
CHAPTER 4

CONGESTION HANDLING USING PRC-FBA TECHNIQUES

4.1 INTRODUCTION

In previous work, PRC technique has been proposed to handle congestion in WSNs. To gather information from every edge node, the PRC approach splits a single physical queue into two virtual queues according to the importance and priority of the traffic originating from the source node. Applying the criteria of virtual queue, the PRC adjusts the data of child node rates if the incoming packet indicates congestion. So, this PRC method would deal with congestion and buffer overflow in WSNs by factoring in both the priority of the traffic type and the condition of the queue. Nevertheless, it does not consider the issue of equitably allocating bandwidth while managing congestion in WSNs.

In light of the aforementioned, the PRC with Fair Bandwidth Allocation (PRC-FBA) approach is used in this instance. This method combines the concepts of traffic type priority and fair bandwidth distribution. The Signal-to-Noise and Interference Ratio (SINR) model is applied to the bandwidth allocation problem in WSN as a first step in establishing an effective communication between equity and efficiency. Then it will give an innovative utility factor for bandwidth that considers both efficiency and fairness. The final response is approximately calculated by combining the results of the node-to-node computation with the allotment of time slots. Furthermore, it is framed as a non-linear programming issue, which is then broken down into two smaller problems. Because of this, the 2-phase approach has been adopted. During the first stage, the connections between nodes are calculated, and in the second, time slots are allotted with the goal of optimizing the utility factor. As a consequence, WSNs are able to increase their efficiency and achieve more equitable bandwidth distribution.

In Real-Time (RT) and Non-RT (NRT) settings, WSN can generate a wide variety of data types. Because of these variables and the available bandwidth, these categories must be carefully managed in order to minimize congestion. As a result, a method called Proficient Rate Control and Fair Bandwidth Allocation (PRC-FBA) was created, which creates a virtual queue just for certain traffic categories and grants them precedence.

In an attempt to strike a balance between equity and performance, PRC-FBA addresses the bandwidth allocation problem in WSN using the Signal-to-Noise and Interference Ratio (SINR) model. After that, an innovative bandwidth utility factor is determined that is both equitable and efficient. FBA technique in PRC-FBA was created with throughput improvement as its aim; latency was not considered into reason. On the other hand, the primary cause of lost NRT packets is delay. PRC-QDBA, or Quality of Service aware dynamic bandwidth allocation, is a method of allocating bandwidth that gives packets priority based on the traffic classifications they include. This model employs a dynamic bandwidth allocation technique associated with quality of service to efficiently divide the unused time slots among the required nodes.

A parent-child association of tree topology is used to build a hierarchical distribution approach. Traffic Indication Maps (TIMs) are sent by the child nodes to the parent node, which adopts them and uses them to assign time slots according to the characteristics of the nodes. In case the parent node is unable to supply the necessary spaces, it generates a Traffic Indication Map (TIM) detailing the requirements and transmits it to its nearest parent node. Consequently, the total performance rate of real-time traffic rises. This technique additionally ensures packet forwarding for previously approved flows by permitting node transmission based on ancestor connection capabilities. Lastly, simulation findings demonstrate that the suggested paradigm significantly improves the throughput and delay for bandwidth allocation in addition to enabling QoS support for RT traffic in WSNs.

4.2 PROFICIENT RATE CONTROL WITH FAIR BANDWIDTH ALLOCATION (PRC-FBA)

In second phase, PRC-FBA technique is constructed traffic type priority and equitable assignment of bandwidth. As a first step toward finding a communication between equity and performance, it will use the SINR model to the problem of bandwidth distribution in WSN. Next, a novel utility factor for bandwidth is given in terms of productiveness and fairness. The approximate solution is derived from the sum of the node-to-node computation and the allocation of time slots. Furthermore, the subject has been framed as a non-linear programming problem and partitioned into two halves. Because of this, the 2-phase approach has been adopted. During the first stage, the connections between nodes are calculated and metrics are

determined. In the second stage, time slots are allotted with the goal of optimizing the utility factor. As a consequence, WSNs are able to increase their efficiency and achieve more equitable and width distribution.

