simulation time is 120 seconds. The minimum E2E delay associates with the maximum throughput and the less packet loss.

4.4 Energy utilization

It represents the total percentage of network energy consumption over all time steps of the simulation.

Energy utilization (in %) during simulation period is shown in Fig. 6 for DSMC, WPFQGR, PRC-FBA, RACC, PRCDA-FBA, and EPRCDA-FBA. EPRCDA-FBA is able to reduce energy consumption when compared to competing methods. EPRCDA-FBA's energy consumption is 93.88% lower than DSMC's, 91.43% lower than WPFQGR's, 90.32% than PRC-FBA's, 88.46% lower than RACC's, and 75% lower than PRCDA-FBA's. That the EPRCDA-FBA reduces energy use relative to conventional methods is thus self-evident.

5. Conclusion

An energy-efficient, battery-powered, and power-management-friendly approach called EPRCDA-FBA is proposed. When the data rate is greater than a predetermined threshold value, network coding is implemented. In order to ensure that everyone gets their fair share of battery life, we apply a sophisticated data aggregation, coding condition, and coding collision method. An effective predictive model has been suggested for managing the power control. In conclusion, when compared to DSMC, WPFQGR, PRC-FBA, RACC, and PRCDA-FBA, EPRCDA-FBA achieves 4.4% greater throughput, 49.2% lower delay, 25% lower packet loss, and 67% lower energy usage in simulations. In future, it is possible to expand this work by applying the same situation to wireless recharging models, in which the confluence of congestion control via EPRCDA-FBA and suitable wireless recharging solves both the lifetime improvement and congestion control issues simultaneously.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Conceptualization, methodology, software, validation, Vanitha ; formal analysis, investigation, Amutha; resources, data curation, writing—original draft preparation, Vanitha ; writing—review and editing, Amudha; visualization, Vanitha; supervision Sivakumari.

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Quality of Service Aware Dynamic Bandwidth Allocation for Rate Control in WSN

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Abstract— Different types of data can be generated by Wireless Sensor Networks (WSNs) in both Real-Time (RT) and Non-RT (NRT) scenarios. The combination of these factors, along with the limited bandwidth available, necessitates careful management of these categories in order to reduce congestion. Due to this, a Proficient Rate Control and Fair Bandwidth Allocation (PRC-FBA) method has been created that prioritizes certain types of traffic and creates a virtual queue for them. In PRC-FBA, the Signal-to-Noise and Interference Ratio (SINR) model is applied to the problem of bandwidth allocation in WSN in an effort to find a compromise between equity and performance. Then, a brand-new bandwidth utility factor is defined with regard to equity and effectiveness. The FBA method in PRC-FBA is developed for only improving throughput, but not considering delay. However, delay is the main factor for transmitting NRT packets. This paper offers a PRC with Quality of Service (QoS) aware Dynamic Bandwidth Allocation (PRC-QDBA) approach for allocating bandwidth while prioritizing packets based on their traffic classes. This model employs a QoS associated dynamic bandwidth allocation strategy which efficiently distributes the unused time slots among the required nodes. The distribution technique is performed based on hierarchical manner utilizing a parent-child association of tree topology. The parent node receives traffic indication maps (TIMs) from the children nodes and adopts them to allocate time slots based on their demands. If the parent node is unable to allocate the required slots, it creates a TIM that indicating the demands and transfer it to its immediate parent node. This increases the entire performance rate of RT traffic. Furthermore, this model assures the packet forwarding for previously accepted flows by allowing node transmission based on ancestral connection capabilities. Finally, simulation results demonstrate that the suggested model significantly increases the throughput and delay for bandwidth allocation while also enabling QoS support for RT traffic in WSNs.

Keywords- WSN, Congestion handling, PRC, Bandwidth Demand, Throughput, Delay.

I. INTRODUCTION

In order to construct WSNs, a large number of sensors with a low power consumption must be configured. Using a wireless connection, each sensor may take in data from its surrounding nodes and relay it to others in the same area. Because of its flexibility and honesty, it makes an effort to make use of accurate data recorded by agents and managed by a central controller. As a result, a system of trustworthy information exchange can be established. The reliability of this type of network is ensured by a plethora of helpful measures which is utilized for different RT applications like medical procedures, agricultural modeling, emergency monitoring, etc. All sensor nodes are fully equipped with the necessary features for data transmission [1]. Congestion can increase the risk of data loss, degrade data integrity and cause performance inconsistencies,

even when such nodes use their full bandwidth. The link and node are two levels of congestion in WSNs. The node level congestion occurs when an average packet rate causes the data buffer size to grow above its intended capacity. Therefore, there is significant delay and data loss during transmission. Link-level congestion occurs when more than two sensors are using a medium at once. It leads to higher queuing latency, power use and a lower efficiency. Because of this, these issues are among the most challenging in standard data transport setups. Congestion must be identified and managed to combat these issues, which improves the dependability of data transport [2-3]. Congestion management relies on controlling traffic through the WSN. Many protocols were developed to handle the three primary operations of congestion recognition, notification and rate adaptation. Congestion Detection and Avoidance (CODA) [4], Priority-based Congestion

Control Protocol (PCCP) [5], Active Queue Management (AQM) [6] and Fairness Rate Control (FRC) [7] were the most well-known congestion management protocols. Priority, traffic density and bandwidth use formed the foundations of these protocols. However, it is still difficult to reduce traffic by transmitting both RT and NRT data.

To get over this difficulty, a DDR method dependent on the DDR between the sink and source nodes needs to be created. When the DDR at the sink is combined with the WP of the traffic type, a WPDDR method is provided [8]. The goal of this method was to manage both RT and NRT network traffic in tandem. To facilitate the RT traffic class over the NRT packets, WPDDR has updated the cumulative priority by specifying the WP of traffic kinds with a higher-order DRC described by different nodes. However, this method does not consider the issue of equitable bandwidth allocation while dealing with congestion in WSNs.

So, the PRC-FBA strategy was developed to prioritize the traffic types and FBA in WSNs. The SINR model is used to identify the tradeoff among the fairness and performance. In this model, a new utility parameter for bandwidth is developed to prioritize the efficiency and fairness. Mutually computing node relationships and time slot assignment provides an approximate solution. The challenge is presented as disruptive programming problem with a two-stage methodology, the primary phase calculating connections between nodes and the secondary phase allocating timeslots to maximize utility factors. This improves network efficiency and achieves a more equitable bandwidth distribution in WSNs. But, the FBA method in PRC-FBA was developed for only improving throughput, but not considering delay. However, delay is the main factors for transmitting NRT packets.

In order to solve this, this article develops PRC-QDBA approach to improve the throughput and delay for bandwidth allocation while prioritizing packets according to their traffic classes. The unused time slots are effectively distributed among the needed nodes using QDBA mechanism. This method follows parent-child connection of a tree topology for the hierarchical distribution tasks. The parent node gets TIMs from the child nodes, which it utilizes to assign time slots in accordance with their requests. The parent node creates a TIM stating the demand and transfer it to the adjacent parent node if it is unable to allot the required slots. This model effectively allows transmission of nodes depending on ancestral link capacity which ensures the packet directing towards the accepted flows. In this way, the throughput and delay is improvised for bandwidth allocation and facilitates QoS support for RT traffic in WSNs.

This paper's remaining sections are laid out as follows: Congestion management in WSNs and related works are discussed in Section 2. In Section 3, the PRC-QDBA

procedure is outlined and its stimulation evaluation with existing models are exhibited in Section 4. Section 5 provides a summary of the paper which also includes the suggestions for further research.

II. LITERATURE SURVEY

The throughput can be maximized with the help of the Reliable, Efficient, Fair and Interference-Aware Congestion Control (REFIACC) technique [10]. This method avoided interferences by timing the transmission and it also ensured that all nodes used the available bandwidth fairly. By taking facility differences between paths into account during scheduling, we have been able to avoid inter- and intra-route disruptions. To get the most out of the available bandwidth, linear programming has been used. Despite attempts to prioritize traffic, average throughput remained below expectations.

A congestion avoidance strategy based on Packet Priority Intimation (PPI) bits in each data packet has been proposed [11]. The goal was to send more urgent data with as minimum latency as possible. An Ad-hoc On-demand Distance Vector (AODV) routing approach was used to find the smallest path from the initial point to the target node. However, the time and effort required for computation were substantial.

A two-stage cognitive network congestion scheme [12] has been designed by the TOPSIS and response surface mechanism. Initially, the MAC layer buffer occupancy fraction and congestion condition of the downstream node were calculated. Upstream nodes received these ranges and used the TOPSIS to rank their neighbors and choose the next set of assisting nodes. In addition, a response surface optimization regression analysis was used to get the optimal transfer ratio. However, it placed a heavy computational strain and had low energy efficiency.

A novel approach for fairness-aware congestion management [13] was developed to reduce the energy consumption of WSNs by modifying their specific number motile nodes, position and speed. In addition, the reporting rate was adjusted to accommodate the buffer availability of each node and ease the existing congestion. However, the packet loss ratio remained high and the packet delivery rate (PDR) was poor.

The Dynamic Hybrid Slot-Size BA (DHSSBA) technology [14] was developed to decrease the data delay and jitter variance of RT congestion in an Ethernet passive visible network. This method dynamically allotted each optical network module's prime time period for priority traffic. Additional bandwidth from the unassigned portion of the time cycle was utilised if the window size needed by the highly prioritized optical network which exceeds the largest assigned window size. The best-effort traffic was negatively impacted by the increased latency.

To improve multicast transmission's throughput, quality of service and fairness, a new congestion avoidance technique called Extended Logarithmic Increase and Multiplicative Decrease (ELIMD) [15] was developed. The method used queue delay, packet loss and network performance to control congestion. In addition, the Adaptive IMD (AIMD) framework was employed to provide constant throughput from a multicast source to the destination's receiver. Stability, fairness and security were all areas where the performance fell short.

In order to provide data transfer at an optimal rate while minimizing energy consumption, a new congestion handling approach [16] was presented. Energy consumption was kept to a minimum by employing cluster routing and the rate-based congestion handling strategy. In the first stage, a combination of the K-means and Greedy best first search algorithms was used to group similar nodes together. The firefly optimization then performed the necessary rate adjusting to ensure the highest possible packet delivery ratio. Finally, ant colony optimization-based routing enabled the maximum possible data transmission rates. However, this was not a success for energy efficiency.

The Fuzzy Sliding Mode congestion Controller (FSMC) [17] was designed to handle congestion in the Transmission Control Protocol (TCP) by using a cross-layer congestion management model among the Transmission and Media Access Control (MAC) layers. Then, Fuzzy-SMC was suggested for managing queue sizes in overburdened nodes and mitigating the effects of external uncertain interferences. However, the network was less reliable.

III. PROPOSED METHODOLOGY

The PRC-QDBA method is briefly explained here. Let's pretend that the WSN in question has P parent nodes (represented by a_1, \dots, a_p) and C child nodes (represented by u_1, \dots, u_c) spread out evenly across the coverage area. In addition, a_i is a node that processes the results of the PRC-FBA and obtains the utility factor for allocating the timeslots to u_j . Consider a wireless system that operates on time slots but has limited bandwidth. r_{ij} describes the bit rate between sources a_i and u_j . I_{ij} is the sum of all interference experienced by node j as a result of node i . Under the SINR paradigm, wireless connection efficiency is denoted by I_{ij} and is tied to interference from other wireless connections.

$$I_{ij} = g \left(\text{SINR} \left(\frac{RSS_{ij}}{\sum_{p \in [1, P], c \in [1, C], c \neq j} RSS_{pc} + N_0} \right) \right) \quad (1)$$

Received Signal Strength (RSS) from parent node p to child node c is denoted by RSS_{pc} in Eqn. (1), while RSS from parent node i to child node j is denoted by RSS_{ij} and g thus represents an ascending operation. In particular, nodes with indexes p and i are parents, while nodes with indexes c and j

are children. To represent the conditions of the wireless medium, a standard model is used.

$$RSS = E_t - l_w(d_0) - 10\eta \log \left(\frac{d}{d_0} \right) \quad (2)$$

In Eqn. (2), E_t stands for the transfer energy, l_w for the path loss, $l_w(d_0) - 10\eta \log \left(\frac{d}{d_0} \right)$ signifies the log-distance radio transmission system which is a large-scale route loss model that uses logarithm distance. d_0 is denoted as the reference distance for the received energy, where d represents the interval between the initial and terminal nodes and η represents the route loss coefficient. The transfer period is calculated once time slots have been assigned using an algorithm.

A. Problem Formation

The fairness statistic known as Jain's index is a measure of the range over which resources are distributed.

$$f(X) = \frac{[\sum_{i=1}^p x_i]^2}{p \sum_{i=1}^p x_i^2} \quad (3)$$

In Eqn. (3), x_i represents the allocated resource for individual $i = 1, \dots, p$ and $X = (x_1, \dots, x_n)$. The formulation to determine equitable bandwidth sharing is shown in Eqn. (4):

$$f(X) = \frac{[\sum_{j=1}^c b_j]^2}{c \sum_{j=1}^c b_j^2} \quad (4)$$

The formulation is defined as follows in this PRC-QDBA:

$$f(x, p) = \sum_{j \in U} \omega_j \log b_j \quad (5)$$

In Eqn. (5), U represents the group of nodes and b_j represents the node-specific effective bandwidth allocation. Let's pretend that the relationship between u_j and a_i is denoted by x_{ij} and that $b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij}$. Due to physical limitations, a child node can only establish a synchronous connection with a single parent node. As such, $x_{ij} \in \{0, 1\}$, t_{ij} indicates the transition time that a_i allocates to u_j and ω_j indicates the weight of u_j , which reflects the traffic class priority of u_j in WSN.

Since there is free reign over the quantity used to calculate Jain's fairness index, we can build a Logarithmic Utility Function (LUF) for bandwidth. It's defined in Eqn. (6),

$$LUF: f(x, p) = \frac{[\sum_{j=1}^c (\omega_j \log b_j)]^2}{c \sum_{j=1}^c (\omega_j \log b_j)^2} \quad (6)$$

Notably, LUF derives from the utility factor to ensure equitable bandwidth allocation. This LUF is assigned by taking the equality of every $\omega_j \log b_j$. Since each distributable resource has the form $\omega_j \log b_j$, the LUF is Jain's index and u_j is the utility factor. The ultimate goal of the LUF is to provide a form of equality that makes $\omega_j \log b_j$ as similar to zero as possible. Therefore, everyone has an equal opportunity to transmit the same quantity of data. However, this might results

with the unexpected result of users with lower bit rates using up a larger proportion of the medium for a longer period of time than users with higher bit rates, severely lowering network efficiency. Therefore, time-based fairness is implemented and the network's efficiency improves as a result of everyone being allotted the same amount of transfer time. Along with b_j and the transfer time T , the throughput may be calculated. Maximum bandwidth is defined as:

$$\frac{\sum_{j=1}^C b_j}{T} = \frac{\sum_{j=1}^C b_j}{T_{a_i}} = \frac{\sum_{j=1}^C \sum_{i=1}^P x_{ij} t_{ij} r_{ij}}{\sum_{j=1}^C \sum_{i=1}^P x_{ij} p_{ij}} = \sum_{j=1}^C \sum_{i=1}^P x_{ij} p_{ij} r_{ij} \quad (7)$$

The transmission time at parent node a_i is denoted by T_{a_i} in Eqn. (7). If the parent nodes may operate in parallel, then the transfer period for the WSN is $T = T_{a_i}$, where a and i are the times at which the parent nodes can send and receive data. $\sum_{j=1}^C x_{ij} t_{ij} = 1$ is the same thing as saying that $T_{a_i} = \sum_{j=1}^C x_{ij} t_{ij} = 1$. Network throughput and fairness are always at odds with one another. Two utility considerations, including fairness and network throughput, are taken into account in this work. The weighted sum of two fitness values is used as a single fitness factor to strike a balance between equality and throughput.

Non-linear programming is used to solve the bandwidth distribution problem. The goal is to share the available bandwidth while striking a balance between equity and performance. These formulations for optimization are as follows in Eqn. (8) to Eqn. (14):

$$\max \frac{\left[\sum_{j=1}^C (\omega_j \log(\sum_{i=1}^P x_{ij} t_{ij} r_{ij})) \right]^2}{c \sum_{j=1}^C (\omega_j \log(\sum_{i=1}^P x_{ij} t_{ij} r_{ij}))^2} \quad (8)$$

$$\max \sum_{i,j=1}^C \sum_{i=1}^P x_{ij} t_{ij} r_{ij} \quad (9)$$

$$\text{subject to } \sum_{i=1}^P x_{ij} = 1 \quad (10)$$

$$x_{ij} \in \{0,1\} \quad (11)$$

$$\sum_{j=1}^C x_{ij} t_{ij} = 1 \quad (12)$$

$$t_{ij} \in [0,1] \quad (13)$$

$$i \in [1, P], j \in [1, C] \quad (14)$$

The challenge of dynamic bandwidth allocation is illustrative expression of NP-hard issues. Increasing LUF for equity is the key utilitarian element, while throughput improvements are secondary. Since it is assumed that r_{ij} is known, we can instead apply the bandwidth distribution b_j to the connection x_{ij} and the transfer time assignment t_{ij} . According to the constraints (10) and (11), u_j can only have one parent node, a_i . The constraint (12) states that a_i has a transfer period of 1 and the constraint (13) states that p_{ij} can take on values between 0 and 1. Last but not least, constraint

(14) specifies that node indices i and j are, respectively, the parent and child indices.

B. Quality of service (QoS) aware Dynamic Bandwidth Allocation (QDBA)

QDBA is deployed in response to the bandwidth requirements of the children nodes. Through TIM, the bandwidth requirement of children nodes are transmitted to the parent. A parent node will try to allocate time slots in line with the TIMs it gets from its offspring. If a parent node doesn't have enough slots to assign to its children, it will generate a TIM indicating the problem and deliver it to the node's adjacent parent. This separates the requirements of the child nodes into two groups like Quality (Q)-demand and Supplementary (S)-demand. The Q-demand describes the entire bandwidth request for latency and bandwidth-sensitive RT traffic, whereas the S-demand describes the need for NRT (best-effort) traffic. The combined requests will decide the amount of slots availability for the next action. TIMs are transmitted to the final transmission channel of the node using either customized packets or regular data packets. TIMs will be transmitted if there is no available transmission slots during the node's contention slot.

QDBA initiates when a parent node has acquired TIMs from all of its children which involves constructing transmission schedules for those children while attempting to fulfill the bandwidth requirements. The rescheduling systems give more priority to, before trying to schedule the S-demands to Q-demands than S-demands. Therefore, a parent node decides the Q-demands of all its children. The parent node generates the schedule and distributes it to all of its children. One example of a decentralized scheduling mechanism is when a parent creates transmitting strategies for its 1-hop children and delivers them without affecting the neighboring nodes.

The behavior of the clusters in a parent-child connection is consistent with one another excluding the cluster that contains the leaf nodes. There are R_k^Z nodes in cluster k on level Z , so that, $R_k^Z - 1$ are direct children of any specific node of the parent. The number of clusters in the network at any given level Z is f . $N_{p_k}^Z$ is the parent node in a k cluster of level Z and $N_{i_k}^Z$ is the i^{th} child node in the same cluster given that $0 < c < R_k^Z$. If the cluster's parent node $N_{p_k}^Z$ has a transmission slot S_k in a certain time cycle T_c , then the children of that particular node might utilize the slot provided at the transition times t_i and t_j independently to one another.

The slot allocation procedure is initiated by the source node, which performs the action of central coordinator. T_c is split evenly among the source and its 1-hop children nodes with an execution that the source which has superior transmission abilities to deliver the traffic beyond the network.

Consequently, if the aggregate number of slots in a provided multiple access time period is α , then the bandwidth allocation acquired by the i^{th} node of children in the k with Z may be indicated as $\alpha_{N_{i_k}^Z}$ in Eq. (15)

$$\alpha_{N_{i_k}^Z} = \frac{\alpha_{N_{p_k}^Z}}{R_k^Z} \quad (15)$$

Consider the demand from the i^{th} children node in the cluster $N_{i_k}^Z$ be $\beta_{N_{i_k}^Z}$ and the slot allotted to the cluster parent $N_{p_k}^Z$ be $\alpha_{N_{p_k}^Z}$. As a result, we the slots assigned the child node $N_{i_k}^Z$ is computed as follows.

$$\alpha_{N_{p_k}^Z} = \min(\beta_{N_{i_k}^Z}, \alpha_{N_{p_k}^Z} * \frac{\beta_{N_{i_k}^Z}}{\sum_{j=0}^{R_k^Z} \beta_{N_{i_k}^Z}}) \quad (16)$$

In the above Eq. (16), $\alpha_{N_{i_k}^Z}$ is the bandwidth share with total number of i^{th} node belonging to k^{th} cluster of level Z . When a child model's Q - demands are less than the bandwidth allocated to it, as it returns the S - bandwidth to its parent so that the other nodes might adopts the unexploited slots. In certain cases, only upto 80% of their entire bandwidth is made accessible. The remaining 20% will be followed up to the subsequent node. This mechanism is termed as bandwidth delivery. If the total bandwidth requirements of its children exceed the available bandwidth, the available bandwidth is divided fairly among the children, and the parent receives any requests for further bandwidth. The process of demanding for the subsidiary slots are similar for the children reassuring their parent that for their bandwidth necessities. The leaf nodes ultimately initiate the dynamic slot scheduling process, which continues until the root of the 1-hop children carried out in a

hierarchical manner. The fig. 1 depicts the flow chart of this proposed model.

Algorithm: QDBA method

Input: Multi access time frame (T_r), Slots assigned to N_t (α_{N_k}), Q – demand for i^{th} node (γ_i), S – demand for i^{th} node (β_i)

Output: Bandwidth demand of every child node, transfer period and relationship data

1. $Q \leftarrow 0.8 * \alpha_{N_k}; S \leftarrow 0.2 * \alpha_{N_k}; N_c: \text{Child number}$
2. $c \leftarrow 0; \gamma^c \leftarrow 0; \beta^c \leftarrow 0; N_c \leftarrow 0$
3. While $c < N$ do
4. $\gamma^c \leftarrow \gamma^c + \gamma_i$
5. $\beta^c \leftarrow \beta^c + \beta_i$
6. Increment c
7. End while
8. For all T_c in T_r do
9. If t_i is allocated to N_k then
10. $f \leftarrow (N_c + +) \bmod n$
11. $v \leftarrow 0$
12. While $R < N$ do
13. If $(\alpha_f > 0 \ \& \ \frac{Q}{\alpha_{N_k}} > 0)$
14. Allocate $t_{(i+1) \bmod 2}$ to Child $[f]$
15. Reduce $\alpha_f, \frac{Q}{\alpha_{N_k}}$
16. If $\frac{Q}{\alpha_{N_k}} = 0$ then
17. RESOURCE_REQUEST ($\frac{Q}{\alpha_{N_k}}, \alpha_{N_k}, \gamma^c, \beta^c$)

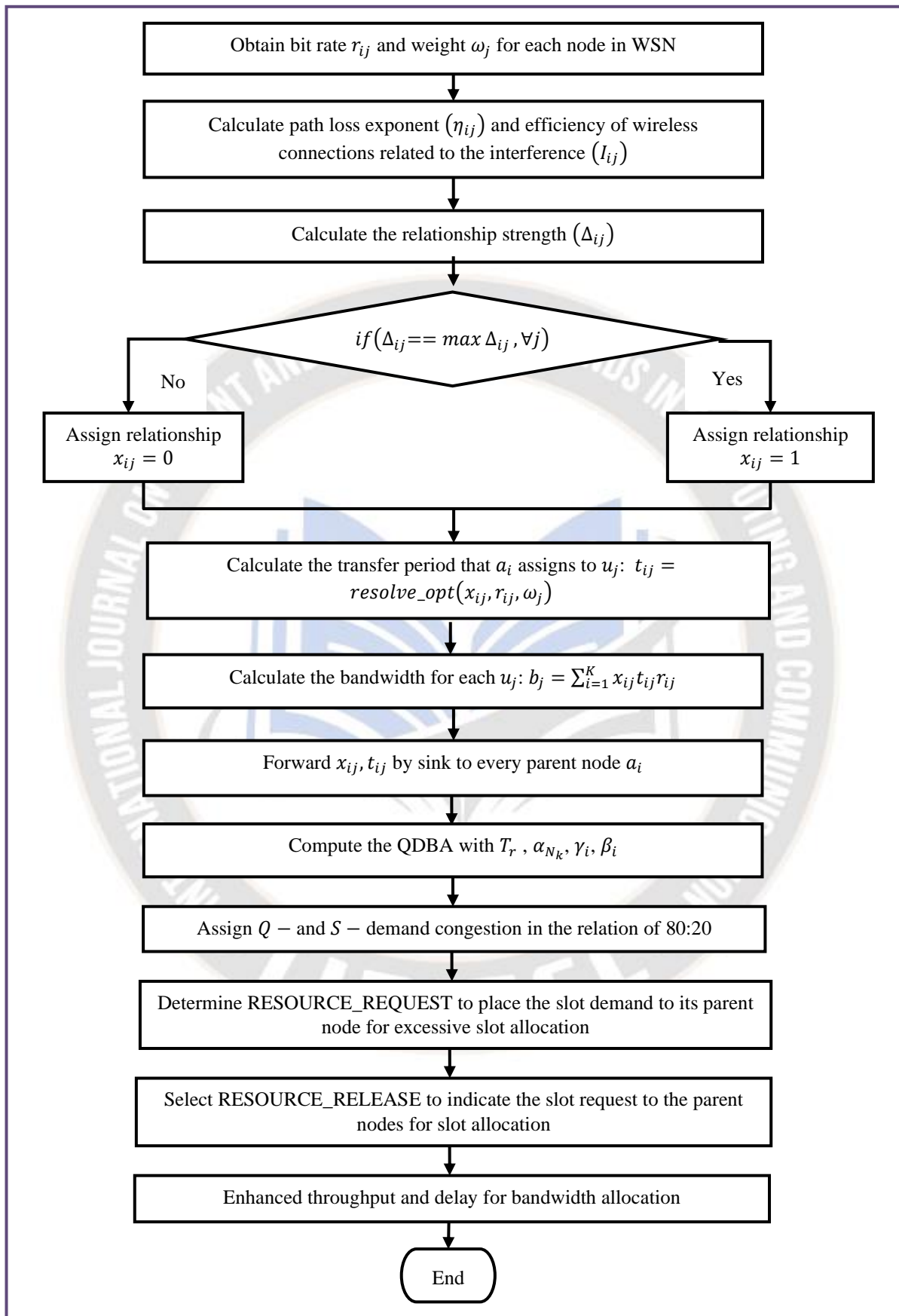


Figure 1. Flowchart of PRC-QDBA model

18. end if
19. break loop
20. End if
21. end while
22. If $R = N$ then
23. $R \leftarrow 0$
24. While $R < N$ do
25. If $(\beta_f > 0 \ \& \ (\alpha_{N_k}^S + \alpha_{N_k}^Q) > 0$ then
26. Allocate $t_{(i+1) \bmod 2}$ to *Child* [f]
27. Decrement $\beta_f, \alpha_k^S + \alpha_{N_k}^Q$
28. Break loop
29. End if
30. End while
31. End if
32. End if
33. End for
34. If $(\alpha_{N_k}^Q + \alpha_{N_k}^S) > 0$ then
35. RESOURCE_RELEASE (p_{N_k}, α_{N_k})
36. End if
37. RESOURCE_REQUEST ($\alpha_{N_k}^Q, \alpha_{N_k}, \gamma^c, \beta^c$)
38. $\alpha_{N_k} \leftarrow \gamma^c + \beta^c$
39. End procedure
40. Procedure RESOURCE_RELEASE
 $(\alpha_{N_k}^Q, \alpha_{N_k}^S, \gamma^c, \beta^c)$
41. Divulge the rest $(\alpha_{N_k}^Q + \alpha_{N_k}^S)$ number of slots
42. $\alpha_{N_t} \leftarrow (\gamma^c + \beta^c) - (\alpha_{N_k}^Q + \alpha_{N_k}^S)$
43. End procedure

The aforementioned algorithm defines the framework of dynamic slot allocation tasks. A total of α_{N_k} slots with respect to T_r are being distributed by the cluster head of cluster k, N_k . Before giving the other slot to any of the children node, this algorithm verifies whether the node has a slot assigned to it. The bandwidth α_{N_k} is distributed in an 80:20 ratio between Q-demand and S-demand traffic. After the slots are assigned for Q-demand, any available slots will be allocated to S-demand.

The time periods between Q- and S-demand traffic are denoted by $\alpha_{N_k}^Q$ and $\alpha_{N_k}^S$ correspondingly. The parent node calculates the complete Q- and S-demand and represented it as γ^c and β^c based on the Q-demand (γ_i) and S-demand (β_i) achieved from of all its children nodes

considering *Child* [$0..(N-1)$]. It satisfies the Q-demand of all of its children by selecting the optimal shots from among those in $\alpha_{N_k}^Q$. The S-demand of all child nodes is allotted 20% of the bandwidth are consistently framed for S-demand $\alpha_{N_k}^S$, especially satisfying the criteria of Q-demand. After the slots allocation, some slots are left unused are assigned to S-demand for improvising the RT traffic in WSNs.

The RESOURCE_RELEASE mechanism sends unused time slots from children nodes to parents for usage in a high-state cluster. If a child node's Q-demand does not meet the criterion, the cumulative slot demand ($\gamma^c + \beta^c$) is allocated to the immediate parent node for insufficient slot allocation. This is effectively handled by RESOURCE_REQUEST. A parent node distributes the Q-demand of child nodes in a round-robin manner. As a result, the unused slots of the children nodes are quickly reallocated to the other active nodes. The objective of resource request and release is implicitly met by shifting the increased slot demand to the parent and assigning unused slots in a round-robin manner. This improves throughput and latency for bandwidth allocation and enhances the QoS support for RT traffic in WSNs.

IV. SIMULATION RESULT

In this part, the PRC-QDBA is implemented in Network Simulator version 2.35 (NS2.35) and its efficacy is compared to the PRC-FBA [9], DHSSBA [14], WPDDRC [8] and DDRC [8] techniques. The evaluation is conducted based on throughput, packet loss, End-to-End (E2E) latency, queue size and source data transfer rate adjustment. Table 1 provides a list of the simulation parameters utilized in this system.

Table 1. Simulation Parameters

Parameter	Range
Simulation area	1000x1000m ²
Number of nodes	50
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Number of traffic categories	4
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW
Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility speed	10m/s
Simulation time	120sec

A. Throughput

It measures how much information a target can take in during a given time period.

$$\text{Throughput} = \frac{\text{Total amount of data accepted by the target}}{\text{Time}} \quad (17)$$

Fig. 2 shows the throughput (in Kbps) for different simulation times (in sec) for the DDRC, WPDDRC, DHSSBA, PRC and PRC-FBA methods. The results show that PRC-QDBA outperforms than other competing methods in terms of throughput. In 120s simulation time, PRC-QDBA outperforms DDRC, WPDDRC, DHSSBA and PRC-FBA methods by 13.19%, 9.57%, 7.1% and 5.1%, respectively, in terms of

throughput. This is made possible by giving different types of traffic equal bandwidth and priority in each virtual queue across the network.

B. Packet Loss

It refers to information that was lost or never received during a transmission.

$$\text{packet loss} = \frac{\text{Amount of lost data}}{\text{amount of lost data} + \text{Amount of accepted data}} \quad (18)$$

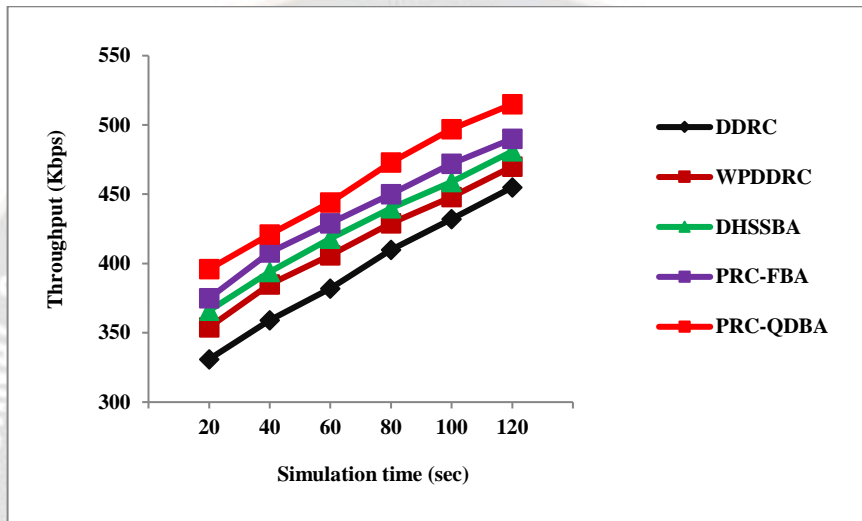


Figure 2. Throughput vs. Simulation Time

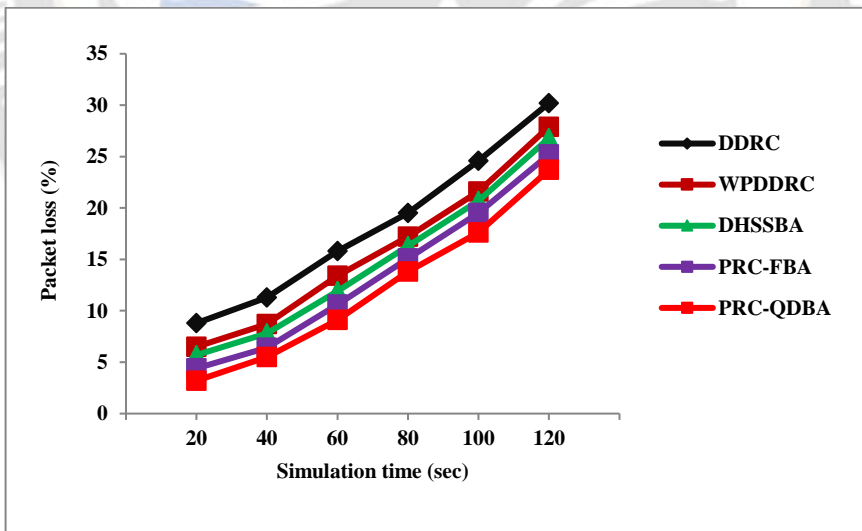


Figure 3. Packet Loss vs. Simulation Time

Fig. 3 compares the packet loss (%) over different simulation times (in seconds) for the DDRC, WPDDRC, DHSSBA, PRC-FBA and PRC-QDBA methods. There is evidence here to suggest that PRC-QDBA achieves lower packet loss than alternative methods. While consider the

stimulation time of 120sec, PRC-QDBA results with 21.5% reduction in packet loss compared to DDRC, 15.1% reduction compared to WPDDRC, 11.6% reduction compared to DHSSBA and 6% reduction compared to PRC-FBA. Therefore, lower the results of PRC-QDBA packet loss can be

attributed to by applied in many virtual queues and each node's bandwidth allocation in relieving WSN congestion.

C. End-to-end Delay

The time it takes for information to travel from its source to its destination.

$$E2E\ Delay = Time_{sink} - Time_{origin} \tag{19}$$

With respect to Eqn. (19), $Time_{sink}$ represents the time it took for the sink to take the data and $Time_{origin}$ represents the time it took for the origin to convey the data.

Fig. 4 shows the E2E delay (in msec) for different simulation times (in sec) for the DDRC, WPDDRC, DHSSBA, PRC- FBA and PRC-QDBA methods. When compared to the other methods, the PRC-QDBA have resulted to be lowest E2E delay. In a 120sec simulation time, PRC-QDBA reduces E2E latency by 13.1%, 9.5%, 7.5% and 6% compared to

DDRC, WPDDRC, DHSSBA and PRC - FBA methods. Hence, the lower E2E delay corresponds with the maximum throughput and the less packet loss.

D. Queue Size

The quantity of information waiting to be processed. When there are several people waiting, the wait time increases.

Fig. 5 shows the average number of packets in the queue for each of the DDRC, WPDDRC, DHSSBA, PRC and PRC-FBA methods as the simulation time (in seconds) changes. The results show that the PRC-QDBA method produces the shortest average queue length (mean queue size) among the tested methods.

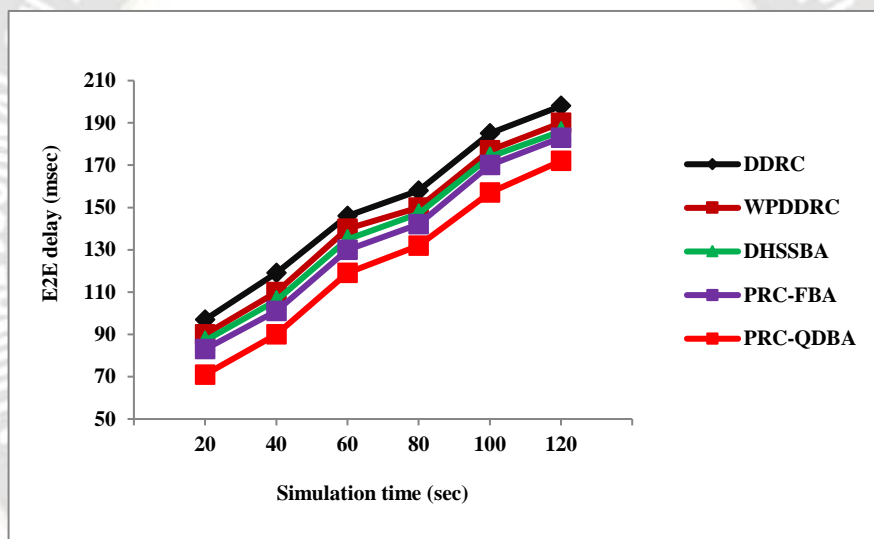


Figure 4. E2E Delay vs. Simulation Time

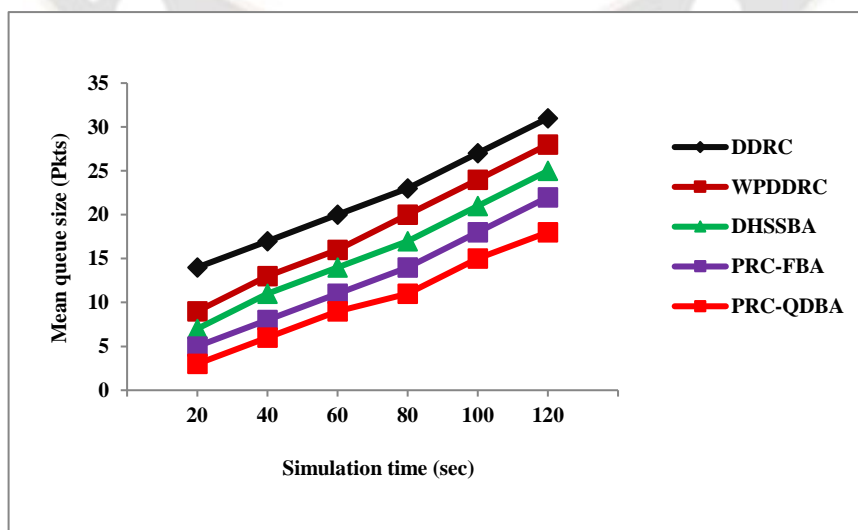


Figure 5. Mean Queue Size vs. Simulation Time

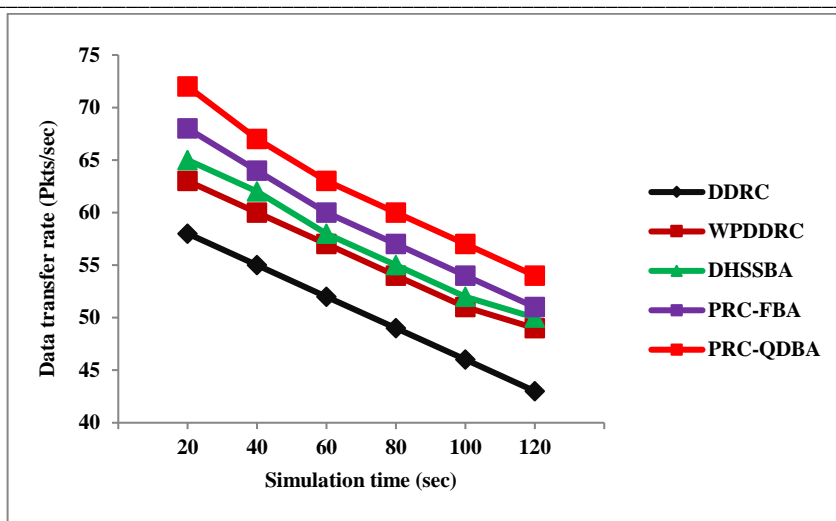


Figure 6. Data Transfer Rate vs. Simulation Time

The mean queue size of PRC-QDBA is 41.9%, 35.7%, 28% and 18.2% smaller than DDRC, WPDDRC, DHSSBA and PRC-FBA methods for the simulation time of 120 sec. Consequently, there can be a decline in packet loss and E2E latency if the minimum queue length is increased. It is clear that the PRC-FBA stabilizes the queue length around a target value and provides more stability for the mean queue size.

E. Data Transfer Rate Adjustment

Congestion and buffer overflow in WSN are managed by the data transfer rate at the source.

Fig. 6 shows the packets-per-second (pps) data transfer rate for different simulation times (in sec) for DDRC, WPDDRC, DHSSBA, PRC-FBA and PRC-QDBA. The results of this study show that the PRC-QDBA method, with its efficient rate adjustment and bandwidth distribution, provides the maximum data transfer rate. PRC-QDBA has a data rate that is 25.6%, 10.2%, 8% and 5.9% higher than DDRC, WPDDRC, DHSSBA and PRC-FBA method for the stimulation period of 120 sec. It is observed that that PRC-QDBA can reduce the data transfer rate may progressively lower the data transfer rate compared to the nodes' initial transfer rate. Therefore, the highest priority traffic classes are correctly transmitted without any congestion before lowering the transfer rate.

V. CONCLUSION

This paper proposes a PRC-QDBA approach for allocating bandwidth while selecting packets based on traffic types. Initially, the challenges faced in WSNs bandwidth distribution is investigated using the SINR model in an attempt to find a balance among fairness and efficiency in the network. Then, QDBA was utilized to

disperse unused time slots across nodes by utilizing a hierarchical tree structure. The parent node acquires TIMs from the children nodes and allocates spaces in accordance with their demands. If it is unable to assign slots, it initiates TIM stating the demand and transmits it to its adjacent parent node, improving RT traffic throughput. Finally, PRC-QDBA technique surpasses traditional models in terms of throughput and delay in WSN bandwidth allocation for efficient bandwidth allocation and enables QoS support for RT traffic in WSNs.

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Smart Bandwidth Prediction, Power Management and Adaptive Network Coding for WSN

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Abstract: WSN has been widely used in many sensitive applications and it also has novel possibilities for laying the groundwork for using ubiquitous and pervasive computing, but it has also presented a number of issues and challenges, such as a dynamic network topology and a congestion problem that hinders not only network bandwidth utilisation but also performance. Proficient rate control and fair bandwidth allocation (PRC-FBA) was one of the schemes in the literature to solve issues of WSN by combining the ideas of traffic class priority and bandwidth fairness. However, because of the nature of WSN, the energy of nodes near the sink node is diminished when packets move from lowly congested nodes to highly congested nodes. This paper proposes a proficient rate control with data aggregation and fair bandwidth allocation (PRCDA-FBA) to address this problem by using an effective data aggregation approach for reducing the number of transmissions. In the proposed method, fair bandwidth allocation is simplified by an artificial intelligence-based bandwidth prediction method. Thus, PRCDA-FBA increases the network's durability. Despite having lower bandwidth utilizations, energy-critical sensor nodes require careful power management to avoid being eavesdropped upon. Along with data aggregation and fair bandwidth allocation, the effects of overhearing packets by energy-critical nodes are mitigated through network-wide route adjustments based on the energy level of nodes. Thus, in the proposed method, data aggregation is scheduled based on the availability of bandwidth, energy, queue size and packet priority. The proposed method is named as energy-aware proficient rate control with data aggregation and fair bandwidth allocation (EPRCDA-FBA). The proposed algorithms have been deployed on the Network Simulator 2.35 platform, and a comparative analysis has been performed using several metrics, including throughput, packet loss, End-to-End (E2E) delay and energy utilization. The EPRCDA-FBA method archives highest throughput which is 9.17%, 5.48%, 4.68% and 2.45% higher than congestion control strategies like discrete-time sliding mode congestion controller (DSMC), weighted priority based fair queue gradient rate control (WPFQGR), PRC-FBA and rate adjustment-based congestion control (RACC).

Keywords: Wireless Sensor networks, Congestion control, PRCDA-FBA, EPRCDA-FBA.

1. Introduction

WSNs are developed by connecting a large number of sensor nodes where each sensor can collect information from its neighbours and transmit it to them over a wireless network within its distribution centre. WSN is extensively used in a variety of applications, including medical practises, agricultural modelling, disaster monitoring, and so on, and it relies on a set of efficacious measures to preserve stability.

Every sensor node is equipped with all of the necessary data transmission capabilities [1]. But, due to continuous transmission congestion occurred which causes high delay, low throughput, high energy consumption, more data loss, poorer integrity and performance degradation even if such nodes employ the maximum capacity.

Over the last ten years, in the literature, many researchers focussed on developing several tailored Networking protocols [2]. An effective methods are required in WSN to handle massive amounts of frequently sensed data with limited bandwidth and

energy utilization. It's critical to get the signal from the originator node to the sink node with as little loss as possible. Congestion in the network is among the most important factors in data loss, and avoiding congestion has piqued the interest of many academics [3, 4].

In the literature, a variety of traffic delay tactics has been identified, with rate control being one of them. It has been discovered that real time (RT) traffic necessitates minimal latency and excellent consistency, and hence must be prioritised. In RT applications, WSNs can generate a wide range of data packets [5]. Due to bandwidth constraints in WSNs, such a wide range of data must be handled with different levels of priority, which helps to keep the network from becoming congested [6]. Various algorithms have been developed over the years to control congestion based on the traffic priorities of RT packets. Weighted Priority Difference of Differential Rate Control (WPDDRC) algorithm [7] has been developed which combines the DDR of a particular node with the WP of traffic class. Variations in next hops across routing paths between the transmitter and the receiver in the WPDDRC algorithm can lead to an increase in the WSN's unintended energy consumption.

For dealing with congestion and buffer overflow in WSNs, a PRC-FBA congestion control algorithm was proposed [8] in previous study. In this method, two different virtual queues are used on a single physical queue to collect incoming packets from all child nodes based on the priority. This technique prioritise different kinds of traffic and distributing bandwidth fairly. This approach first analyses the problem of bandwidth assignment in WSN using the Signal to Interference and Noise Ratio (SINR) model, which aims to find a balance between neutrality and network efficiency. Packets flow from low-congested nodes to highly-congested nodes in a WSN network, reducing the energy of nodes near sink nodes in the PRC-FBA.

To address the above problem, PRCDA-FBA is proposed in this paper that uses a well-organized aggregation mechanism to reduce the battery power across all participating nodes and leading to higher total network throughput. Aggregation mechanism just a form of adaptive network coding built on top of random linear network coding (RLNC). An adaptive network combines data for transmission to the next hop which increases channel usage and reducing packet redundancy in the network. An adaptive methodology is triggered only when congestion occurs Based on packet priority, residual energy, and latency, the parent node decides whether or not to activate networking coding, as per the

adaptive network coding approach. Long Short-term Memory (LSTM) based neural network is also used to anticipate the required bandwidth for nodes by learning from previous data, which includes packet drop rate, energy, priority of packets, latency of packets, and bandwidth use. Even though data aggregation mechanism reduce the unnecessary transmission and energy consumption, the energy management additionally required to improve the network performance further. As a result energy saving criteria also include in PRCDA-FBA and named as EPRCDA-FBA. The path selection is considered along with residual energy of nodes. The major purpose of this proposed method is ensure to meet QoS standards in terms of fast data delivery, reduced energy consumption of energy-intensive nodes and increased network durability. The excess power of the node is taken into account in this protocol's primary concern rate control approach.