4.3 FAIRNESS BANDWIDTH ALLOCATION IN WSN

Studies of fairness, an interdisciplinary subject related to resource distribution, are beneficial for multi-rate WSNs, namely wireless multi-media sensor networks (Guo et al. 2015; Teymouri et al. 2015; Xu et al. 2017). As a special case of WSNs, multi-rate networks allow for simultaneous operation of connections with widely different data rates. However, can prevent the converse from occurring, in which a resource-rich sensor node receives more from the provider than a resource-poor sensor node. Resources may be distributed unevenly as a result of unequal distribution. The transmission time, rate and bandwidth are all examples of resources that can be scheduled or allotted. With such a network, there will always be a tension between ensuring every node gets an equal share of the resources available and maximizing the efficiency with which those resources are used (i.e., throughput). For example, the widespread 802.11 MAC protocol suffers from a performance anomaly, causing a severe drop in network speed due to its design emphasis on long-term, equitable transmission opportunities (throughput-based fairness).

Fairness metrics are used to evaluate the level of progress made toward parity. Quantitative fairness criteria include Jain's Index and Entropy, whereas qualitative fairness criteria include Max-Min Fairness and Proportional Fairness (Huaizhou et al. 2013). Jain's index is widely used as a benchmark for issue fairness (Chiu, 1984). The degree of fairness is quantified on a scale from 0 to 1, with greater values of the J indicating more fairness has been done. Both maximum-minimum fairness and proportional fairness guarantee that every sensor node contributes the same amount of data, while proportional fairness finds a medium between the two (Kelly, 1997) single-Access Point WLANs, throughput-based fairness and max-min fairness are interchangeable. Also, if all users have the same priority, time-based fairness, which gives each user the same amount of time to access the channel is identical to proportional fairness (Li et al. 2014). There are various methods that assist in energy conservation inside WSNs which is used to monitor variables like temperature, humidity, vibrations, seismic activity, and more. It is crucial to take into account association control in cluster heads as well as cluster creation,

which is controlled by scheduling, when allocating resources in WSN. When the selected cluster heads are joined by the sensor nodes, the cluster is formed. Yen et al., (2011) used modelling approaches from game theory to analyse clustering formulations. It is possible to consider association control and fairness simultaneously. In order to control the high quality of bandwidth distribution in an, association control strategies based on proportional fairness were described in Li et al. (2008). The max-min fair allocation is possible with the predicted technique. Li et al., (2014) delves deeper into the issue of associating access points to achieve equal data rates in multi-rate WLANs. In the worst scenario, a relaxation technique is applied, according to Li et al. (2014), to produce a solution that is better than 50% of the ideal. More specifically, Yu and Wong (2014) describe an optimization problem that considers both association and bandwidth allocation in order to find the trade-off between resource efficiency and user fairness in WSNs. When faced with congestion in WSNs, the previously established PRC model faces the same challenge of bandwidth distribution. As a solution, PRC with Fair bandwidth Allocation (PRC-FBA) was suggested, allowing the ideas of traffic type priority and fair bandwidth assignment. Initially, the Signal-to-Noise and Interference Ratio (SINR) model is applied to the bandwidth allocation problem in WSN in an attempt to establish a relationship between performance and fairness.

Next, an innovative utility factor for bandwidth that ensures both efficiency and fairness are considered. This aspect introduces an innovative utility factor for bandwidth that allows for both efficiency and fairness. Combining the time-slot allocation with the node-to-node computation yields a near approximation of the final result. It is also presented as a two-part decomposition of a non-linear programming problem. Consequently, a two-stage strategy is used. While allocating time slots to maximize utility is the focus of phase two, step one entails figuring out how connected the nodes are. In WSNs, this leads to an improvement in network efficiency and the achievement of equitable bandwidth allocation.

4.4 PROPOSED METHODOLOGY

The WSN having K the quantity of parent nodes indicated as a_1, \dots, a_K and C quantity of child nodes indicated as u_1, \dots, u_C in a region with equal coverage. Also, a_i is a node which receives, obtains the utility factor for allocating the time slots to the PRC-

FBA's result u_j . Here, denote a time slots systems with constrained bit rate wireless connections. The bit rate between a_i and u_j is characterized by r_{ij} . The parent node interference i to child node j is denoted as I_{ij} . When under SINR framework, I_{ij} is the efficiency of wireless connections and is associated with the interference from other wireless connections.

$$I_{ij} = g \left(\text{SINR} \left(\frac{RSS_{ij}}{\sum_{k \in [1, K]; c \in [1, C], c \neq j} RSS_{kc} + N_0} \right) \right) \quad (4.1)$$

In Eq. (4.1), RSS_{kc} represents the parent node's Received Signal Strength (RSS). k to child node c , RSS_{ij} denotes the RSS from parent node i to child node j , correspondingly, g suggests a growing business. Specifically, k and i are the parent nodes' indices, in contrast m and j are the child nodes indices. To replicate the conditions of the wireless medium, a standard model is used, which is created as,

$$RSS = P_t - PL(d_0) - 10\eta \log \left(\frac{d}{d_0} \right) \quad (4.2)$$

In Eq. (4.2), P_t represents the energy transfer, PL shows the lost route, $PL(d_0) - 10\eta \log \left(\frac{d}{d_0} \right)$ represents the logarithmic distance used in the large-scale path loss model known as the log-distance radio propagation framework, d_0 indicates the distance in reference and $PL(d_0)$ represents the energy received. at d_0 , d shows the separation between the source and destination nodes, and η represents the exponent of path loss. Slots are allotted, and the algorithm's result is used to calculate the transfer time.