Leftover paper units are made as follows: related works in section 2. PRCDA-FBA and EPRCDA-FBA are explained in section 3. Simulated findings are in section 4. Section 5 summarises the article and suggests future work.

2. Related works

There is a proposal for congestion control [9] that uses fuzzy heuristic and metaheuristic search to balance a variety of objectives, including travel time, energy consumption, and network density. Multiple goals are taken into account when controlling the cluster leader's queue. The reduced power usage from this technology increases the longevity of the network. However, as the simulation time increases, the delay and throughput progressively worsen. Cooperation game theory [10] is used to describe data transfer priorities. The level of congestion and the quality of service (QoS) requirements of each type of data inform the ant-based routing algorithm that is integrated with game theory to construct the path. Due to the lack of queue control, significant packet loss happens while employing this technique. To achieve this, a DSMC is developed, which successfully adjust queues at bottleneck nodes to the appropriate value [11]. In terms of latency and packet loss, this strategy is superior. However, the congestion issue will get more severe, resulting in greater delays, as the simulation time increases.

An adaptive access control is developed for more efficient traffic management and lower power usage [12]. To determine which nodes should be allowed access to the wireless channel first, second, or third, a fuzzy technique is utilised. In high-traffic settings, however, dynamic time-slot management is

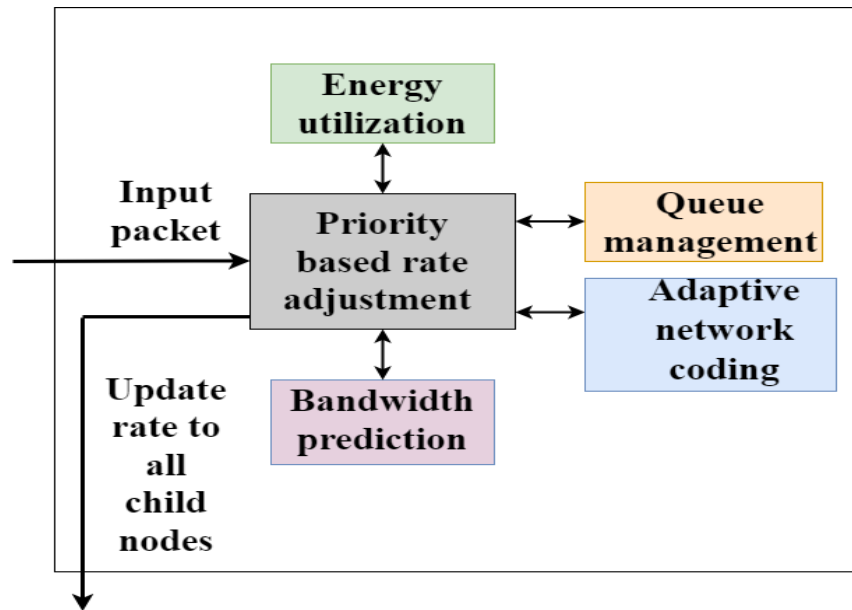


Figure. 1 The proposed method is depicted in a block diagram

challenging and will impair network throughput. To boost network functionality, an effective congestion avoidance strategy [13] is presented based on Huffman coding algorithm and ant colony optimization. This strategy is an amalgam of resource-based and traffic-based optimization strategies. Although effective initially perform well, this strategy has higher delay and low throughput as the duration of the simulation time increases.

By calculating the retransmission likelihood of packet arrival and the average energy usage, we may avoid transmission collision [14]. As energy consumption at individual nodes climbed above 50%, however, throughput began to degrade. Weighted priority based fair queue gradient rate control (WPFQGR) [15] ensures that available bandwidth is shared equitably by considering traffic class priorities, average queue sizes, and a node's connected loads. Every efficiency metric is improved upon by this technique. As the simulation period increases, however, key metrics like energy and throughput inevitably drop.

Artificial intelligence algorithms are employed for awakening scheduling of active nodes [16], while the Spatial Spider Optimization algorithm and K-means clustering enhancement are used to pick cluster heads. Provides improved delay and throughput at first, but both degrade with time. A system called RACC [17] has been developed to alleviate traffic congestion. Node buffer occupancy is monitored and used to dynamically alter the transmission rate. Additionally, a variety of modulation algorithms were used to lessen the load

on the available bandwidth. However, delays and reduced throughput become more common once a certain amount of time has passed during transmission.

3. Energy-aware proficient rate control with data aggregation and fair bandwidth location algorithm (PRCDA-FBA)

The model of the system is illustrated as a graph $G(V, E)$. Here, V represent sensor nodes and E is connections among them. $e(a, b) \in E$ defines the communication relationship between different nodes $a \in V$ and $b \in V$, and sink node is the ultimate receiving node. The connection $e(a, b) \in E$ also symbolises the nodes a and b at the transmitter (T_r) and reception (R_r) ends, respectively. Connections are established between nodes in a network when the space between them is less than the maximum range of the transmission medium. The sensor node communicated the collected data to the subsequent node after returning from the application field.

The proposed method aggregates data via network coding to lessen latencies in data transmission and power consumption while increasing network throughput. The transmission frequency is the average rate at which packets are sent from a single node during a single transmission round. Reduced transmission frequency, on the other hand, increased network channel capacity, which enhanced overall network throughput. The network coding path combines data for transmission to the next hop, increasing channel usage and reducing

packet redundancy in the network [18]. When congestion occurs, an adaptive methodology is given in which the packet dropping rate is increased and the node sends packets by aggregating them using network coding.

In a dynamic environment, network coding offers a few advantages in terms of performance and throughput. In contrast, network coding necessitates extensive computational complexity on both ends of the transmission link. As a result, the necessity to devise an algorithm that provides optimal performance while minimising operating cost. A new adaptive network coding method is developed based on [19] to enable the source node to switch back and forth between archiving and transmitting actual packets into networks and going to perform RLNC of data packets and trying to deliver them into system. Fig. 1 represents the proposed congestion control mechanism.

3.1 Energy-aware proficient rate control

Due to the use of battery power and energy consumption, lots of energy will be loss hence power management is required to overcome this difficulty. To establish a relationship between the strength of the transmission signal and the quality of the forward connection, researchers at EPRCDA-FBA developed a receiver-based prediction model. The EPRCDA-FBA algorithm is presented to handle power regulation and extend battery life.

In the proposed EPRCDA-FBA algorithm, energy aware Proficient Rate control scheme is proposed. The major purpose is to ensure that QoS standards are met in terms of delayed data delivery, reduced energy consumption of energy-intensive nodes, and increased network lifespan. The surplus power of the node is taken into account in this protocol's priority-based rate control method. Initially, a prediction model is used to determine the proportion of node transmit energy levels that can be reduced without drastically reducing the packet delivery ratio. Then, to avoid overhearing energy-critical nodes, a priority of nodes for delivering traffic classes of packets is determined using a combination of energy.

The nodes employ this prediction model for two objectives. First, a node can use this model to determine how much power it can lower in relation to a receiver while keeping a specific level of connection quality. Second, the node can determine how much overhearing is transmitted to energy essential neighbours at a given transmit power level. Since the broadcast power level of the broadcaster greatly affects the link quality between a pair of

nodes, it is important to build a prediction model at the receiver end that links the broadcast power level at the transmitter together with the lifetime at the receiver. Traffic load of node is calculated in Eq. (1)

$$TL = \frac{\sum_{j=1}^N q(j)}{N} \quad (1)$$

The number N here represents the number of packets, $q(j)$ represent the j^{th} packet in the queue. q_{max} is the maximum queue size. Traffic Load Intensity is calculated Eq. (2).

$$TLI_{(i)} = \frac{TL_{(i)}}{q_{max}^{(i)}} \quad (2)$$

The cost of the link is calculated based on the energy utilized for packets transmission Eq. (3).

$$LC_{i,n} = \frac{O_i}{E_{i,j}} \quad (3)$$

$E_{i,j}$ energy for transmitting j^{th} packet by i^{th} node. O Represent out coming packet from previous sensor nodes of current node. The network coding is applicable in the node whoever TLI and LC exceeds maximum limit.

Proficient rate control is followed by the previous work [8]. The primary goal of this algorithm is to deal with various kinds of non live time (NLT) packets, such as high preference NLT (HNLT), Middle preference NLT (MNLT), and Little preference NLT (LNLT). When these packets are sent out, they each have a different priority level. Therefore, the packets are identified by data rates of varying values. The live time (LT) traffic class is extremely important and receives the highest consideration.

Consider ptp_n^k and lp_n^k are packet type of preference and the location preference of packets in n^{th} queue of k^{th} intermediate sensor node. sp_i^{kn} is the source preference of n^{th} queue of k^{th} node, the packet types are $i \in \{LT, HNLT, MNLT, LNLT\}$.

First, the packet type of preference in n^{th} queue of k^{th} node is calculated as Eq. (4)

$$ptp_n^k = \sum_n \sum_i sp_i^{kn} \quad (4)$$

The overall preference of packets type in n^{th} queue of k^{th} node is computed as

$$Op_n^k = ptp_n^k \cdot lp_n^k + [O_{LT} - \delta(O_{HNLT} + O_{MNLT} + O_{LNLT})] \quad (5)$$

In Eq. (5), δ is the values ($0 \leq \delta \leq 1$) and $O_{LT}, O_{HNLT}, O_{MNLT}, O_{LNLT}$ are the preference assigned to *LT* and *NLT* packet types. Likewise, the packet type preference in n^{th} queue of l^{th} next level node is computed as Eq. (6).

$$ptpt_n^l = \sum_n \sum_i sp_i^{ln} \quad (6)$$

After the preference rate has been updated, the sensor node transmits the information to the subsequent node in the hierarchy. If priorities are set properly, network congestion, buffer overflow, and dropped packets can be avoided.

3.2 Adaptive RLNC for data aggregation

According to the adaptive RLNC technique, the origin node determines whether to switch networking coding ON or OFF based on number of factors including packet size, the estimated disconnection time among connected hubs, and the network's data flow or packet rate. In cases where the total amount of the content being sent by the nodes is less than the maximum transmitting capacity of the link, network coding should be disabled. When the amount of information to be transmitted grows beyond a certain threshold, network coding is used. [20]. Using encoding, the packets are constructed and sent as a concatenation of the actual packets. An encoded data packet received by a node is then decoded to reveal the original data. Parameters for establishing network coding are calculated from Eq. (7) to Eq. (10)

$$Packet(sizeinbits) = 8 \times Packet(size) \quad (7)$$

$$D = Data\ rates\ in\ bps \quad (8)$$

$$ET = Estimated\ link\ expiration\ Time \quad (9)$$

$$MDT = Max\ Data\ rate\ Transmit = D \times ET \quad (10)$$

For network coding to take place, it is necessary and sufficient that nodes satisfy certain conditions in order to establish optimal pathways with potential coding nodes. Before to look at the network coding situation, let's establish some notations. $a \in d_f$ denotes node a beside the data flow d_f , whereby the source nodes and sink node. The single-hop neighbour set of nodes a is referred as $Ns(a)$. $Forward(a, d_f)$ and $Backward(a, d_f)$ respectively represent nodes towards destination and nodes set from origin of data flow d_f . Fig. 2 represent the sample network coding from source to intermediate and destination node, As a result, the in-between

sensor node e where incoming flows meet, encrypt the obtained data and delivered by the intervening node if the network condition is met. The packet flow in the network is denoted by the letters O_1 and O_2 . The critical and adequate conditions under which system coding is performed should be expressed to uncover ways with possible coding chances. Unless the preceding condition is met when the flows d_{f1} and d_{f2} overlay at node e is network coding possible [20]. Due to the possibility of distinct flows interfering with each other, the issue of network coding collision has arisen.

Condition:

1: Existing node $n_1 \in Backward(a, d_{f1})$ while $n_1 \in N_s(m_2) \wedge m_2 \in Forward(e, d_{f2})$ or $n_1 \in Forward(e, d_{f2})$

2: Existing node $n_2 \in Backward(a, d_{f2})$ while $n_2 \in N_s(m_1) \wedge m_1 \in Forward(e, d_{f1})$ or $n_2 \in Forward(e, d_{f1})$

Here, n_1, n_2, m_1 and m_2 are neighbours of node a and e respectively. For a network with many flows, the one that best satisfies the coding criterion is the one along which the most possible codes can be transmitted. However, a native packet may not be decoded at the final node due to excessive coding at several contradicting nodes along the route. Flow d_{f3} does, however, connect to the network at a certain point. Node E_1 pleased aggregation with the d_{f1} and d_{f3} . Node E_2 perform the coding of d_{f2} and d_{f3} . Node E_1 gets $O_1 \delta O_3$ when it encodes packets $O_1 \delta O_3$ and delivers them along route d_{f3} . Furthermore, node E_2 is the coding node, which will again encode packets $O_1 \delta O_3$ and O_2 , i.e., $O_1 \delta O_2 \delta O_3$, and send them to D_3 and N_2 , correspondingly, through the paths d_{f3} and d_{f2} . Since that overhears packets O_1 and O_2 from source nodes $S1$ and $S2$, it may see that destination node D_3 decodes packets O_3 from $O_1 \delta O_2 \delta O_3$. If packets arrive at destination node D_2 , it is unable to decode original packets O_2 , but it can decode packet O_3 . However, node E_2 cannot be utilised as a coding node, as can be seen. Due to extensive coding along the path, d_{f3} has an impact on the coding collision problem in this situation. In order to avoid the code collision problem, extra limits should be imposed.

3.3 LSTM based fair bandwidth allocation

A learning based bandwidth assignment takes into account high – bandwidth traffic patterns. Training and testing done by LSTM [21] which used to handle bandwidth and traffic of various levels of burstiness. Bandwidth allocation is initially assigned

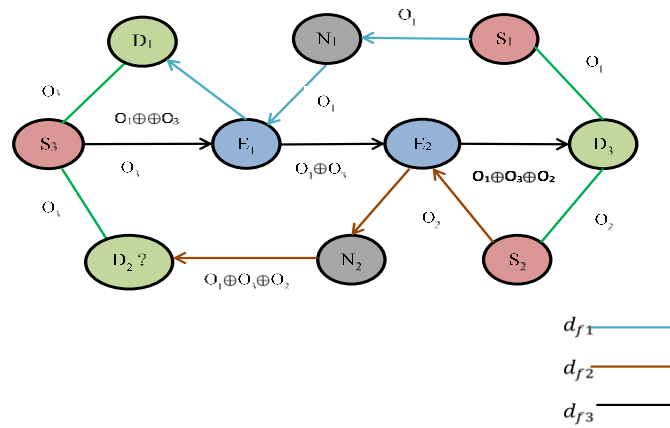


Figure. 2 An example network coding in network

based on the fair allocation scheme proposed in the previous study [8]. In this paper, the calculation of utility of bandwidth for links at every time is avoided by intelligent prediction model using LSTM. First LSTM is trained for higher and lower throughput for the parameters like packet transmit duration T_o , Packet size O_s , number of packets in the flow N_o , Bandwidth utilized BW_o and packet transmission rate O_R . The trained LSTM is used to predict required bandwidth for present packet transmission.

3.4 Algorithm for EPRCDA-FBA

Algorithm : EPRCDA-FBA

Input: Set of path

Output: Selected path

Step 1: Set the parameters: β, δ, μ are the priority values for traffic classes

Step 2: Service time (receiving packets) of sink node (ST_n^{sink})

Step 3: Compute the mean service time of available queues in sink node

$$\overline{ST}_n^{sink}(t+1) = (1 - \alpha)\overline{ST}_n^{sink}(t) + \alpha \cdot ST_n^{sink}$$

α is a fixed variable ranges 0 and 1

Step 4: Calculate the rate variance n^{th} queue in the sink node using the formula

$$\Delta r^{sink} = \beta \cdot r_{out}^{sink} - r_{in}^{sink}$$

where r_{out}^{sink} is the outage rate and the receiving rate of the sink node r_{in}^{sink} .

β is a fixed variable ranges 0 and 1.

Step 5: Compute k^{th} parent nodes using the following formula

$$\Delta r^k = \beta \cdot r_{out}^k - r_{in}^k$$

where, r_{out}^k is the outage rate of k^{th} node connected with sink. The receiving rate of the k^{th} parent node is r_{in}^k

Step 6: Calculate the updated outage rate of queue in the k^{th} node

Step 7: Calculate the updated outage rate of queue in the l^{th} child node

Step 9: Continue Steps 2 to Steps 7 for updating the rate of transmission for sensor nodes

Step 10: Check for active neighbouring nodes

Step 11: If Nodes has information to share

Step 12: if ($O_R > MDT$ or $TLI > max_{TLI}$ or $LC > max_{LC}$)

{

Execute adaptive network coding

$$O_1, O_2, O_3, \dots, O_n$$

$$P(n) = O_1 \oplus O_2 \oplus O_3 \oplus O_n \dots$$

$$P(n) = \sum_{k=1}^n A_k \times O_k$$

}

Step 13: Eliminate coding collision

When flow d_{f1} and d_{f1} overlap at the node e , network coding is possible only

if

{

Existing node $n_1 \in Backward(a, d_{f1})$

while $n_1 \in N_s(m_2) \wedge m_2 \in Forward(e, d_{f2})$ or $n_1 \in Forward(e, d_{f2})$.

Existing node $n_2 \in Backward(a, d_{f2})$

while $n_2 \in N_s(m_1) \wedge m_1 \in Forward(e, d_{f1})$ or $n_2 \in Forward(e, d_{f1})$

}

Step 14: intelligent fair bandwidth allocation

Node parameters : $x_p = \{P_s, T_p, N_p, BW_p, P_R\}$

$x_{model} = Train(LSTM(x_p))$ // Training using LSTM

$$BW_{(p+1)} = Predict(LSTM, x_{model}) //$$

bandwidth prediction for next packet transmission

Step 15:

}
Step 16: Else GOTO step 2

The link cost conditions checked in the if conditions in step 12 of algorithm is removed in EPRCDA-FBA. This paper evaluate the performance of both PRCDA-FBA and EPRCDA-FBA under various network characteristics.

4. Simulation results

In this section, the PRCDA-FBA and EPRCDA-FBA technique is executed in network simulator version 2.35 (NS2.35) and its effectiveness is analysed compared to the DSMC [11], WPFQGR [15], PRC-FBA [8] and RACC [17] techniques. The analysis is conducted based on throughput, packet loss, end-to-end (e2e) delay and energy utilization. Table 1 gives the simulation parameters considered in this analysis.

4.1 Throughput

It's the total amount of information transmitted from sensors to sink in a certain amount of time Eq. (11).

$$\text{Throughput} = \frac{\text{Total amount of data accepted by the target}}{\text{Time}} \quad (11)$$

Fig. 3 shows the throughput (in Mbps) for the approaches compared to the DSMC, WPFQGR, PRC-FBA, RACC, PRCDA, and EPRCDA-FBA under different simulation times in network simulator 2.35 (NS2.35) (in sec). EPRCDA-FBA is shown to have the highest throughput of all the methods studied. Throughput for EPRCDA-FBA is 9.17% higher than DSMC, 5.48% higher than WPFQGR, 4.68% higher than PRC-FBA, 2.45% higher than RACC, and 0.41% higher than PRCDA-FBA if the simulation time is 120sec. This is made possible by allocating equal bandwidth to all network nodes and assigning different traffic classes different priority levels in each virtual queue.

4.2 Packet loss

It is the amount of data dropped or missed during transfer Eq. (12)

$$\text{packet loss} = \frac{\text{Amount of lost data}}{\text{amount of lost data} + \text{Amount of accepted data}} \quad (12)$$

Fig. 4 compares the packet loss (in %) across several different simulation times for the DSMC,

Table 1. Simulation parameters

Parameter	Range
Distance Covered by Nodes	300m
Data transfer rate	2Mbps
MAC layer type	IEEE802.11
Network Nodes	500
Traffic types	4
Operating frequency	5GHz
Packet size	200bytes
Routing protocol	AODV
Boundary of Simulation	1000×1000m ²
Duration of Simulation	120sec
Cause of Traffic	CBR
Transmission power	285.63mW

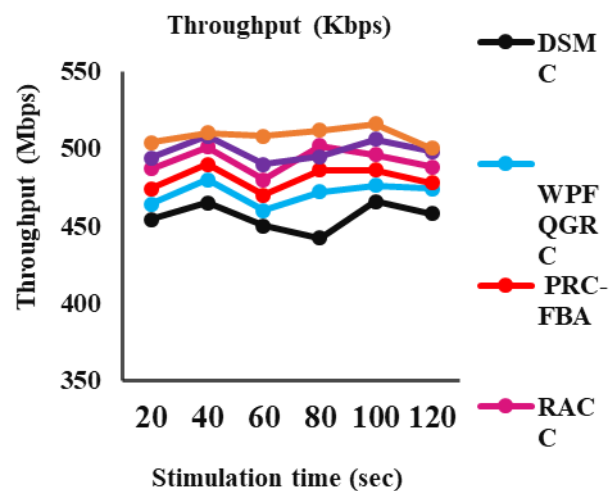


Figure. 3 Throughput vs. simulation time

WPFQGR, PRC-FBA, RACC, PRCDA, and EPRCDA-FBA methods (in sec). This finding suggests that EPRCDA-FBA achieves lower packet loss than competing methods. In a 120-second simulation, EPRCDA-FBA reduces packet loss by 57% compared to DSMC, 54% compared to WPFQGR, 49% compared to PRC-FBA, 42% compared to RACC, and 33% compared to PRC-FBA. EPRCDA-FBA uses virtual queues and fair bandwidth allocation at each node to mitigate the effects of WSN congestion, making it the most effective protocol in terms of packet loss.

4.3 End-to-end delay

The amount of time it takes for information to travel from its source to its destination (sink)

$$E2E \text{ Delay} = \text{Time}_{\text{sink}} - \text{Time}_{\text{origin}} \quad (13)$$

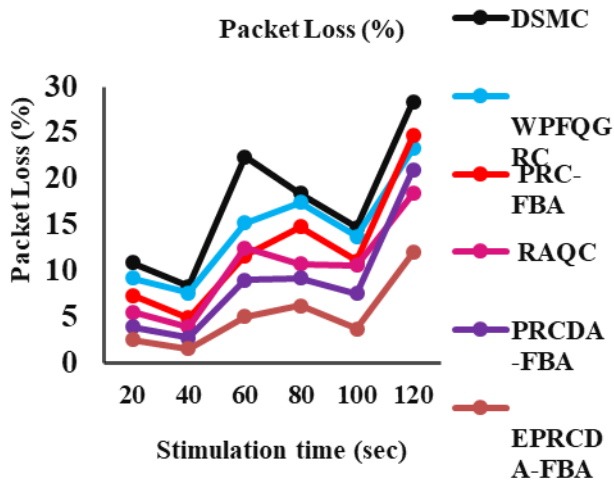


Figure. 4 Packet loss vs. simulation time

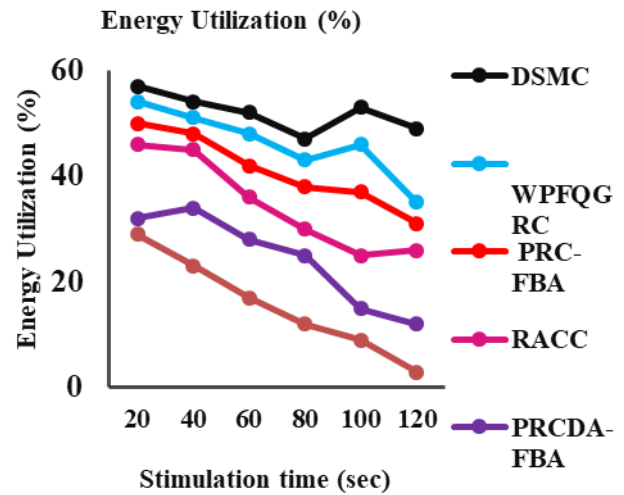


Figure. 6 Energy utilization (%) vs. simulation time

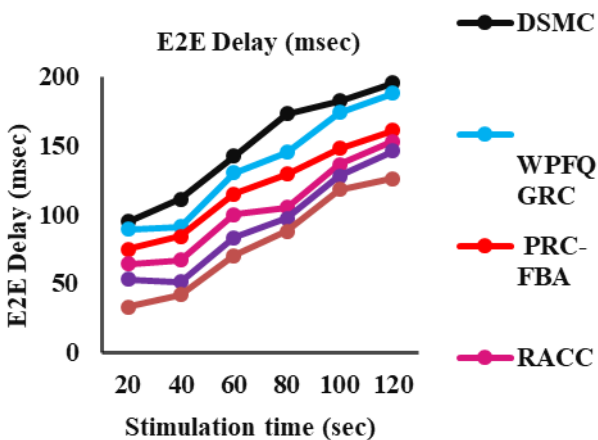


Figure. 5 E2E delay vs. simulation time

In this Eq. (13) $Time_{sink}$ is the time at the sink while accepting the data and $Time_{origin}$ is the time at the origin while forwarding that data.

The E2E delay (in ms) for different simulation times (in sec) is shown in Fig. 5 for the DSMC, WPFQGR, PRC-FBA, RACC, PRCDA and EPRCDA methods. When compared to the other approaches, the EPRCDA-FBA is found to have the shortest E2E delay. EPRCDA-FBA has a 35.38% lower E2E delay than DSMC, 32.97% lower than WPFQGR, 21.74% lower than PRC-FBA, 17.64% lower than RACC, and 13.69% lower than PRCDA-FBA when the simulation time is 120 seconds. The minimum E2E delay associates with the maximum throughput and the less packet loss.

4.4 Energy utilization

It represents the total percentage of network energy consumption over all time steps of the simulation.

Energy utilization (in %) during simulation period is shown in Fig. 6 for DSMC, WPFQGR, PRC-FBA, RACC, PRCDA-FBA, and EPRCDA-FBA. EPRCDA-FBA is able to reduce energy consumption when compared to competing methods. EPRCDA-FBA's energy consumption is 93.88% lower than DSMC's, 91.43% lower than WPFQGR's, 90.32% than PRC-FBA's, 88.46% lower than RACC's, and 75% lower than PRCDA-FBA's. That the EPRCDA-FBA reduces energy use relative to conventional methods is thus self-evident.

5. Conclusion

An energy-efficient, battery-powered, and power-management-friendly approach called EPRCDA-FBA is proposed. When the data rate is greater than a predetermined threshold value, network coding is implemented. In order to ensure that everyone gets their fair share of battery life, we apply a sophisticated data aggregation, coding condition, and coding collision method. An effective predictive model has been suggested for managing the power control. In conclusion, when compared to DSMC, WPFQGR, PRC-FBA, RACC, and PRCDA-FBA, EPRCDA-FBA achieves 4.4% greater throughput, 49.2% lower delay, 25% lower packet loss, and 67% lower energy usage in simulations. In future, it is possible to expand this work by applying the same situation to wireless recharging models, in which the confluence of congestion control via EPRCDA-FBA and suitable wireless recharging solves both the lifetime improvement and congestion control issues simultaneously.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Conceptualization, methodology, software, validation, Vanitha ; formal analysis, investigation, Amutha; resources, data curation, writing—original draft preparation, Vanitha ; writing—review and editing, Amudha; visualization, Vanitha; supervision Sivakumari.

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Analysis of Algorithms to Control the Congestion by Improve Energy Efficiency in WSN

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Abstract

Congestion is a major significant challenge in WSNs because it directly impacts energy efficiency and the network lifetime of sensor nodes in the network. This paper aims to analyze the different congestion control or avoidance routing protocols performances in WSNs with their drawbacks for identifying the upcoming scope of congestion-aware routing protocols in WSNs. This article proposed an adaptive queuing system with the WPDDRC called a proficient control (PRC) algorithm to tackle this issue. In this algorithm, two independent virtual queues are considered single physical length (lines), which accumulate the input packets from every child's node depending on the source's traffic significance and priority. A Proficient Rate Control (PRC) technique develops using traffic type priority and virtual queue conditions. Here, a PRC with Fair bandwidth Allocation (PRC-FBA) technique is compared and analyzed. It must handle the congestion due to the mix of RT and Non-RT (NRT) packets effectively in network.

Introduction

In WSNs, Congestion is classified into two types: link-Level and node-Level. The node-level congestion appears if the packet arrival rate exceeds, then the packet service rates and buffer overflow happen in the node. So, the results are high in the Packet Loss and Queuing Delay of the node. Among many of the classical Congestion Control Protocols, the most common protocols are Congestion Detection and Avoidance (CODA)[4], Priority-based Congestion Control Protocol (PCCP) [5], Active Queue Management [6], and Fairness Rate Control (FRC) [7] protocols. These depend on priority, traffic load, and fair bandwidth use. It remains a concern to solve the congestion by forwarding both Real-Time (RT) and Non-RT (NRT) packets. In the PRC algorithm, two independent virtual queues consider the single physical queue length to accumulate the input packets from every child node depending on the source's traffic sign if I cancel and priority. If the arriving' packet' receives, the PRC detects congestion by using the virtual queue status and the node just the child's transmission rates. Thus, this PRC algorithm can control the congestion d buffer overflow n SNs by considering traffic class priority and queue status. This article proposes a PRC with Fair bandwidth Allocation (PRC-FBA) technique by considering traffic type priority and fair bandwidth assignment. First, the challenge of bandwidth assignment in WSN has been investigated under Signal-to-Noise plus Interference Ratio (SINR) model, which intends to discover a trade-off between fairness and network efficiency. Then, a novel bandwidth utility factor is defined concerning fairness and efficiency. Congestion in WSNs has been subcategorized into link and node-level.

Literature Review

A Packet Priority Intimation (PPI)-based congestion avoidance approach [1] has been suggested, using a PPI bit in every data to signify its importance. The purpose was to forward higher priority data with the minimum latency.

A new technique for fairness-aware congestion handling [2] has been developed to reduce the energy use speed by modifying the number of mobile nodes, position, and velocity in WSNs. Also, the reporting rate adjusts to handle every node's buffer availability, alleviating the congestion in the network. But, the packet delivery rate was significantly less, and the packet loss ratio was still high.

A novel dynamic bandwidth assignment method called Dynamic Hybrid Slot-Size BA (DHSSBA) technique [3] has been designed to lessen the data latency and jitter difference of RT traffic in Ethernet passive optical network. In this technique, the time cycle for the primary portion was dynamically assigned for the high-priority traffic of each optical network module.

Fuzzy Sliding Mode congestion Controller (FSMC) [4] has designed a novel cross-layer congestion handling framework between transmission and MAC layer by considering a channel's SNR fraction in TCP structure. After that, FSMC was proposed by fusing fuzzy and SMC to regulate the queue size in congested nodes and avoid the effect of uncertain external interferences. But, the network reliability was less.

Proposed Methodology

The PRC algorithm explains briefly. This algorithm's main intention is to handle different NRT packet categories, and the considered types of PACKETS are HNRT, medium priority NRT (MNRT), and low priority NRT (LNRT). Each of the PACKETS is distributed with a particular priority. Then the general network topology shows in Figure 1, where P1,

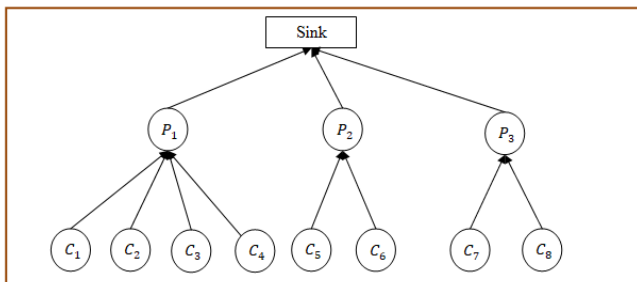


Figure1.GeneralNetworkTopology

P2 and P3 are Parent Nodes, and 'C1-C8' are child nodes. During packet transfer, the traffic classes prioritize the child nodes and the higher priority packets to sink nodes via the parent nodes. Consider TCP_{tnk} and GP_{tnk} are the traffic class priority and the geographical priority nth e virtual queue in a kth node. Also, consider Spain as the traffic source priority of nth virtual (QUEUE) in the kth node where 'I'm traffic class's sets and I ∈ T, HNRT, MNRT, LNRT.

First, the traffic class priority of nth virtual queue in kth node calculates as:

$$TCP_{tnk} = n_i S P_{tikn} \tag{1}$$

The RT traffic class plays a primary role in the overall priority, so the maximum PRIORITY is assigned to the RT. The overall Traffic Class

Priority contributing to the n^{th} virtual queue's overall PRIORITY in the k^{th} node minimizes the WEIG

HTED sum of the NRT traffic classes. Therefore, the weighted

'Overall PRIORITY for n^{th} virtual QUEUE in k^{th} node WP_{nk} is computing as:

$$WP_{nk} = TC_{pt} \cdot nk \cdot GP_{tnk} + WRT - \delta \cdot WHNRT + WMNRT + WLNRT \quad [2]$$

Iraq. (2), δ indicates the constant $0 \leq \delta \leq 1$, and $WRT, WHNRT, WMNRT, WLNRT$ are weighting assigns to the NRT and RT traffic classes. Similarly, traffic class priority of n^{th} virtual queue in l^{th} child node is computing as:

$$TC_{ptnl} = n_i S_{ptiln} \quad [3]$$

In Eq. (3), S_{ptiln} is the source priority of n^{th} virtual queue in l^{th} the child nodes. The weighted overall focus (PRIORITY) for n^{th} virtual lines (QUEUES) in l^{th} the child node WP_{nl} is,

$$WP_{nl} = TC_{ptnl} \cdot GP_{tnl} + WRT - \delta \cdot WHNRT + WMNRT + WLNRT \quad [4]$$

Iraq.(4), δ indicates the constant $0 \leq \delta \leq 1$, and GP_{tn} is the n^{th} virtual queue geographical priority' in the l^{th} child node. The 'Weighted Global PRIORITY' of n^{th} virtual QUEUES in l^{th} the child node WGP_{nl} changes to $WGP_{nl} = WP_{nl}$. The weighted international priority' at then n^{th} virtual queues' of k^{th} parent node WGP_{nk} changes to,

$$WGP_{nk} = n_l \in C_k WGP_{nl} + WP_{nk} \quad [5]$$

Consider TC_{ptnk} and GP_{tnk} are the traffic.

Class priority and the geographical priority n^{th} virtual queue in a k^{th} node. Also, consider Spain as the traffic source priority of n^{th} virtual (QUEUE) in the k^{th} node the PRC-FBA technique is described briefly. Assume the WSN has a K number of parent nodes denoted as a_1, \dots, a_K , and C number of child nodes marked as u_1, \dots, u_C in an equal cover age region. In Eq. (1), RSS_{kc} denotes the Received Signal Strength (RSS) of the parent node to child node, RSS_{ij} denotes the RSS from parent node i to child node j ; accordingly, indicates an increasing operation. In particular, k and i are the indexes of parent nodes, whereas m and j are the child node indexes. Finally, atypical model is adopted to simulate the wireless medium circumstance, which is designed as In Eq. (2), P_t denotes the transfer energy, PL indicates the path loss, $PL(d_0) - 105 \log(d/d_0)$ denotes the large-scale path loss model, which uses logarithm distance called long-distance radio propagation framework, d_0 denotes thereference distance, and $PL(d)$ denotes the received energy at d_0 , d denotes the distance between origin and target nodes and η denotes the path loss exponent. Finally, time slots are assigned, and the algorithm's outcome computes the transfer time. In Eq.(5), U is the node group; b_j is the adequate bandwidth distributed to node u_j .

Assume $b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij}$, where x_{ij} denotes the relationship of u_j with a_i . Use the $\sum K$

Physical restraints, and the one-child node can only connect with one parent node synchronously, so $x_{ij} \in \{0, 1\}$, p_{ij} denotes the transfer period that a_i distributes to u_j , and ω_j denotes the weight of u_j the traffic class priority of u_j in WSN.

A Logarithmic Utility Function (LUF) is defined regarding bandwidth, i.e., Jain's fairness index because there is an available selection of quantity for which the index is determined. It is described as:

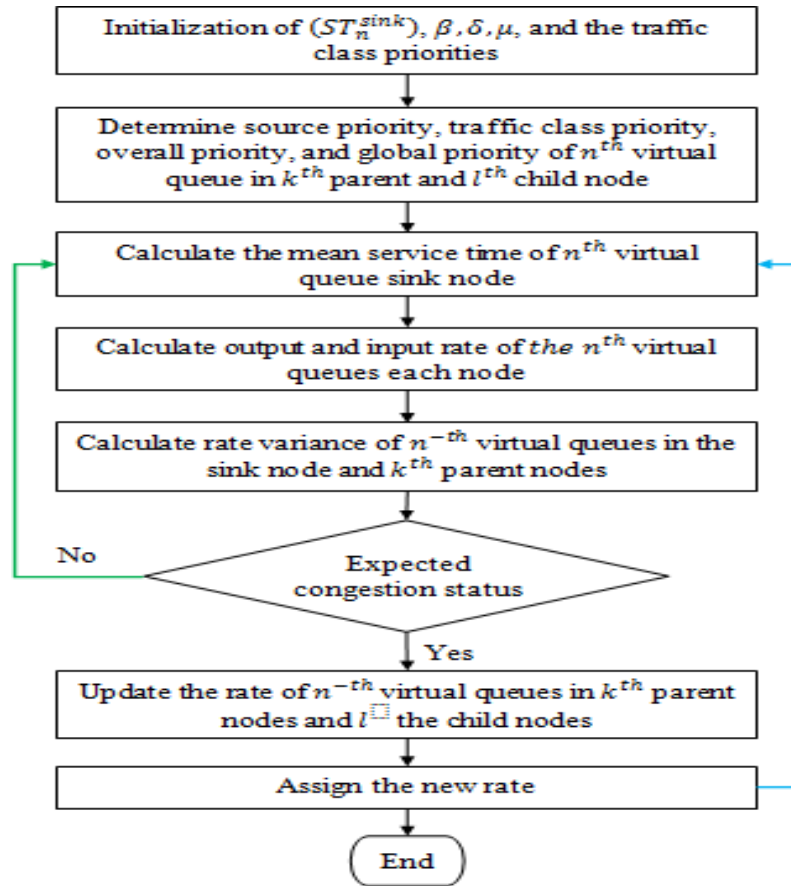


Figure2. Flowchart of PRC Algorithm for Congestion Control

$$I_{ij} = \left(SINR \left(\frac{RSS_{ij}}{\sum_{k \in [1,K]; c \in [1,C], c \neq j} RSS_{kc} + N_0} \right) \right) \quad [1]$$

:

$$RSS = P_t - (d_0) - 105 \log(d / 0) \quad [2]$$

Problem Formation

Fairness resource distribution is estimated by the range of fairness metric called Jain's index defined as:

$$f(X) = \frac{\sum_{i=1}^k x_i^2}{\left(\sum_{i=1}^k x_i \right)^2} \quad [3]$$

In Eq.(3), x_i denotes the resource distributed to individual $i=1, \dots, k$ and $X=(x_1, \dots, x_n)$

.To calculate fairness for bandwidth distribution, the formulation is represented by

$$f(X) = \frac{\sum_{j=1}^C b_j^2}{\left(\sum_{j=1}^C b_j \right)^2} \quad [4]$$

In this PRC-FBA, the formulation is defined as follows:

$$f(x,p) = \sum_{j \in U} \omega_j \log b_j \tag{5}$$

$$f(\cdot) = c \sum_{j=1}^j \frac{[\sum(\omega \log)]^2}{(\omega \log)^2} \tag{6}$$

Network throughput always conflict t with each other. This bandwidth distribution issue is devised as a non-linear programming. The aim is to distribute the bandwidth with trade-off between fairness and throughput. The optimization formulations are defined as: It is known as a non-linear bandwidth distribution dilemma, and it can be verified to be NP-hard. The primary utility factor is to increase LUF for fairness, and the secondary utility factor is to increase throughput. Usually, as r_{ij} is considered known, band width distribution b_j is turned to relationship x_{ij} and transfer period assignment p_{ij} . The restraints (10) and (11) indicate that u_j can only connect with one parent node a_i . The condition (12) denotes that the overall 1 transfer period of a_i is '1', and there straint (13) signifies that p_{ij} is a variable ranging from 0 to 1. At last, condition (14) defines that i is the index of parent nodes and j is the index of child nodes.

Fairness Bandwidth Distribution

Because non-linear bandwidth distribution is an NP-hard issue, an approximate technique is adopted for determining the relationship x_{ij} and transfer period assignment p_{ij} . This problem is resolved in a network structure creation series. Even though x_{ij} and p_{ij}

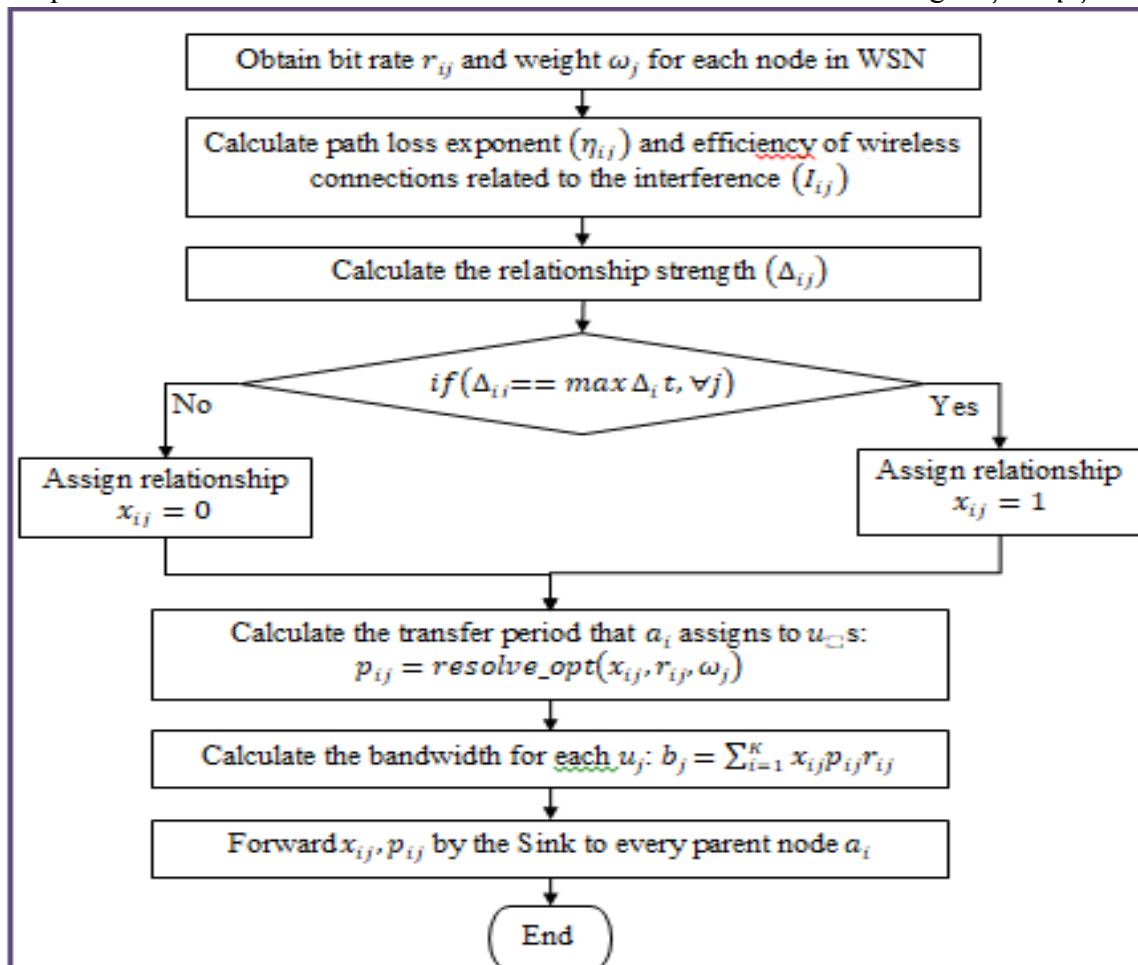


Figure 3. Flow Diagram of Fairness Bandwidth Distribution Process Distribution Phase

It have the association of $\sum_{j=1}^c x_{ij} p_{ij} = 1$, $x_{ij} \in \{0,1\}$, p_{ij} is independent of x_{ij} after the initialization of WSN. This issue is resolved by mutually considering nodes relationship and resource distribution, which intends to increase bandwidth utilities for fairness and throughput. So, this issue is split into two sub-problems and resolved in 2 different phases: relationship computation and distribution. In the initial phase, consider child nodes connect to parent nodes to compute the relationship of child nodes that intends to find x_{ij} . In this phase, u_j connects with a_i . Consider child nodes link to parent nodes, which create wireless connections in multi-rate WSNs. It removes the possible unwanted relationship based on r_{ij} and l_{ij} . The association is chosen by

In Eq.(15), Δ the relationship strength about bit rate and interference, ζ_1 and ζ_2 , are the weights.

Parameter	Range
Simulation area	1000×1000m ²
Number of nodes	50
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Number of traffic categories	4
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW
Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility speed	10m/s
Simulation time	120sec

Table1.SimulationParameters

Throughput

It is the amount of data accepted by the target with in a time.

Throughput=no of packets received/time

[15]

Figure 4 displays the throughput (in Kbps) for DDRRC, WPDDRRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec).

It observes that the PRC-FBA achieves higher throughput than all other techniques. Throughput=Total no. of packets receives by the Simulation time is 120sec, and then the PRC's packet loss is 22.22% less than the DTP-PA, 16.57% less than the DDRC, and 9.68% less than the WPDDRC algorithms. Thus, PRC's packet loss is the minimum because of using independent virtual queues in each node to handle the traffic classes' controlled priority level.

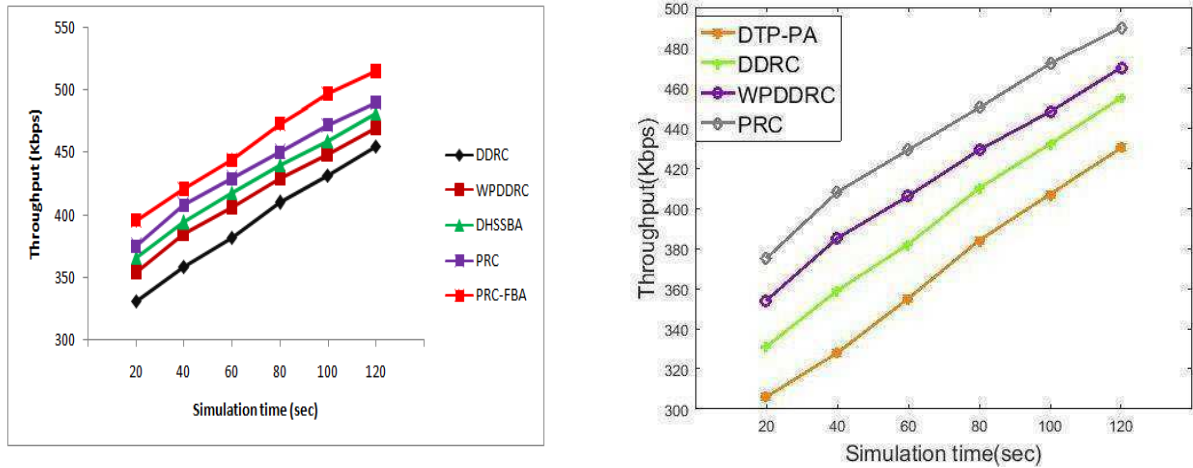


Figure4 Throughputs vs. Simulation time

Figure3 exhibits the throughput (in Kbps) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation times (in a sec). This analysis indicates that the PRC algorithm achieves higher throughput than all other congestion control algorithms.

Packet Loss

It defines the number of packets lost during communication. It has computed as: $\text{Packet Loss} = \frac{\text{Number of dropped packets}}{\text{no. of dropped packets} + \text{no. of received packets}}$ [16].

It defines the number of PACKETS lost during communication. It has computed as: $\text{Packet loss} = \frac{\text{Number of (dropped) 'packet' no. of dropped packets}}{\text{+no. of received packets}}$ [17]

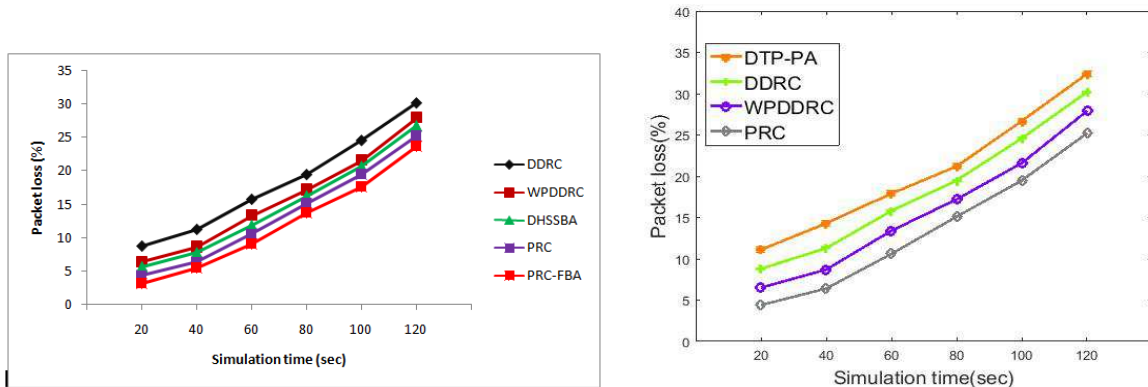


Figure5. Packet Loss vs. Simulation Time

Figure 5 shows the packet loss (in %) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation time (in a sec). This analysis observes that the PRC algorithm achieves less packet loss than the other algorithms. If the simulation time is 120sec, then the PRC's packet loss is 22.22% less than the DTP-PA, 16.57% less than the DDRC, and 9.68% less than the WPDDRC algorithm.

Packet loss = Amount of the lost data / amount of lost data + amount of accepted data [18]

Figure 5 shows the packet loss (in %) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). It indicates that the PRC-FBA technique accomplishes less packet loss than the other methods.

Conclusion

The optimization problem is devised as non-linear programming and partitioned into two sub-problems. To conclude, the simulation outcomes exhibit the effectiveness of the PRC-FBA technique compared to the conventional congestion handling techniques. A PRC-based congestion control algorithm proposes to handle the congestion and buffer overflow in the WSNs. If congestion occurs, using the PRC-based congestion control algorithm for 120sec, it achieves as throughput of 490Kbps, a packet loss of 25.2%, an E2E delay of 183msec, a mean queue size of 22 packets, and a source data transfer rate of 51 packets/sec compared to the DTP-PA, DDRC, and WPDDRC algorithms. It needs to assign the proper bandwidth to control the congestion. This study's future extension could be focusing on integrating the PRC algorithm into the bandwidth allocation mechanism to enhance fairness and throughput.

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Congestion Handling in WSN Using PRC-FBA Techniques

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Abstract:

Wireless Sensor Networks (WSNs) can create different categories of data in both Real-Time (RT) and Non-RT (NRT) practices. Due to their combinations and bandwidth restraints, such types will include controllers to alleviate the congestion using their priorities. For this reason, a Proficient Rate Control (PRC) technique has developed by using traffic type priority and virtual queue conditions. Conversely, it does not consider the problem of fair bandwidth assignment while handling the congestion in WSNs. Hence in this article, a PRC with Fair bandwidth Allocation (PRC-FBA) technique is proposed, which considers the notion of both traffic type priority and fair assignment of bandwidth. First, the challenge of bandwidth assignment in WSN has been investigated under Signal-to-Noise plus Interference Ratio (SINR) model, which intends to discover a tradeoff between fairness and network efficiency. Then, a novel bandwidth utility factor has defines concerning fairness and efficiency. And an Approximate solution in the relationship of a node using time slot assignment. Besides, the problem is formulated as non-linear programming and split into two sub-problems. So, the 2-phase technique has been introduced. In the primary phase, the relationship of the nodes has computed. In the secondary stage, time slots have been assigned to maximize the utility factor and give fair bandwidths in WSNs. At last, the simulation outcomes exhibit the effectiveness of the PRC-FBA technique compared to the conventional congestion handling techniques

Keywords: WSN, Congestion handling, PRC, Bandwidth assignment, SINR, Fairness, Throughput

I. INTRODUCTION

WSNs are built by configuring a large number of sensors, which have a relatively small energy source. Each sensor can receive information from its neighbours and disseminate it to them via a wireless link within their coverage area. It tries to use accurate details recorded by agents through a centralized controller owing to its adaptability and integrity. As a result, reliable information sharing has been established. This kind of network is widely used for numerous purposes, including

medical practices, agricultural modelling, emergency monitoring, etc., depending on a collection of practical measures to maintain stability. Every sensor node contains all of the essential functionalities for transmitting data [1]. Though such nodes use the maximum throughput, congestion can result in more significant information loss, decreased integrity, and inconsistent performance.

Congestion in WSNs has been subcategorized into link and node-level. The node-level congestion exists when the average packet rate raises the data buffer size, resulting in a buffer overflow. As a result, there is a lot of data loss and transfer latency. When it gives more than two sensors use a particular medium simultaneously, the link-level congestion exists. It causes higher queuing latency, power use, and lower efficiency. Therefore, these problems are one of the most significant difficulties in classical data transfer configurations. We will tackle these difficulties; congestion will recognize and handle, enhancing the reliability of data transfer [2-3]. An essential process to manage congestion is regulating the traffic through the WSN. Several protocols have been designed, including the primary functions, namely congestion recognition, notification, and rate adaption. The most standard congestion control protocols were: Congestion Detection and Avoidance (CODA) [4], Priority-based Congestion Control Protocol (PCCP) [5], Active Queue Management (QAM) [6], and Fairness Rate Control (FRC) [7]. Such protocols have based on the concepts of priority, traffic load, and bandwidth usage. However, it is still challenging to alleviate congestion by relaying both Real-Time (RT) and Non-RT (NRT) data.

It can overcome by developing a DDRC technique dependent on the DDR between the sink and source nodes. In addition, A WPDDRC technique has been proposed, then combining the DDR at the sink and the WP of the traffic type [8]. The purpose of this technique was to handle RT traffic and combinations of RT and NRT network traffic. WPDDRC has modified the cumulative priority by specifying the WP of traffic types with a higher-order DRC characterized by various nodes to enable the RT traffic class over NRT packets. However, it neglects buffer availability and queue size because a long queue may increase $\frac{1}{2}$ of the buffer in certain situations, resulting in increased data loss and latency.

Therefore, the WPDDRC with dynamic queuing process known as the Proficient Rate Control (PRC) technique [9] has been suggested to handle congestion in WSNs. The PRC technique considers two different virtual queues on a single specific 'queue' to gather incoming data from each child node based on the importance and prioritization of the sourcenode's traffic. Then, if the incoming packet reaches, the PRC uses the virtual queue condition to recognize congestion and adapts the child's data rates. As a result, by taking into account both traffic type priority and queue condition, this PRC technique would handle congestion and buffer overflow in WSNs. But, it does not consider the problem of fair bandwidth assignment while taking the congestion in WSNs.

So, this article proposes a PRC with Fair bandwidth Allocation (PRC-FBA) technique by considering both traffic type priority and fair assignment of bandwidth. First, the challenge of bandwidth assignment in WSN has been investigated under Signal-to-Noise plus Interference Ratio (SINR) model, which intends to discover a tradeoff between fairness and network efficiency. Then, a novel

bandwidth utility factor is defines concerning fairness and efficiency. Also, an approximate solution is provided by mutually computing the node relationship and time slot assignment. By the side, the problem is formulated as non-linear programming and split into two sub-problems. As a result, the 2-phase technique has been introduced. In the primary phase, the relationship of the nodes has computed, whereas, in the secondary stage, time slots has assigned for maximizing the utility factor. Then the results in increasing the network efficiency and achieving a fair bandwidth assignment in WSNs.

The remaining sections of this paper have prepared as follows: Section 2 discusses the related works on bandwidth assignment for congestion handling in WSNs. Section 3 explains the functioning of the PRC-FBA technique, and Section 4 displays its simulation results. Finally, section 5 has summarized the entire article and recommends future work.

II. LITERATURE SURVEY

The reliable, Efficient, Fair, and Interference-Aware Congestion Control (REFIACC) technique has been developed [10] to maximize throughput. In this technique, the interferences have been prevented, and high fairness of bandwidth usage has been ensured among various nodes via scheduling the transmission. Furthermore, the obstruction and the intervention in inter-and intra-routes have been prevented via considering the divergence among path facilities during scheduling tasks. Again, linear programming has been employed for attaining optimal usage efficiency of the highest accessible bandwidth. However, average throughput was still less, and traffic priority has not considered.

A Packet Priority Intimation (PPI)-based congestion avoidance approach [11] has been suggested, which uses a PPI bit in every data to signify its importance. The purpose was to forward higher priority data with the minimum latency. An Ad-hoc On-demand Distance Vector (AODV) routing mechanism has been employed for creating a path from origin to the target node. On the other hand, its computation burden and overhead were high.

The TOPSIS and response surface mechanism have designed a two-stage cognitive network congestion scheme [12]. Initially, the downstream node's buffer occupancy fraction and congestion status in the MAC layer has computed. Then, these ranges have sent to the upstream nodes, which utilize the TOPSIS for sorting each neighbor and electing the subsequent forwarding nodes. Also, the transfer ratio was fine-tuned through optimized regression analysis using a response surface mechanism. However, its computational burden was high, and energy efficacy was less.

A new technique for fairness-aware congestion handling [13] has developed to reduce the energy use speed by modifying the number of mobile nodes, position, and velocity in WSNs. Also, the reporting rate adjusts to handle every node's buffer availability, alleviating the congestion in the network. But, the packet delivery rate was significantly less, and also, the packet loss ratio was still high.

A novel dynamic bandwidth assignment method called Dynamic Hybrid Slot-Size BA (DHSSBA) technique [14] has been designed to lessen the data latency and jitter difference of RT traffic in Ethernet passive optical network. In this technique, the time cycle for the primary portion was dynamically assigned for the high-priority traffic of each optical network module. Also, suppose the required window size of the high-priority traffic of an optical network module was more significant than the largest assigned window size. In that case, an additional bandwidth from the second portion of the time cycle is used. Because of this situation, the best-effort traffic was affected by higher latency.

A novel congestion avoidance method called Extended Logarithmic Increase and Multiplicative Decrease (ELIMD) [15] has been proposed to maximize throughput, QoS, and fairness during multicast transmission. The congestion is handled based on the queue delay, packet loss, and network throughput. Also, A framework is used for steady-state throughput of a multicast source based on the Adaptive IMD (AIMD) strategy after receiving the destination's receiver. However, the performance was not effective in terms of stability, fairness, and security.

A new congestion handling method [16] has proposed energy-efficient data transfer at an optimized rate. In this method, the rate-based congestion handling method is used base on cluster routing for minimizing energy use in the network. At first, nodes have clustered using the hybrid K-means and Greedy best-first search algorithms. Then, the rate adjustment has executed by the firefly optimization for achieving the maximum packet delivery ratio. At last, data has transmitted with the highest throughput by ant colony optimization-based routing. However, energy efficiency was not effective.

Fuzzy Sliding Mode congestion Controller (FSMC) [17] has designed a novel cross-layer congestion handling framework between transmission and MAC layer by considering a channel's SNR fraction in TCP structure. After that, FSMC was proposed by fusing fuzzy and SMC to regulate the queue size in congested nodes and avoid the effect of uncertain external interferences. But, the network reliability was less.

III. PROPOSED METHODOLOGY

In this section, the PRC-FBA technique is described briefly. Assume the WSN has a K number of parent nodes denoted as a_1, \dots, a_K , and C number of child nodes marked as u_1, \dots, u_C in an equal coverage region. Also, a_i is a node that receives the PRC-FBA's outcome and gets the utility factor for assigning the time slots to u_j . Assume a time slots system with constrained bit rate wireless connections. The bit rate between a_i and u_j is characterized by r_{ij} . The overall effect of interference from parent node 'i' to child node j denotes I_{ij} . When under the SINR framework, I_{ij} is the efficiency of wireless connections and is associated with other wireless connections.

$$I_{ij} = g \left(\text{SINR} \left(\frac{RSS_{ij}}{\sum_{k \in [1, K]; c \in [1, C], c \neq j} RSS_{kc} + N_0} \right) \right) \quad (1)$$

In Eq. (1), RSS_{kc} denotes the Received Signal Strength (RSS) of parent node k to child node c , RSS_{ij} denotes the RSS from parent node i to child node j ; accordingly, g indicates an increasing operation. In particular, k and i are the indexes of parent nodes, whereas m and j are the child node indexes. Finally, a typical model is adopted to simulate the wireless medium circumstance, which is designed as:

$$RSS = P_t - PL(d_0) - 10\eta \log\left(\frac{d}{d_0}\right) \quad (2)$$

In Eq. (2), P_t denotes the transfer energy, PL indicates the path loss, $PL(d_0) - 10\eta \log\left(\frac{d}{d_0}\right)$ denotes the large-scale path loss model, which uses logarithm distance called long-distance radio propagation framework,

d_0 denotes the reference distance, and $PL(d_0)$ denotes the received energy at d_0 , d denotes the distance between origin and target nodes and η denotes the path loss exponent. Finally, time slots are assigned, and the algorithm's outcome computes the transfer time.

3.1 Problem Formation

Fairness resource distribution is estimated by the range of fairness metric called Jain's index defined as:

$$f(X) = \frac{\left[\sum_{i=1}^k x_i\right]^2}{k \sum_{i=1}^k x_i^2} \quad (3)$$

In Eq. (3), x_i denotes the resource distributed to individual $i = 1, \dots, k$ and $X = (x_1, \dots, x_n)$. To calculate fairness for bandwidth distribution, the formulation is represented by

$$f(X) = \frac{\left[\sum_{j=1}^c b_j\right]^2}{c \sum_{j=1}^c b_j^2} \quad (4)$$

In this PRC-FBA, the formulation is defined as follows:

$$f(x, p) = \sum_{j \in U} \omega_j \log b_j \quad (5)$$

In Eq. (5), U is the node group; b_j is the adequate bandwidth distributed to node u_j . Assume $b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij}$, where x_{ij} denotes the relationship of u_j with a_i . Use the physical restraints, and the one-child node can only connect with one parent node synchronously, so $x_{ij} \in \{0,1\}$, p_{ij} denotes the transfer period that a_i distributes to u_j , and ω_j denotes the weight of u_j the traffic class priority of u_j in WSN.

A Logarithmic Utility Function (LUF) is defined regarding bandwidth, i.e., Jain's fairness index, because there is an available selection of quantity for which the index is determined. It is described as:

$$LUF: f(x, p) = \frac{[\sum_{j=1}^C (\omega_j \log b_j)]^2}{C \sum_{j=1}^C (\omega_j \log b_j)^2} \quad (6)$$

Observe that LUF obtains from the utility factor for fair bandwidth distribution. This LUF is assigned by taking the equality of every $\omega_j \log b_j$. The utility factor is the sum of $\omega_j \log b_j$ for every u_j , and the LUF is Jain's index because the unique resource for distribution is $\omega_j \log b_j$. The LUF is to realize a type of fairness that makes $\omega_j \log b_j$ as identical as promising. As a result, every individual is provided with an equal chance to forward an equal amount of data. But, it may tend to the condition that individuals with lower bit rates occupy the medium a higher fraction of the period than those with more significant bit rates, significantly minimizing network efficiency. So, time-based fairness is introducing, and so every individual can acquire equal amounts of the transfer period, which increases the network efficiency. Also, the throughput is computed by b_j and transfer period T . The highest throughput is described as:

$$\frac{\sum_{j=1}^C b_j}{T} = \frac{\sum_{j=1}^C b_j}{T_{a_i}} = \frac{\sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij}}{\sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij}} = \sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij} \quad (7)$$

In Eq. (7), T_{a_i} is the transfer period at parent node a_i . Considering that the parent nodes can run concurrently, the transfer period is the transfer period for WSN, i.e., $T = T_{a_i}$. Also, considering that $\sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} = 1$ and so $T_{a_i} = \sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} = 1$. Thus, fairness and network throughput always conflict with each other. In this work, two utility factors are considered, such as fairness and network throughput. The unified fitness factor is the weighted and sum of 2 fitness values as a unified fitness factor; a tradeoff between fairness and throughput is obtained.

This bandwidth distribution issue is devised as a non-linear programming. The aim is to distribute the bandwidth with tradeoff between fairness and throughput. The optimization formulations are defined as:

$$\max \frac{[\sum_{j=1}^C (\omega_j \log (\sum_{i=1}^K x_{ij} p_{ij} r_{ij}))]^2}{C \sum_{j=1}^C (\omega_j \log (\sum_{i=1}^K x_{ij} p_{ij} r_{ij}))^2} \quad (8)$$

$$\max \sum_{i,j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij} \quad (9)$$

$$\text{subject to } \sum_{i=1}^K x_{ij} = 1 \quad (10)$$

$$x_{ij} \in \{0,1\} \quad (11)$$

$$\sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} = 1 \quad (12)$$

$$p_{ij} \in [0,1] \quad (13)$$

$$i \in [1, K], j \in [1, C] \quad (14)$$

It is known as a non-linear bandwidth distribution dilemma, and it can be verified to be NP-hard.

The primary utility factor is to increase LUF for fairness, and the secondary utility factor is to increase throughput. Usually, as r_{ij} is considered known, bandwidth distribution b_j is turned to relationship x_{ij} and transfer period assignment p_{ij} .

The restraints (10) and (11) indicate that u_j can only connect with one parent node a_i . The condition (12) denotes that the overall transfer period of a_i is '1', and the restraint (13) signifies that p_{ij} is a variable ranging from 0 to 1. At last, condition (14) defines that i is the index of parent nodes and j is the index of child nodes.

3.2 Fairness Bandwidth Distribution

Because non-linear bandwidth distribution is an NP-hard issue, an approximate technique is adopted for determining the relationship x_{ij} and transfer period assignment p_{ij} . This problem is resolved in a network structure creation series. Even though x_{ij} and p_{ij} have the association of $\sum_{j=1}^C x_{ij} p_{ij} = 1$, $x_{ij} \in \{0,1\}$, p_{ij} is independent of x_{ij} after the initialization of WSN. This issue is resolved by mutually considering nodes relationship and resource distribution, which intends to increase bandwidth utilities for fairness and throughput.

So, this issue is split into two sub-problems and resolved in 2 different phases: relationship computation and distribution phase. In the initial phase, consider child nodes connect to parent nodes to compute the relationship of child nodes that intends to find x_{ij} . The utility factor, described as a weighted sum of LUF for fairness and throughput, is increased by assigning time slots in the second phase. Finally, according to relationship data x_{ij} , p_{ij} is computed.

Relationship Computation Phase

In this phase, u_j connects with a_i . Consider child nodes link to parent nodes which tends to the creation of wireless connections in multi-rate WSNs. It removes the possible unwanted relationship based on r_{ij} and I_{ij} . The association is chosen by

$$\max \Delta_{ij} = \zeta_1 r_{ij} / (\sum_{j=1}^C r_{ij}) + \zeta_2 I_{ij}, \forall j \quad (15)$$

In Eq. (15), Δ_{ij} is the relationship strength about bit rate and interference, ζ_1 and ζ_2 are the weights. The first term $\eta_{ij} = r_{ij} / (\sum_{j=1}^C r_{ij})$ decides the highest r_{ij} in every child node. Also, the second term

considers the effect of interference. The $\max \Delta_{ij}$ is the selection of the parent node for child node u_j . For every u_j , the highest Δ_{ij} is selected, and the relationship x_{ij} is computed by assigning x_{ij} as one or zero. Figure 1 illustrates the flow diagram of the fairness bandwidth distribution process for congestion handling in WSN.

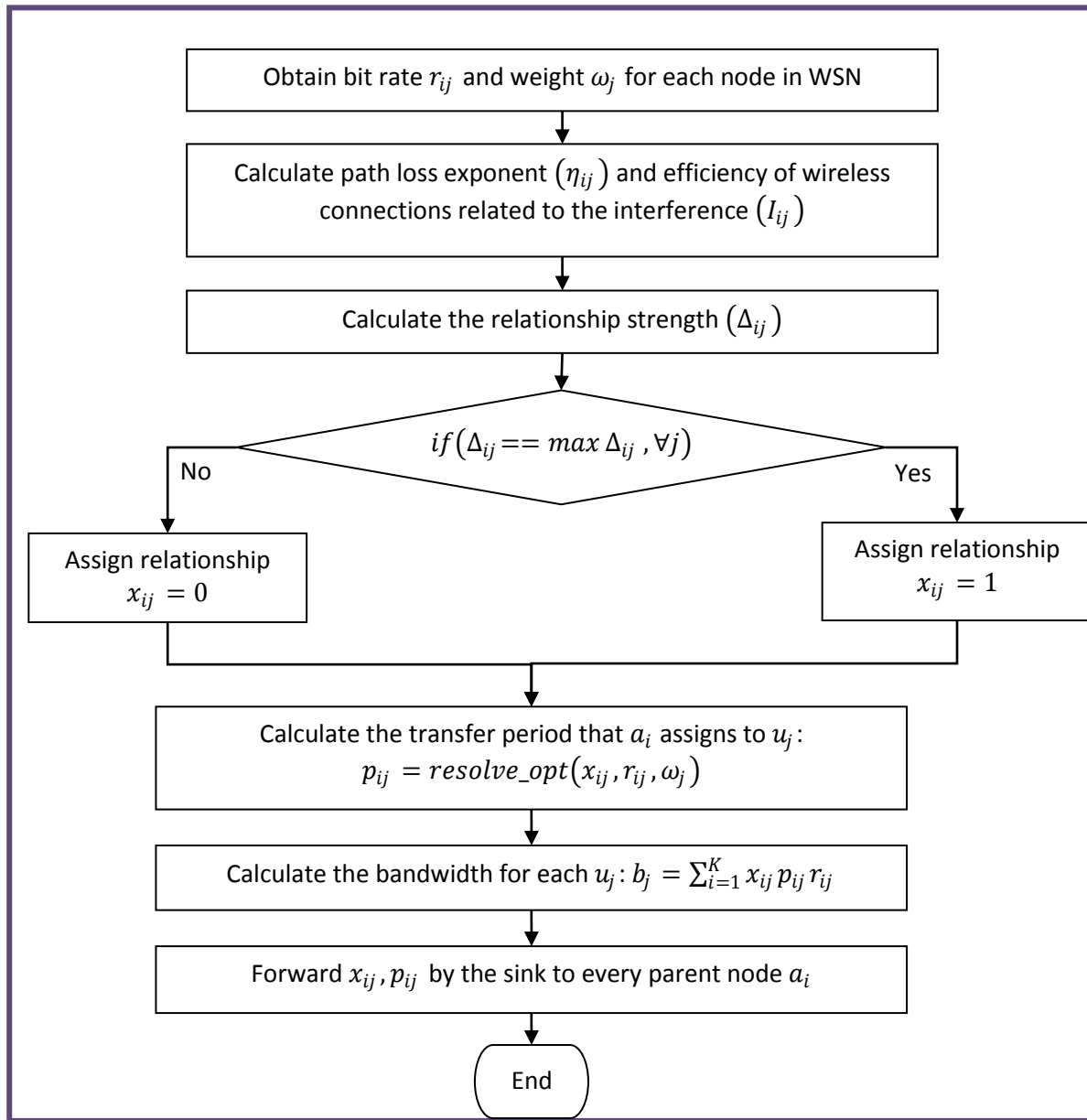


Figure 1. Flow Diagram of Fairness Bandwidth Distribution Process

Distribution Phase

In this phase, non-linear bandwidth distribution only has p_{ij} to be assigned because x_{ij} is computed in the prior phase. The distribution issue $resolve_opt(x_{ij}, r_{ij}, \omega_j)$ is rewritten as:

$$\max \lambda_1 \frac{[\sum_{j=1}^C (\omega_j \log (\sum_{i=1}^K x_{ij} p_{ij} r_{ij}))]^2}{C \sum_{j=1}^C (\omega_j \log (\sum_{i=1}^K x_{ij} p_{ij} r_{ij}))^2} + \lambda_2 \sum_{i,j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij} \quad (16)$$

subject to if $x_{ij} = 0, p_{ij} = 0$;

if $x_{ij} = 1, \sum_{i=1}^K p_{ij} = 1$

$$p_{ij} \in [0,1]$$

$$i \in [1, K], j \in [1, C]$$

As the relationship data x_{ij} is known, this non-linear optimization issue is formulated using time slot assignment; p_{ij} is associates with x_{ij} . If $x_{ij} = 0$, there is no relationship between child node u_j and parent node a_i , and p_{ij} should be 0. If $x_{ij} = 1$, then the sum of the transfer period of each child node is one within single parent node a_i .

Algorithm:

Input: Bit rate r_{ij} between i and j , weight ω_j for every node

Output: Bandwidth for every child node, transfer period and relationship data

Get input r_{ij} and ω_j ;

for($i \in [1, K], j \in [1, C]$)

$$\eta_{ij} = r_{ij} / (\sum_{j=1}^C r_{ij});$$

$$I_{ij} = g \left(SINR \left(\frac{RSS_{ij}}{\sum_{k \in [1, K]; c \in [1, C], c \neq j} RSS_{kc} + N_0} \right) \right);$$

$$\Delta_{ij} = \zeta_1 \eta_{ij} + \zeta_2 I_{ij};$$

if($\Delta_{ij} == \max \Delta_{ij}$ for index j)

$$x_{ij} = 1;$$

else

$$x_{ij} = 0;$$

endif

endfor

$$p_{ij} = \text{resolve_opt}(x_{ij}, r_{ij}, \omega_j);$$

$$\text{Bandwidth for every } u_j: b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij};$$

Forward x_{ij}, p_{ij} by sink to every parent node a_i ;

This algorithm is split into two stages. First, the relationship computation is completed, which may be considered as a branch bounding approach in the entire algorithm. Second, it chooses a branch with the highest Δ and lessens unwanted extensions to minimize the computational difficulty. Thus, the congestion through the network is controlled by using traffic priority and fair bandwidth distribution.

IV. SIMULATION RESULTS

In this section, the PRC-FBA technique is executed in Network Simulator version 2.35 (NS2.35), and its effectiveness is analyzed compared to the PRC [9], DHSSBA[14], WPDDRC [8], and DDRC [8] techniques. The analysis is conducted bases on throughput, packet loss, End-to-End (E2E) delay, queue size, and the source data in the node. Table 1 gives the simulation parameters considered in this analysis.

Table 1. Simulation Parameters

Parameter	Range
Simulation area	1000×1000m ²
Number of nodes	50
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Number of traffic categories	4
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW
Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility speed	10m/s
Simulation time	120sec

4.1 Throughput

It is the amount of data accepted by the target within a time.

$$Throughput = \frac{\text{Total amount of data accepted by the target}}{\text{time}} \quad (17)$$

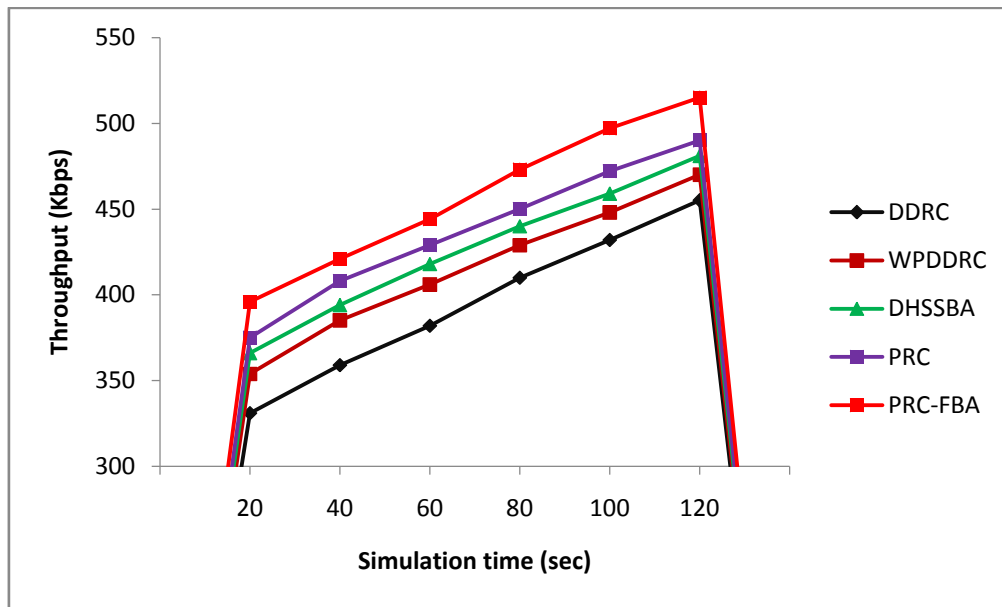


Figure 2. Throughput vs. Simulation Time

Figure 2 displays the throughput (in Kbps) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). It observes that the PRC-FBA achieves higher throughput than all other techniques. For example, if the simulation time is 120sec, then the throughput of PRC-FBA is 13.19% greater than the DDRC, 9.57% greater than the WPDDRC, 7.07% greater than the DHSSBA, and 5.1% greater than the PRC techniques. It realizes that assigning the priority levels of the traffic classes at every virtual queue and the adequate bandwidth of every node in the network. It is also reflected in the packet loss and E2E delay, as shown in Figure 3 & Figure 4, correspondingly.

4.2 Packet Loss

It is the amount of data dropped or missed during transfer.

$$packetloss = \frac{\text{Amount of lost data}}{\text{amount of lost data} + \text{Amount of accepted data}} \quad (18)$$

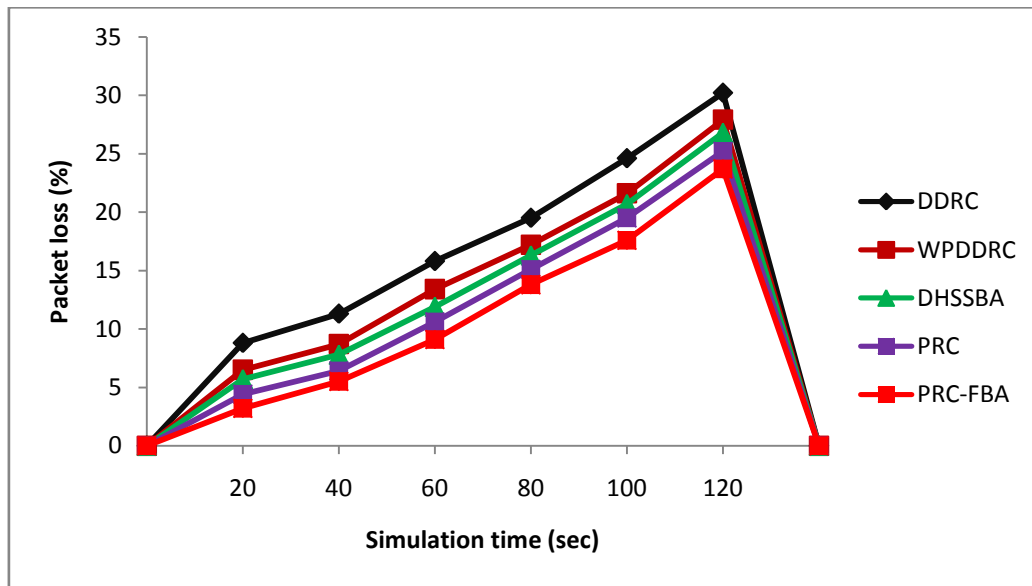


Figure 3. Packet Loss vs. Simulation Time

Figure 3 shows the packet loss (in %) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). It indicates that the PRC-FBA technique accomplishes less packet loss compared to the other methods. For example, if the simulation time is 120sec, then the packet loss of PRC-FBA is 21.5% less than the DDRC, 15.1% less than the WPDDRC, 11.6% less than the DHSSBA, and 6% less than the PRC techniques. So, packet loss in PRC-FBA is the minimum rate; the utilization of virtual queues and distribution of adequate bandwidth in each node has handled the congestion through the WSN.

4.3 End-to-end Delay

It is the time taken for data to be broadcast from an origin to the sink.

$$E2EDelay = Time_{sink} - Time_{origin} \quad (19)$$

In Eq. (19), $Time_{sink}$ is the time at the sink while accepting the data, and $Time_{origin}$ is the time at the origin while forwarding that data.

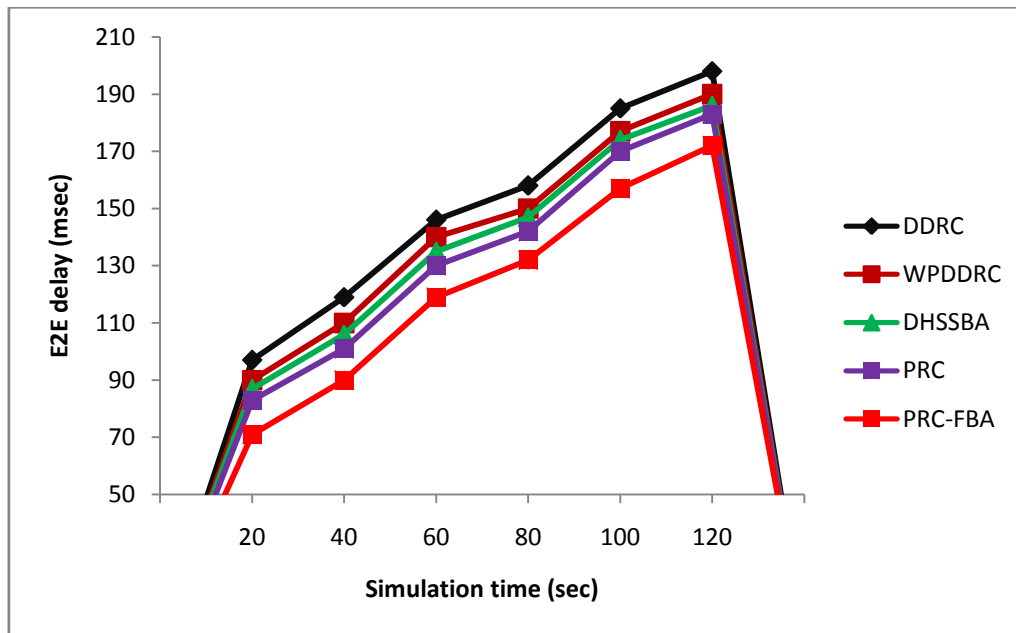


Figure 4. E2E Delay vs. Simulation Time

Figure 4 depicts the E2E delay (in ms) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). It notices that the PRC-FBA achieves minor E2E delay compared to the other methods. For example, if the simulation time is 120sec, then the E2E delay of PRC-FBA is 13.1% less than the DDRC, 9.5% less than the WPDDRC, 7.5% less than the DHSSBA, and 6% less than the PRC techniques. Therefore, the minimum E2E delay associates with the maximum throughput and the less packet loss.

4.4 Queue Size

It is the amount of data in the queue. When the queue size is large, the delay is also high.

Figure 6 displays the mean queue size (in several packets) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). It observes that the PRC-FBA technique achieves less mean queue size, i.e., average queue length, compared to the other methods. For example, if the simulation time is 120sec, then the mean queue size of PRC-FBA is 41.9% less than the DDRC, 35.7% less than the WPDDRC, 28% less than the DHSSBA, and 18.2% less than the PRC techniques. As a result, the minimum queue length may result in less packet loss and E2E delay. Furthermore, it is evident that the PRC-FBA provides higher stability for the mean queue size and stabilizes the queue length around the desired level.

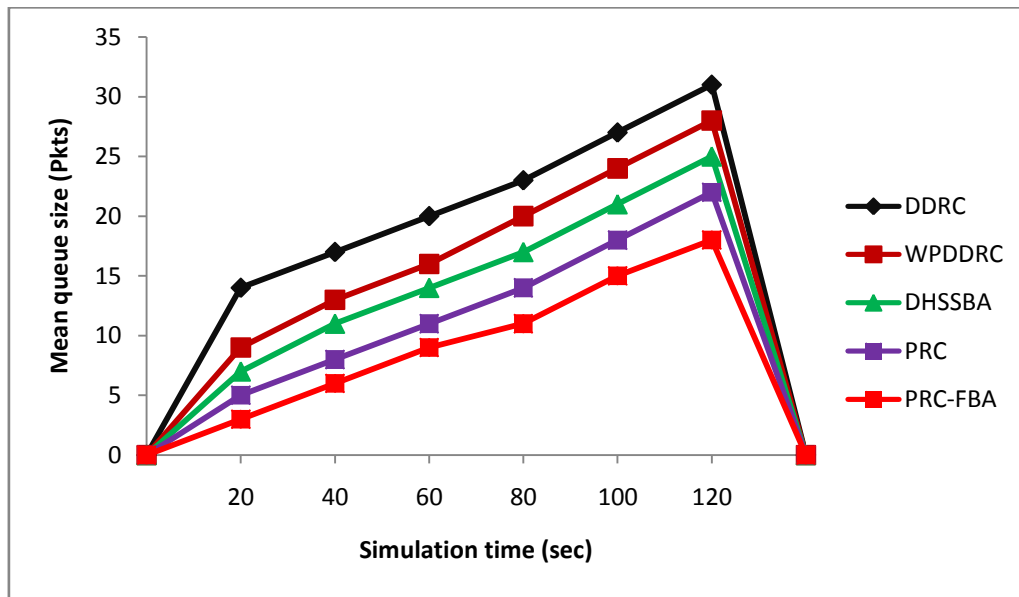


Figure 6. Mean Queue Size vs. Simulation Time

4.5 Data Transfer Rate Adjustment

It is the data transfer rate of origin that handles the congestion and buffer overflow in WSN.

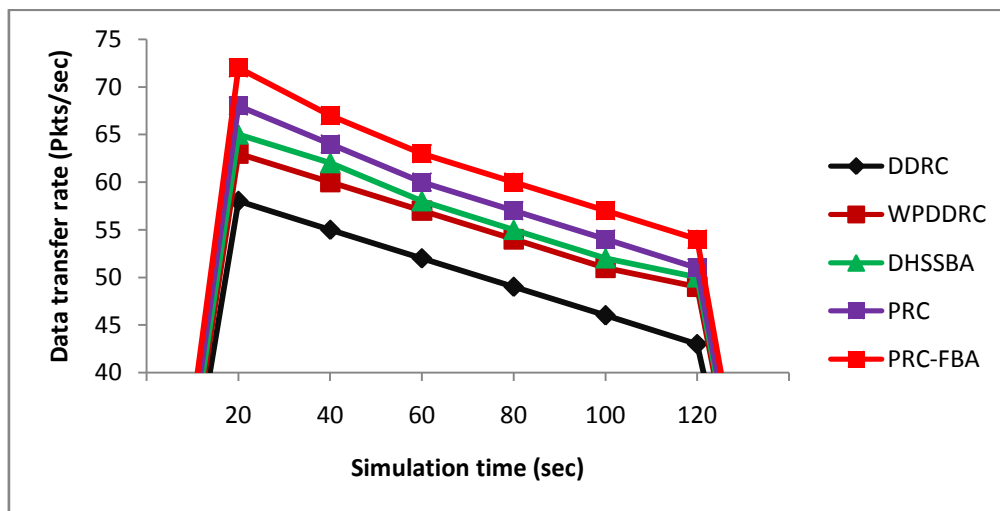


Figure 7. Data Transfer Rate vs. Simulation Time

Figure 7 displays the data transfer rate (in packets/sec) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). This analysis indicates that the PRC-FBA technique achieves the highest data transfer rate due to its effective rate adjustment and bandwidth distribution. For example, if the simulation time is 120sec, then the data rate of PRC-FBA is 25.6% greater than the DDRC, 10.2% greater than the WPDDRC, 8% greater than the DHSSBA, and 5.9% greater than the PRC techniques. Furthermore, it is noticed that the PRC-FBA can gradually reduce the data transfer rate concerning the nodes' initial transfer rate. So, the highest

priority traffic classes are properly broadcasts without any congestion before lowering the transfer rate.

V. CONCLUSION

In this study, a PRC-FBA technique is proposed, which considers both traffic type priority and fair assignment of bandwidth. Initially, the challenge of bandwidth assignment in WSN is investigating under the SINR model, which intends to discover a tradeoff between fairness and network efficiency. After that, a novel bandwidth utility factor is defines concerning fairness and efficiency. As well, an approximate solution is obtained by mutually computing the node relationship and time slot assignment. Moreover, the optimization problem is devised as non-linear programming and partitioned into two sub-problems. Therefore, the 2-phase technique is introduced: the first phase computes the relationship of the nodes, and the second phase assigns time slots for maximizing the utility factor and distributing the fair bandwidths in WSNs. To conclude, the simulation outcomes exhibit the effectiveness of the PRC-FBA technique compared to the conventional congestion handling techniques.

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Energy-Aware Proficient Control Scheme for Congestion Control in WSN

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Abstract: Generally, Wireless Sensor Networks (WSNs) can generate several data packets in Real-Time (RT) applications. Because of bandwidth constraints in WSNs, such data varieties have to be handle with different priorities, which controls the network's congestion. We have to prevent congestion depending on the traffic priorities of RT packets; various algorithms have been developing in the previous decades. On the other side, it must handle the congestion due to the mix of RT and Non-RT (NRT) packets effectively. We have to solve this problem; WPDDRC algorithms develop and combine the DDR of a particular node with the WP traffic class. However, it does not consider the buffer occupancy and queue size because if the queue length is high than the buffer occupancy, it leads to high packet loss and delay. This article proposed an adaptive queuing system with the WPDDRC called a proficient control (PRC) algorithm to tackle this issue. In this algorithm, two independent virtual queues consider in a single physical length (lines), which accumulate the input packets from every child's node depending on the source's traffic significance and priority. If the arrival packet is received, the PRC detects congestion by using the virtual queue status to adjust the child's transmission rate. Finally, the simulation results demonstrate that PRC algorithm's efficiency compared to the State-of- The-Art congestion control algorithms.

Keywords: WSN, Congestion Control, Traffic Class Priority, Rate Control, Queue Management, Buffer Occupancy

1. INTRODUCTION

WSN is constructing by deploying many sensor nodes which has a limited power supply. Each node will accumulate the data from its nearby nodes and distribute them to each other through a transmission channel in their communication range. Its versatility and competence intend to utilize the actual data generated by agents via a virtual layer. Therefore, reliable data communication is realizing in the network. It is bases on promising solutions to ensure sustainability; this network is deploying in various appliances like medicinal systems, industrial forecasting, rescue management, etc. Every sensor node encompasses every introductory module for data transmission and reception [1]. Even if these nodes have a high data rate, Traffic congestion leads to a high data loss, less competence, and less consistency.

In WSNs, Congestion is classifying into two types: link-Level and node-Level. The node-level congestion appears if the packet arrival rate exceeds, then the packet service rates and buffer overflow happens in the node. So, it results are high in the Packet Loss and Queuing Delay of the node. Link-Level congestion occurs if more than two nodes share the channel at the same time. Its outcomes are high Packet service time, high energy depletion, and fewer throughputs. So, the Congestion in WSNs has become one of the most challenging in earlier data transmission scenarios. We have to solve this problem and improve data transmission efficiency in WSNs; the congestion has to detect and controls [2-3]. One of the most primary tasks to prevent congestion is managing the traffic flow through the network. For this purpose, many of the protocols are developing, comprising fundamental mechanisms like congestion identification, congestion notification, and rate adjustment. Among many of the classical Congestion Control Protocols, the most common protocols are Congestion Detection and Avoidance (CODA) [4], Priority-based Congestion Control Protocol (PCCP) [5], Active Queue Management [6], and Fairness Rate Control (FRC) [7] protocols. These are depending on the notion of priority, traffic load, and fair bandwidth use. It remains a concern to solve the congestion by forwarding both Real-Time (RT) and Non-RT (NRT) packets.

We will solve this problem by designing a DDRC algorithm depending on the DDR between the Sink and Origin Nodes. Also, a WPDDRC Algorithm will be creating using merging the DDR at the Sink and the traffic class's WP [8]. This algorithm aimed his to control the RT packets and the pair of both RT and NRT packets. In WPDDRC, an overall priority is adjusting by assigning the WP of traffic classes with a higher-order DRC associated with different nodes to facilitate the RT traffic class over NRT packets. It does not consider the buffer occupancy and queue size; since the queue's length is high, it may exceed half of the buffer in some instances then it leads to high packet loss and delay.

Hence, in this paper, WPDDRC, with an adaptive queuing system called the Proficient Rate Control (PRC) algorithm, proposes controlling the congestion in the WSNs. In the PRC algorithm, two independent virtual queues consider the single physical queue length to accumulate the input packets from every child node depending on the source's traffic significance and priority. If the arriving 'packet' receives, then the PRC detects congestion by using the virtual queue status and then adjusts the child's transmission rates. Thus, this PRC algorithm can control the congestion and buffer overflow in WSNs by considering both traffic class priority and queue status. The rest of the article structures as follows: Section II presents the existing studies relates to the Congestion Control Protocols in WSNs. Section III describes the methodology of the PRC algorithm, and Section IV illustrates its performance efficiency. Then finally concludes the entire article and suggests the future scope.

To control the RT packets and the pair of both RT and NRT packets. In WPDDRC, an overall priority is adjusting by assigning the WP of traffic classes with a higher-order DRC associated with different nodes to facilitate the RT traffic class over NRT packets. It does not consider the buffer occupancy and queue size; since the queue's length is high, it may exceed half of the buffer in some instances then it leads to high packet loss and delay.

2. LITERATURE SURVEY

Suggest Packet Priority Intimation-based (PPI) congestion control technique [9] for WSN to achieve congestion-free traffic management. This technique uses a PPI bit in every packet, which operates to reflect its significance. The objectives' critical value was to broadcast high priority Packets with a minor Delay and Ignore the Congestion through the network by assigning the priority indicates within the data packet itself. Nonetheless, this technique has a high mean delay while increasing the node mobility and high computational cost.

The developed Congestion-Adaptive Data Collection (CADC) technique [10] is to prevent Congestion in WSNs. The key intent was to reduce the data transfer rate while maintaining the computation error more minor than the given limit at the sink node. K-means clustering scheme was applied to lessen the data distortion via reducing the transfer rate. Further, extended it by creating the dynamic network and aggregation schemes to guarantee data correctness. It did not evaluate the data loss while the path failure exists, and the bandwidth overhead was high because of retransferring the data.

A novel Active Queue Management scheme [11] designs the packet loss likelihood. In this scheme, QAM was integrated with the early random identification and (FuzzyPID) controller to recognize the network's congestion. It transmits an implicit congestion warning to the fuzzy controller for adjusting the data transmission rate if it identifies the congestion. But, mean energy consumption was still not reduced effectively

Data Transmission Protocol based on the Priority Approach (DTP-PA) [12] is designing to present the data delivery in the sink node with variable reporting rate in a particular decision. Two progressive approaches, such as network traffic first and Packet scheduling, depending on the packet priority and hop count. Initially, high- priority traffic serves by the hop node. Then it transmits the notification message on the buffer overflow event. The adaptive rate control method presents high consistency for various traffic flows by the decision interval window. Also, the buffer occupancy uses to update the rate. However, it is not considering the queuing model of the network

An enhanced congestion control [13] protocol has to minimize the data loss and maximize the QoS performance. Initially, the packet transmits from origin to the target depending on the capacity of the IP-multicast. A Distance Vector Multicast Routing Protocol (DVMRP) uses web service authority between origin and multicast route. The target's feedback was forwarded through unicast to verify the minor queue delay and handle the congestion. But, it has less scalability and fairness for large- scale networks.

A rate-based congestion control method [14] was introduced depending on the cluster routing to lessen the energy use in WSN. Initially, nodes are groups by the hybrid K-means and Greedy Best- First Search Algorithms. After that, the firefly optimization performed the rate control scheme to increase the packet delivery rate. Also, broadcast the database on the "ant colony optimization-based routing." But, the convergence time was high because it doesn't converge fastly.

Suggests CCR Protocol [15] to prevent Congestion in WSN. In the CCR protocol, each process's number performs in each process has a setup and a transfer phase. During the initial cycle, the network partitions into various clusters where every group has its Primary CH (PCH) and Secondary CH (SCH). The remaining processes (cycle) are performers to rotate PCH and SCH nodes among cluster members. Also, the transfer phase has intra- cluster and inter-cluster routing to forward the data between origin and target nodes. But, energy consumption was high because of utilizing the GPS for estimating the distance between nodes

Fuzzy Sliding Mode congestion Controller (FSMC) [16] design using novel cross-layer congestion is handling the framework transmission between MAC layers through considering a channel's Signal-to-Noise (SNR) fraction in TCP structure. FSMC was proposed by fusing fuzzy and SMC to regulate the queue size in congested nodes and avoid uncertain external interferences. But, the network reliability was less

3. PROPOSED METHODOLOGY

Algorithm's main intention is to handle different NRT packet categories, and the considered types of PACKETS are HNRT, medium priority NRT (MNRT), and low priority NRT (LNRT). Each of the PACKETS is distributing with a particular priority. These data rates in the packet recognize different values.

For RT traffic, the notion of higher-order derivative uses provides when determining the virtual queues rate in the node given. It calculates the Differentials regarding the Sink. Different traffic classes' priorities are weighted, and the preferences of

the new weighted traffic class obtain. Then the general network topology shows in Figure 1, where P1, P2, and P3 are Parent Nodes, and 'C1-C8' are child nodes. During packet transfer, the traffic classes prioritize the child nodes and the higher priority packets to sink nodes via their parent

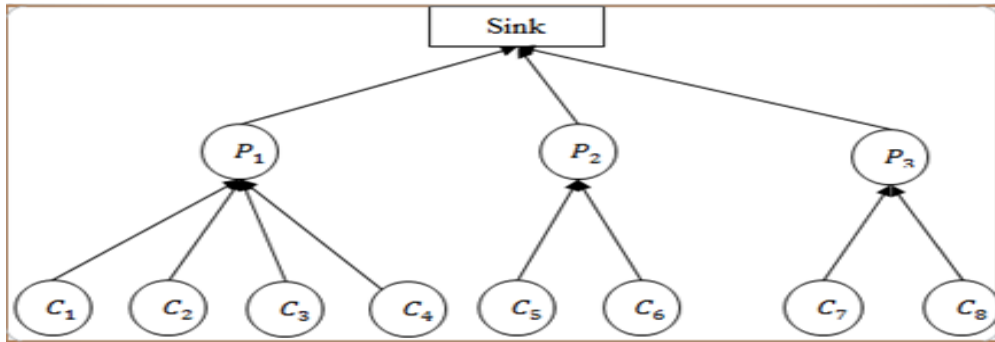


Figure 1. General Network Topology

Consider TCP_{nk} and GP_{nk} are the traffic class priority and the geographical priority nth virtual queue in a kth node. Also, consider, and Spain is the traffic source priority of nth virtual (QUEUE) in the kth node where 'I' is traffic class' s sets and I ∈ RT, HNRT, MNRT, LNRT

First, the traffic class priority of nth virtual queue in kth node calculates as:

$$TCP_{nk} = \sum_i S_{P_{tikn}} \quad (1)$$

The RT traffic class plays a primary role in the overall priority, and so the maximum PRIORITY is assigning to the RT. The overall Traffic Classes

Priority contributing to the nth virtual queue's overall PRIORITY in the kth node minimizes the WEIGHTED sum of the NRT traffic classes. Therefore, the 'weighted 'overall PRIORITY for nth virtual QUEUE in kth node WP_{nk} is computing as:

$$WP_{nk} = TCP_{nk} \cdot GP_{nk} + WRT - \delta W_{HNRT} + W_{MNRT} + W_{LNRT} \quad (2)$$

In Eq. (2), δ indicates the constant $0 \leq \delta \leq 1$, and WRT, W_{HNRT}, W_{MNRT}, W_{LNRT} are weighting assigns to the NRT and RT traffic classes. Similarly, traffic class priority of nth virtual queue in lth child node is computing as:

$$TCP_{nl} = \sum_i S_{P_{tiln}} \quad (3)$$

In Eq. (3), S_{P_{tiln}} is the source priority of nth virtual queue in lth child nodes. The weighted overall focus(PRIORITY) for nth virtual lines(QUEUES) in lth child node WP_{nl} is,

$$WP_{nl} = TCP_{nl} \cdot GP_{nl} + WRT - \delta W_{HNRT} + W_{MNRT} + W_{LNRT} \quad (4)$$

In Eq. (4), δ indicates the constant $0 \leq \delta \leq 1$, and GP_{nl} is the n-th virtual queue geographical priority' in the l-the child node. The 'Weighted Global PRIORITY' of nth virtual QUEUES in lth child node WGP_{nl} changes to WGP_{nl} = WP_{nl}. The 'weighted international priority' at the nth 'virtual queues 'of k th parent node WGP_{nk} changes to

$$WGP_{nk} = \sum_{l \in C_k} C_k WGP_{nl} + WP_{nk} \quad (5)$$

The highest output rate of the n th virtual queue in the k th parent node using weighted priority is computing as follows:

$$OR_{nk} = OR_{nsink} \cdot WGP_{nk} / WGP_{nsink} \quad (6)$$

In Eq. (6), WGP_{nsink} is the weighted global priority of the n th virtual queue in the sink node and is calculates as:

$$WGP_{nsink} = \sum_{k \in C_{sink}} C_{sink} WGP_{nk} \quad (7)$$

Eq. (7) is the sum of the weighted global priority' of the Sink's links child nodes. Also, the input rate of the n th virtual queue in the sink node is giving as:

$$IR_{nk} = \sum_{k \in C_{sink}} C_{sink} OR_{nk} \quad (8)$$

In Eq. (8), $OR_{n,k}$ corresponds to every child node's output rate. Using the modified global priority of Eq. (5) and Output Rate of the Equation (6), the Updated Rates of an n th virtual queue in the parent node and the sink nodes are calculating as:

$$\Delta R_{nsink} = \beta \cdot OR_{nsink} - IR_{nsink} \quad (9)$$

$$OR_{nk} = OR_{nk} + \Delta R_{nsink} \cdot WGP_{nk} / WGP_{nsink} \quad (10)$$

$$\Delta R_{nk} = \beta \cdot OR_{nk} - IR_{nk} \quad (11)$$

The updated rate is represented by,

$$OR_{nl} = OR_{nl} + \Delta R_{nk} WGP_{nl} / WGP_{nk} + \mu \Delta R_{nsink} - \Delta R_{nk} WGP_{nl} / WGP_{nk} \quad (12)$$

The updates rate propagates to the child node by its corresponding Parent Node. The congestion through the network is controlling by assigning the proper data rate, which prevents the buffer overflow and packets from dropping during transmission. The overall flow diagram of the PRC algorithm is portraying in Figure 2.

Algorithm:

Step 1: Declare the parameters: service time (ST)n Sink, ' β ,' ' δ ,' ' μ ' and the traffic class priorities. Step 2: Compute the mean service time value of n th virtual queue in the sink node as: $ST_{nsink,t+1} = 1 - \alpha \cdot ST_{nsink,t} + \alpha \cdot ST_{nsink}$ (13)

Step 3: Calculate the rate variance n th virtual queue in the sink node and k th parent nodes using Equation. (9) & (11)

. Step 4: Calculate the Updates Output Rates of the n th virtual queue in the k th parent node using Equation. (10).

Step 5: Calculate the n th virtual queue's update rate in the k th parent node propagates to the l th child node using Eq. (12). Step 6: Continue Steps 2 to Steps 5 until the completion of the specified simulation period.

Therefore, this algorithm, one of most significant contributions is the weighted global priority of n th virtual queue in k th parent and l th child node given in (2) & (4). The novelty in the rate estimates the weighted global priority and difference (12) of differential. The Difference of Differential is the last term of (1).N

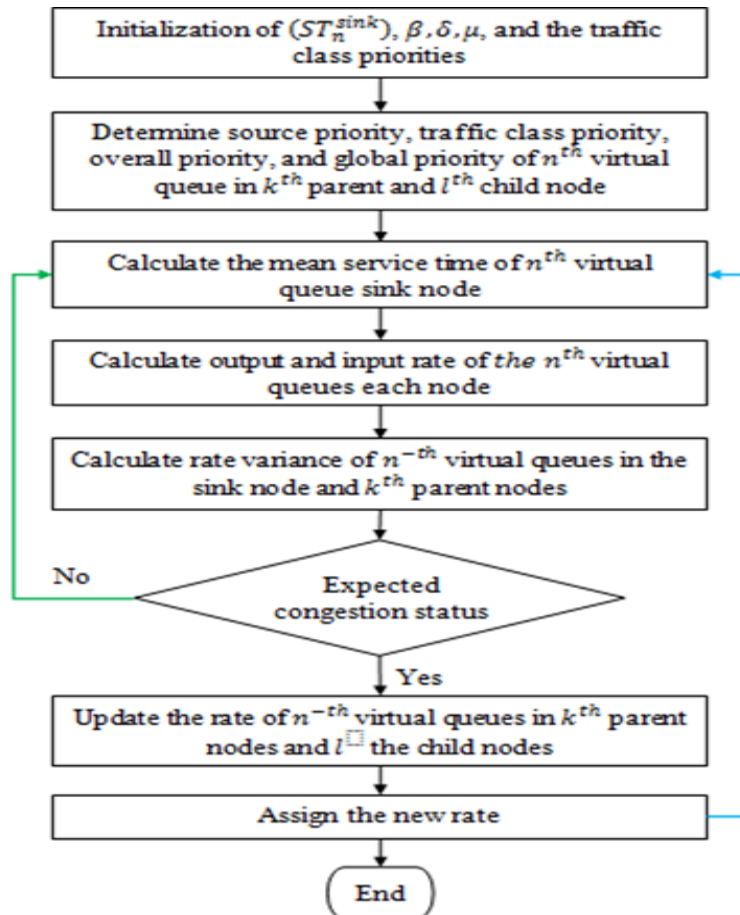


Figure 2. Flowchart of PRC Algorithm for Congestion Control

4. SIMULATION RESULT

Here, the PRC Algorithm is simulating in Network Simulator version 2.35 (NS2.35), and its performance is comparing with the WPDDRC [8], DDRC [8], and DTP-PA [12] algorithms. The comparison analysis carries out the various metrics like throughput, packet loss, End-to-End (E2E) Delay, queue size, source data transmission, and rate adjustment. Table 1 presents the simulation parameters used in this analysis.

Parameter	Range
Simulation area	1000×1000m ²
Number of nodes	50
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Number of traffic categories	4
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW

Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility speed	10m/s
Simulation time	120sec

4.1 Throughput

It defines the no. of packets received by the target within a particular period

Throughput= total number of packets received by target time (14)

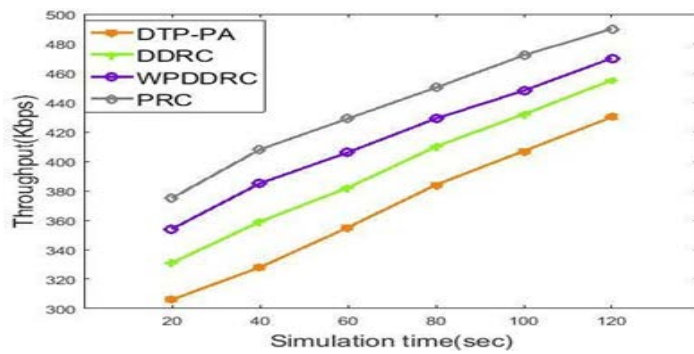


Figure 3. Throughput vs. Simulation Time

In Eq. (16), in the sink node, the time calculates the name as 'Time sink' while receiving the packet, and at the source node, the time calculates by the name of 'time source' while transmitting that packet.

Figure 3 exhibits the throughput (in Kbps) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation times (in a sec). This analysis indicates that the PRC algorithm achieves higher throughput than all other congestion control algorithms. If the simulation time is 120sec, then the throughput of PRC is 13.95% higher than the DTP-PA, 7.69% higher than the DDRC, and 4.26% higher than the WPDDRC algorithms. It achieves by controlling the traffic classes' priority levels at each virtual queue in the nodes. It reflects the packet loss and E2E delay, which illustrates in Figures 4 & Figure 5.

4.2 Packet Loss

It defines the number of packets lost during communication. It has computed as:

Packet Loss=Number of dropped packet /no. of dropped packets + no. of received packets. (15)

Figure 4 shows the packet loss (in %) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation time (in a sec). This analysis observes that the PRC algorithm achieves less packet loss compared to the other algorithms. If the simulation time is 120sec, then the PRC's packet loss is 22.22% less than the DTP-PA, 16.57% less than the DDRC, and 9.68% less than the WPDDRC algorithms. Thus, PRC's packet loss

is the minimum because of using independent virtual queues in each node to handle the traffic classes' controlled priority levels.

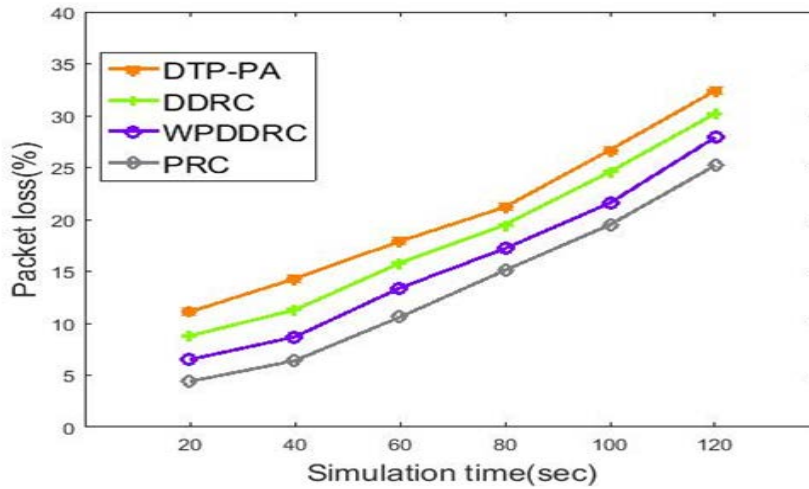


Figure 4. Packet Loss vs. Simulation Time

4.3 End-to-End delay Process

It defines the time taken for a packet sent from a source node to the Sink.

$$E2E\ Delay = Time\ sink - Time\ source \quad (16)$$

In Eq. (16), in the sink node, the time calculates the name as 'Time sink' while receiving the packet, and at the source node, the time calculates by the name of 'time source' while transmitting that packet

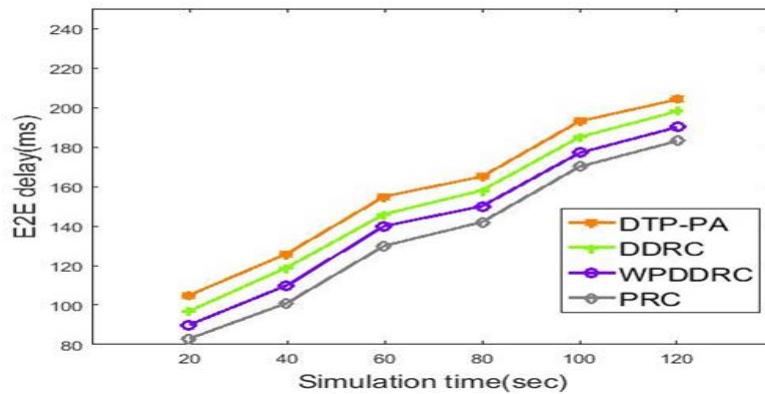


Figure 5. E2E Delay vs. Simulation Time

Figure 5 depicts the E2E delay (in ms) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation times (in a sec). This analysis notices that the PRC algorithm achieves minor E2E delay compared to the other algorithms. If the simulation time is 120sec, then the E2E Delay of PRC is 10.29% less than the DTP-PA, 7.58% less than the DDRC, and 3.68% less than the WPDDRC algorithms. Thus, the lowest E2E delay corresponds to the highest throughput and the less packet loss

4.4 Queue Size

It defines the number of packets in the queue.

It is a key value metric to estimate the delay.
If the queue size is large, then it causes more delay

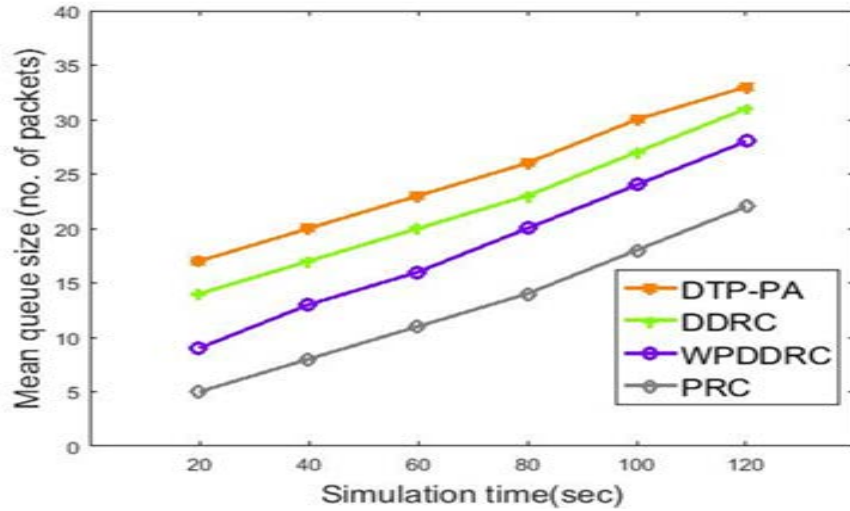


Figure 6. Mean Queue Size vs. Simulation Time

Figure 6 displays the mean queue size (in several packets) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation times (in a sec). This analysis indicates that the PRC algorithm achieves less mean queue size, i.e., average queue length, compared to the other algorithms. If the simulation time is 120sec, then the mean queue size of PRC is 33.33% less than the DTP-PA, 29.03% less than the DDRC, and 21.43% less than the WPDDRC algorithms. Thus, the queue length reduces by the result in less packet loss and E2E delay. It is evident that the PRC provides for mean queue size as higher stability and stabilizes the queue's length around a desired level.

4.5 Data Transmission Rate Adjustment

It defines the source node's data transmission rate, which controls the congestion and buffer overflow in the network.

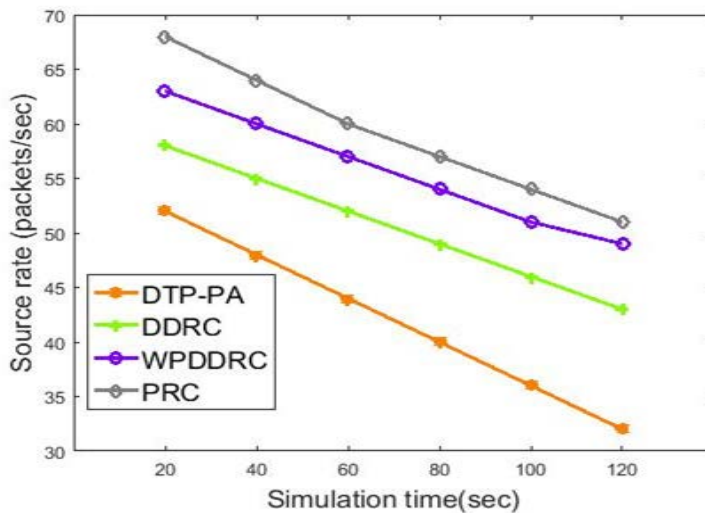


Figure 7. Source Data Transfer Rate vs. Simulation Time

Figure 7 displays the source data transfer rate (in packets/sec) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation times (in a sec). This analysis indicates that the PRC algorithm achieves the highest source data transfer rate overall because of its effective rate adjustment by considering the queue's length and controls traffic priorities.

If the simulation time is 120sec, then the PRC's source rate is 59.38% higher than the DTP-PA, 18.6% higher than the DDRC, and 4.08% higher than the WPDDRC algorithms. The PRC can gradually reduce the data transfer rate concerning the nodes' initial transfer rate. Thus, the highest priority traffic classes are properly transferring before lowering the transfer rate

5.CONCLUSION

In this work, a PRC-based congestion control algorithm proposes to handle the congestion and buffer overflow in the WSNs. To achieve the two different virtual queues, which are considered single physical QUEUES to gather the incoming packets from all the child nodes based on the source's traffic significance and priority. If the incoming packet accepts the 'packet,' the algorithm can identify the congestion by using the status of virtual queues. If congestion occurs, using the PRC-based congestion control algorithm for 120sec, it achieves a throughput of 490Kbps, a packet loss of 25.2%, an E2E delay of 183msec, a mean queue size of 22 packets, and a source data transfer rate of 51packets/sec compared to the DTP-PA, DDRC, and WPDDRC algorithms. It needs to assign the proper bandwidth to control the congestion. This study's future extension could be focusing on integrating the PRC algorithm into the bandwidth allocation mechanism to enhance fairness and throughput.

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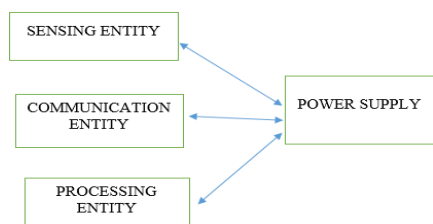


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WSNs are determined the speed or location, and the actuators control the mechanical device. It will simulate the parameter like cost of the node (data), distance of the neighbor node to calculate the delay.

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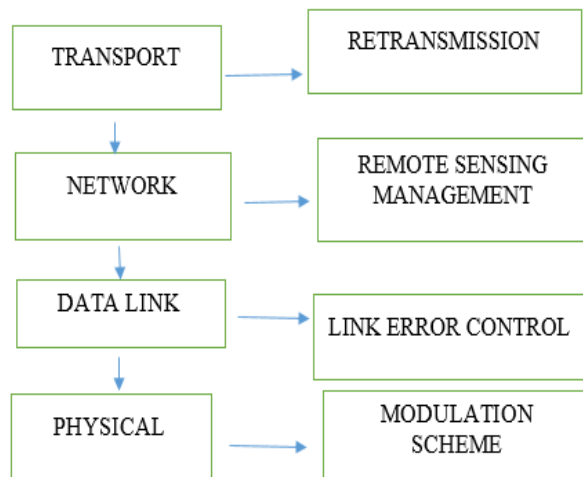


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The upper layer is using to include application processing in application layer, data storage and processing in the layer, and then the fourth layer is used to transport data, is used to transport data function from one layer to another layer if any kind of data is missed during transmission process transport layer is used to retransmission the Process. The third layer is a network layer, which is used to access topological function and manage the process in a every time. The second layer is a data link layer that is using in a channel transfer from one locality to another locality due to particular time. Then finally, it communicates channels, sensing a node, actuation, and signal processing in physical layer.

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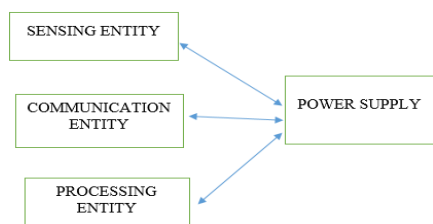


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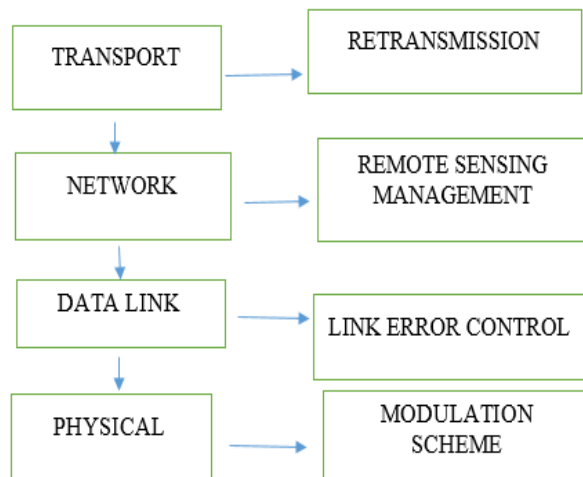


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Abstract

Congestion is a major significant challenge in WSNs because it directly impacts energy efficiency and the network lifetime of sensor nodes in the network. This paper aims to analyze the different congestion control or avoidance routing protocols performances in WSNs with their drawbacks for identifying the upcoming scope of congestion-aware routing protocols in WSNs. This article proposed an adaptive queuing system with the WPDDRC called a proficient control (PRC) algorithm to tackle this issue. In this algorithm, two independent virtual queues are considered single physical length (lines), which accumulate the input packets from every child's node depending on the source's traffic significance and priority. A Proficient Rate Control (PRC) technique develops using traffic type priority and virtual queue conditions. Here, a PRC with Fair bandwidth Allocation (PRC-FBA) technique is compared and analyzed. It must handle the congestion due to the mix of RT and Non-RT (NRT) packets effectively in network.

Introduction

In WSNs, Congestion is classified into two types: link-Level and node-Level. The node-level congestion appears if the packet arrival rate exceeds, then the packet service rates and buffer overflow happen in the node. So, the results are high in the Packet Loss and Queuing Delay of the node. Among many of the classical Congestion Control Protocols, the most common protocols are Congestion Detection and Avoidance (CODA)[4], Priority-based Congestion Control Protocol (PCCP) [5], Active Queue Management [6], and Fairness Rate Control (FRC) [7] protocols. These depend on priority, traffic load, and fair bandwidth use. It remains a concern to solve the congestion by forwarding both Real-Time (RT) and Non-RT (NRT) packets. In the PRC algorithm, two independent virtual queues consider the single physical queue length to accumulate the input packets from every child node depending on the source's traffic sign if I cancel and priority. If the arriving' packet' receives, the PRC detects congestion by using the virtual queue status and the node just the child's transmission rates. Thus, this PRC algorithm can control the congestion d buffer overflow n SNs by considering traffic class priority and queue status. This article proposes a PRC with Fair bandwidth Allocation (PRC-FBA) technique by considering traffic type priority and fair bandwidth assignment. First, the challenge of bandwidth assignment in WSN has been investigated under Signal-to-Noise plus Interference Ratio (SINR) model, which intends to discover a trade-off between fairness and network efficiency. Then, a novel bandwidth utility factor is defined concerning fairness and efficiency. Congestion in WSNs has been subcategorized into link and node-level.

Literature Review

A Packet Priority Intimation (PPI)-based congestion avoidance approach [1] has been suggested, using a PPI bit in every data to signify its importance. The purpose was to forward higher priority data with the minimum latency.

A new technique for fairness-aware congestion handling [2] has been developed to reduce the energy use speed by modifying the number of mobile nodes, position, and velocity in WSNs. Also, the reporting rate adjusts to handle every node's buffer availability, alleviating the congestion in the network. But, the packet delivery rate was significantly less, and the packet loss ratio was still high.

A novel dynamic bandwidth assignment method called Dynamic Hybrid Slot-Size BA (DHSSBA) technique [3] has been designed to lessen the data latency and jitter difference of RT traffic in Ethernet passive optical network. In this technique, the time cycle for the primary portion was dynamically assigned for the high-priority traffic of each optical network module.

Fuzzy Sliding Mode congestion Controller (FSMC) [4] has designed a novel cross-layer congestion handling framework between transmission and MAC layer by considering a channel's SNR fraction in TCP structure. After that, FSMC was proposed by fusing fuzzy and SMC to regulate the queue size in congested nodes and avoid the effect of uncertain external interferences. But, the network reliability was less.

Proposed Methodology

The PRC algorithm explains briefly. This algorithm's main intention is to handle different NRT packet categories, and the considered types of PACKETS are HNRT, medium priority NRT (MNRT), and low priority NRT (LNRT). Each of the PACKETS is distributed with a particular priority. Then the general network topology shows in Figure 1, where P1,

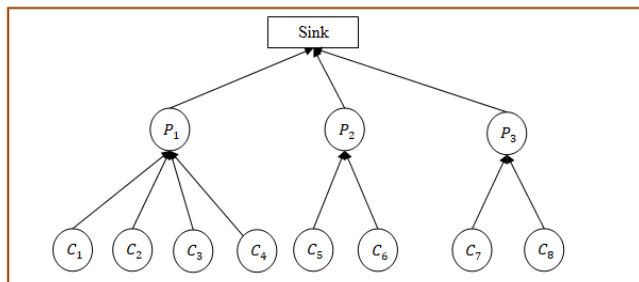


Figure1.GeneralNetworkTopology

P2 and P3 are Parent Nodes, and 'C1-C8' are child nodes. During packet transfer, the traffic classes prioritize the child nodes and the higher priority packets to sink nodes via the parent nodes. Consider TCP_{tnk} and GP_{tnk} are the traffic class priority and the geographical priority n^{th} e virtual queue in a k^{th} node. Also, consider Spain as the traffic source priority of n^{th} virtual (QUEUE) in the k^{th} node where 'I'm traffic class's sets and $I \in T, HNRT, MNRT, LNRT$.

First, the traffic class priority of n^{th} virtual queue in k^{th} node calculates as:

$$TCP_{tnk} = n_i S P_{tikn} \tag{1}$$

The RT traffic class plays a primary role in the overall priority, so the maximum PRIORITY is assigned to the RT. The overall Traffic Class

Priority contributing to the n^{th} virtual queue's overall PRIORITY in the k^{th} node minimizes the WEIG

HTED sum of the NRT traffic classes. Therefore, the weighted

'Overall PRIORITY for n^{th} virtual QUEUE in k^{th} node WP_{nk} is computing as:

$$WP_{nk} = TC_{pt} \cdot nk \cdot GP_{tnk} + WRT \cdot \delta \cdot WHNRT + WMNRT + WLNRT \quad [2]$$

Iraq. (2), δ indicates the constant $0 \leq \delta \leq 1$, and $WRT, WHNRT, WMNRT, WLNRT$ are weighting assigns to the NRT and RT traffic classes. Similarly, traffic class priority of n^{th} virtual queue in l^{th} child node is computing as:

$$TC_{ptnl} = n_i S_{ptiln} \quad [3]$$

In Eq. (3), S_{ptiln} is the source priority of n^{th} virtual queue in l^{th} the child nodes. The weighted overall focus (PRIORITY) for n^{th} virtual lines (QUEUES) in l^{th} the child node WP_{nl} is,

$$WP_{nl} = TC_{ptnl} \cdot GP_{tnl} + WRT \cdot \delta \cdot WHNRT + WMNRT + WLNRT \quad [4]$$

Iraq.(4), δ indicates the constant $0 \leq \delta \leq 1$, and GP_{tn} is the n^{th} virtual queue geographical priority' in the l^{th} child node. The 'Weighted Global PRIORITY' of n^{th} virtual QUEUES in l^{th} the child node WGP_{nl} changes to $WGP_{nl} = WP_{nl}$. The weighted international priority' at then n^{th} virtual queues' of k^{th} parent node WGP_{nk} changes to,

$$WGP_{nk} = n_l \in C_k WGP_{nl} + WP_{nk} \quad [5]$$

Consider TC_{ptnk} and GP_{tnk} are the traffic.

Class priority and the geographical priority n^{th} virtual queue in a k^{th} node. Also, consider Spain as the traffic source priority of n^{th} virtual (QUEUE) in the k^{th} node the PRC-FBA technique is described briefly. Assume the WSN has a K number of parent nodes denoted as a_1, \dots, a_K , and C number of child nodes marked as u_1, \dots, u_C in an equal cover age region. In Eq. (1), RSS_{kc} denotes the Received Signal Strength (RSS) of the parent node to child node, RSS_{ij} denotes the RSS from parent node i to child node j ; accordingly, indicates an increasing operation. In particular, k and i are the indexes of parent nodes, whereas m and j are the child node indexes. Finally, atypical model is adopted to simulate the wireless medium circumstance, which is designed as In Eq. (2), P_t denotes the transfer energy, PL indicates the path loss, $PL(d_0) - 105 \log(d/d_0)$ denotes the large-scale path loss model, which uses logarithm distance called long-distance radio propagation framework, d_0 denotes thereference distance, and $PL(d)$ denotes the received energy at d_0 , d denotes the distance between origin and target nodes and η denotes the path loss exponent. Finally, time slots are assigned, and the algorithm's outcome computes the transfer time. In Eq.(5), U is the node group; b_j is the adequate bandwidth distributed to node u_j .

Assume $b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij}$, where x_{ij} denotes the relationship of u_j with a_i . Use the $\sum K$

Physical restraints, and the one-child node can only connect with one parent node synchronously, so $x_{ij} \in \{0, 1\}$, p_{ij} denotes the transfer period that a_i distributes to u_j , and ω_j denotes the weight of u_j the traffic class priority of u_j in WSN.

A Logarithmic Utility Function (LUF) is defined regarding bandwidth, i.e., Jain's fairness index because there is an available selection of quantity for which the index is determined. It is described as:

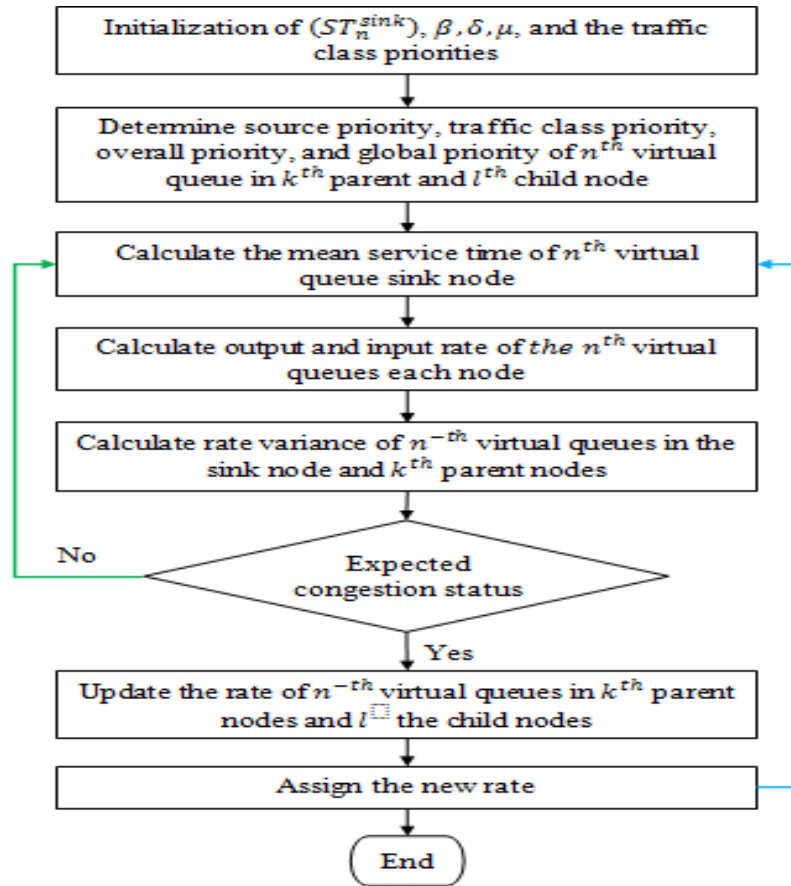


Figure2. Flowchart of PRC Algorithm for Congestion Control

$$I_{ij} = \left(SINR \left(\frac{RSS_{ij}}{\sum_{k \in [1,K]; c \in [1,C], c \neq j} RSS_{kc} + N_0} \right) \right) \quad [1]$$

:

$$RSS = P_t - (d_0) - 105 \log(d / 0) \quad [2]$$

Problem Formation

Fairness resource distribution is estimated by the range of fairness metric called Jain's index defined as:

$$f(X) = \frac{\sum_{i=1}^k x_i^2}{\left(\sum_{i=1}^k x_i \right)^2} \quad [3]$$

In Eq.(3), x_i denotes the resource distributed to individual $i=1, \dots, k$ and $X=(x_1, \dots, x_n)$

.To calculate fairness for bandwidth distribution, the formulation is represented by

$$f(X) = \frac{\sum_{j=1}^C b_j^2}{\left(\sum_{j=1}^C b_j \right)^2} \quad [4]$$

In this PRC-FBA, the formulation is defined as follows:

$$f(x,p) = \sum_{j \in U} \omega_j \log b_j \tag{5}$$

$$f(\cdot) = c \sum_{j=1}^j \frac{[\sum(\omega \log)]^2}{(\omega \log)^2} \tag{6}$$

Network throughput always conflict t with each other. This bandwidth distribution issue is devised as a non-linear programming. The aim is to distribute the bandwidth with trade-off between fairness and throughput. The optimization formulations are defined as: It is known as a non-linear bandwidth distribution dilemma, and it can be verified to be NP-hard. The primary utility factor is to increase LUF for fairness, and the secondary utility factor is to increase throughput. Usually, as r_{ij} is considered known, band width distribution b_j is turned to relationship x_{ij} and transfer period assignment p_{ij} . The restraints (10) and (11) indicate that u_j can only connect with one parent node a_i . The condition (12) denotes that the overall 1 transfer period of a_i is '1', and there straint (13) signifies that p_{ij} is a variable ranging from 0 to 1. At last, condition (14) defines that i is the index of parent nodes and j is the index of child nodes.

Fairness Bandwidth Distribution

Because non-linear bandwidth distribution is an NP-hard issue, an approximate technique is adopted for determining the relationship x_{ij} and transfer period assignment p_{ij} . This problem is resolved in a network structure creation series. Even though x_{ij} and p_{ij}

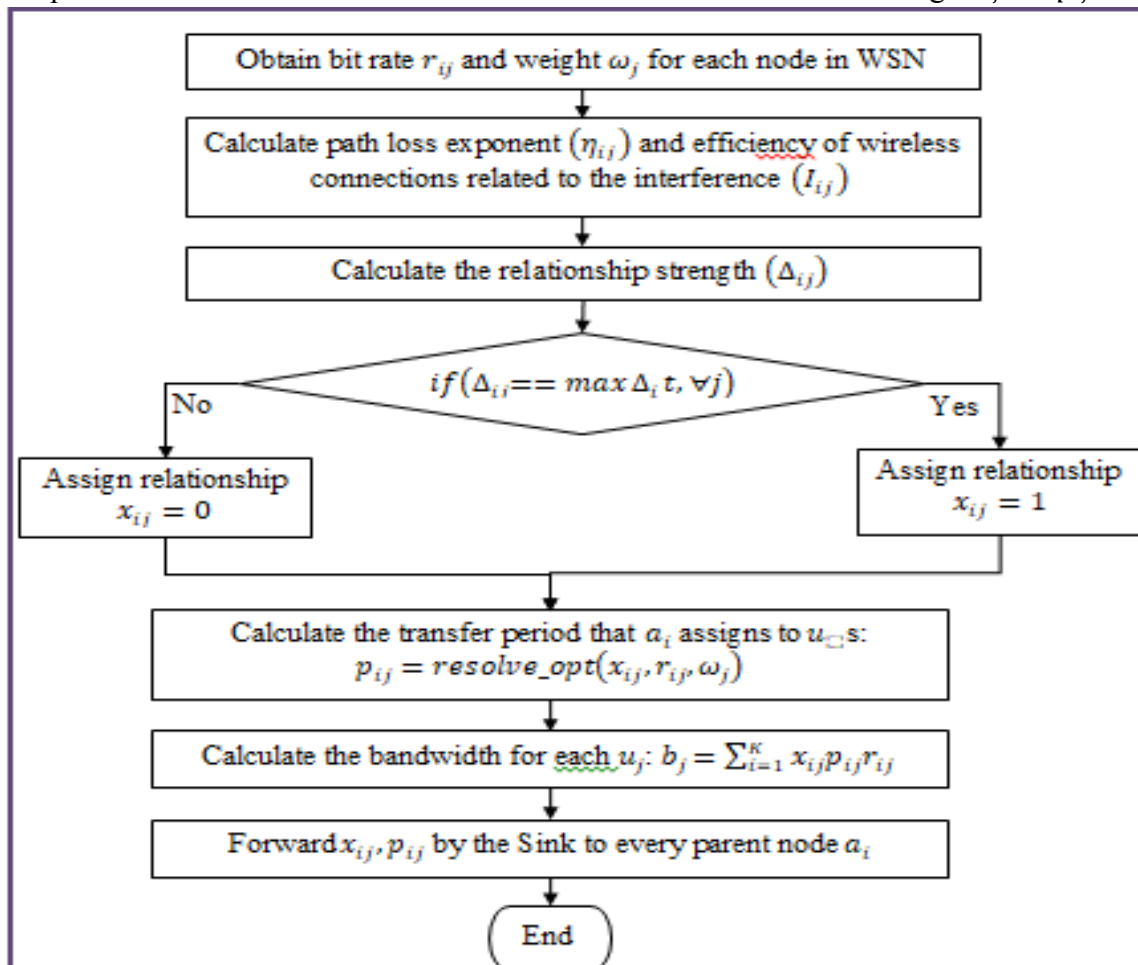


Figure 3. Flow Diagram of Fairness Bandwidth Distribution Process Distribution Phase

It have the association of $\sum_{j=1}^c x_{ij} p_{ij} = 1$, $x_{ij} \in \{0,1\}$, p_{ij} is independent of x_{ij} after the initialization of WSN. This issue is resolved by mutually considering nodes relationship and resource distribution, which intends to increase bandwidth utilities for fairness and throughput. So, this issue is split into two sub-problems and resolved in 2 different phases: relationship computation and distribution. In the initial phase, consider child nodes connect to parent nodes to compute the relationship of child nodes that intends to find x_{ij} . In this phase, u_j connects with a_i . Consider child nodes link to parent nodes, which create wireless connections in multi-rate WSNs. It removes the possible unwanted relationship based on r_{ij} and l_{ij} . The association is chosen by

In Eq.(15), Δ the relationship strength about bit rate and interference, ζ_1 and ζ_2 , are the weights.

Parameter	Range
Simulation area	1000×1000m ²
Number of nodes	50
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Number of traffic categories	4
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW
Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility speed	10m/s
Simulation time	120sec

Table1.SimulationParameters

Throughput

It is the amount of data accepted by the target with in a time.

Throughput=no of packets received/time

[15]

Figure 4 displays the throughput (in Kbps) for DDRRC, WPDDRRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec).

It observes that the PRC-FBA achieves higher throughput than all other techniques. Throughput=Total no. of packets receives by the Simulation time is 120sec, and then the PRC's packet loss is 22.22% less than the DTP-PA, 16.57% less than the DDRC, and 9.68% less than the WPDDRC algorithms. Thus, PRC's packet loss is the minimum because of using independent virtual queues in each node to handle the traffic classes' controlled priority level.

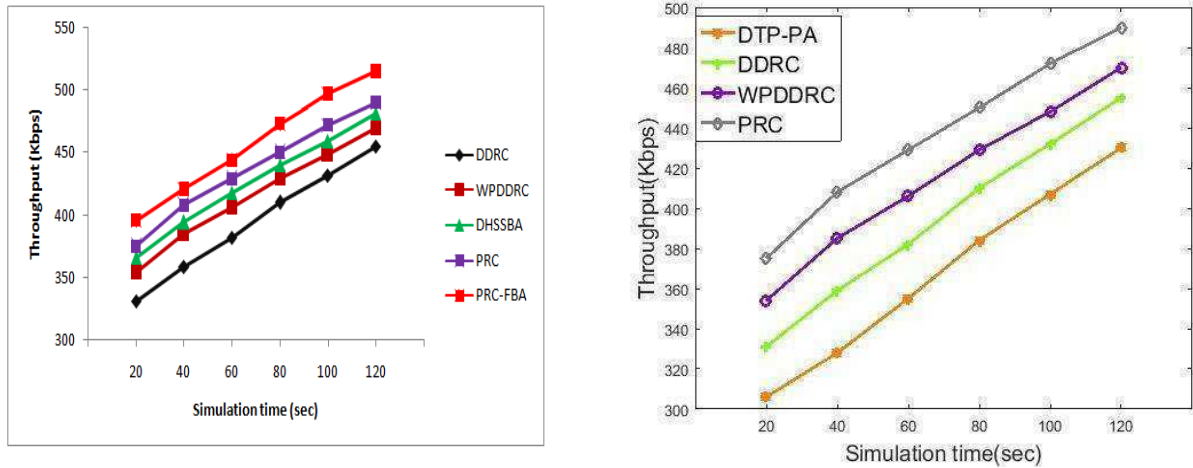


Figure4 Throughputs vs. Simulation time

Figure3 exhibits the throughput (in Kbps) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation times (in a sec). This analysis indicates that the PRC algorithm achieves higher throughput than all other congestion control algorithms.

Packet Loss

It defines the number of packets lost during communication. It has computed as: $\text{Packet Loss} = \frac{\text{Number of dropped packets}}{\text{no. of dropped packets} + \text{no. of received packets}}$ [16].

It defines the number of PACKETS lost during communication. It has computed as: $\text{Packet loss} = \frac{\text{Number of (dropped) 'packet' no. of dropped packets}}{\text{+no. of received packets}}$ [17]

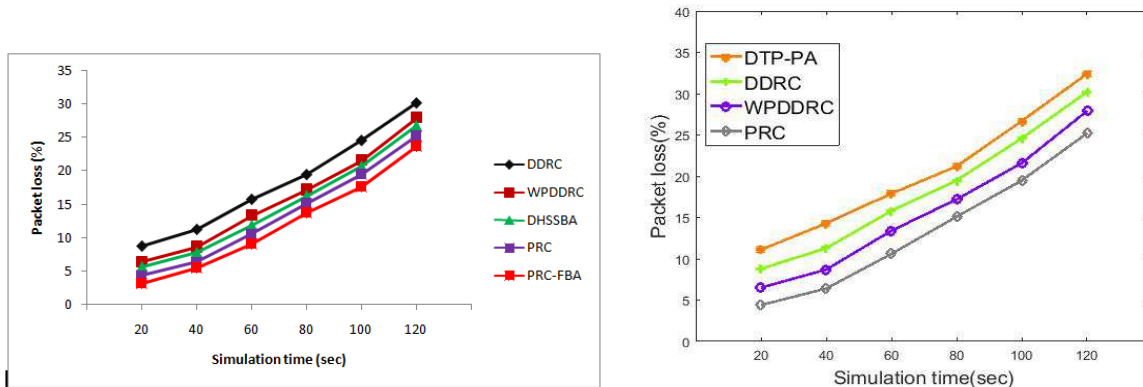


Figure5. Packet Loss vs. Simulation Time

Figure 5 shows the packet loss (in %) for DTP-PA, DDRC, WPDDRC, and PRC algorithms under varying simulation time (in a sec). This analysis observes that the PRC algorithm achieves less packet loss than the other algorithms. If the simulation time is 120sec, then the PRC's packet loss is 22.22% less than the DTP-PA, 16.57% less than the DDRC, and 9.68% less than the WPDDRC algorithm.

Packet loss = Amount of the lost data / amount of lost data + amount of accepted data [18]

Figure 5 shows the packet loss (in %) for DDRC, WPDDRC, DHSSBA, PRC, and PRC-FBA techniques under varying simulation time (in a sec). It indicates that the PRC-FBA technique accomplishes less packet loss than the other methods.

Conclusion

The optimization problem is devised as non-linear programming and partitioned into two sub-problems. To conclude, the simulation outcomes exhibit the effectiveness of the PRC-FBA technique compared to the conventional congestion handling techniques. A PRC-based congestion control algorithm proposes to handle the congestion and buffer overflow in the WSNs. If congestion occurs, using the PRC-based congestion control algorithm for 120sec, it achieves as throughput of 490Kbps, a packet loss of 25.2%, an E2E delay of 183msec, a mean queue size of 22 packets, and a source data transfer rate of 51 packets/sec compared to the DTP-PA, DDRC, and WPDDRC algorithms. It needs to assign the proper bandwidth to control the congestion. This study's future extension could be focusing on integrating the PRC algorithm into the bandwidth allocation mechanism to enhance fairness and throughput.

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