4.4.1 Problem Formation for Energy Consumption

The Jain index assesses how fairly the nodes in a WSN uses energy. The Jain index measures how fairly energy is consumed by the nodes in a WSN, where some nodes may use up more energy than others because of different workloads or roles (such cluster heads). Better energy fairness between the nodes is indicated by a higher Jain index. The distribution of fair resources is assessed using a variety of fairness metrics known as Jain's index, which is defined as follows:

$$f(X) = \frac{\left[\sum_{i=1}^k x_i \right]^2}{k \sum_{i=1}^k x_i^2} \quad (4.3)$$

In Eq. (4.3), x_i indicates the resource allocated to each individual $i = 1, \dots, k$ and $X = (x_1, \dots, x_n)$. The concept is represented in order to determine bandwidth distribution fairness by Eq. (4.4).

$$f(X) = \frac{[\sum_{j=1}^C b_j]^2}{c \sum_{i=1}^C b_j^2} \quad (4.4)$$

The formula is defined as follows in this PRC-FBA:

$$f(x, p) = \sum_{j \in U} \omega_j \log b_j \quad (4.5)$$

In Eq. (4.5), U is the group of nodes, b_j is the effective bandwidth distributed to node u_j . Assume $b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij}$, where x_{ij} indicates the connection of u_j with a_i . One child node can only connect synchronously to one parent node using the physical constraints, so $x_{ij} \in \{0, 1\}$, p_{ij} indicates the time of transfer that a_i gives out to u_j and ω_j indicates the weight of u_j . This displays the priority of the traffic class of u_j in WSN.

When it comes to bandwidth, or Jain's fairness index, a Logarithmic Utility Function (LUF) is defined because the quantity for which the index is calculated is subject to open selection. It is given in Eq. (4.6),

$$LUF: f(x, p) = \frac{[\sum_{j=1}^C (\omega_j \log b_j)]^2}{c \sum_{j=1}^C (\omega_j \log b_j)^2} \quad (4.6)$$

The utility factor yields LUF for equitable bandwidth distribution. This LUF is determined by evaluating each person's equality $\omega_j \log b_j$. The utility factor is the sum of $\omega_j \log b_j$ for every u_j and since each resource is used individually for distribution, the LUF equals Jain's index 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 an identical chance to forward an equal amount of data. But, it may tend to the condition that individual with lower bit rates occupy the medium a higher fraction of period compared to those with larger bit rates, significantly minimized the network efficiency. So, time-based fairness is introduced and so every individual can acquire equal amounts of 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:

$$\frac{\sum_{j=1}^C b_j}{T} = \frac{\sum_{j=1}^C b_j}{T_{a_i}} = \frac{\sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij}}{\sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij}} = \sum_{j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij} \quad (4.7)$$

In Eq. (4.7), T_{a_i} is the transfer period at parent node a_i . Considering that the parent nodes be able to run concurrently, the parent node's transfer period is the transfer period for WSN i.e., $T = T_{a_i}$. Also, considering that $\sum_{j=1}^C x_{ij}p_{ij} = 1$ and so $T_{a_i} = \sum_{j=1}^C x_{ij}p_{ij} = 1$. Fairness and network throughput always conflict with every other. In this work, two utility factors are considered such as fairness and network throughput. A trade-off between throughput and fairness is established by using the weighted sum of the two fitness values as the unified fitness factor. The solution to this bandwidth distribution problem is a non-linear programming. The goal is to allocate bandwidth while balancing throughput and fairness. The definition of the optimization formulations is:

$$\max \frac{[\sum_{j=1}^C (\omega_j \log(\sum_{i=1}^K x_{ij}p_{ij}r_{ij}))]^2}{c \sum_{j=1}^C (\omega_j \log(\sum_{i=1}^K x_{ij}p_{ij}r_{ij}))^2} \quad (4.8)$$

$$\max \sum_{i,j=1}^C \sum_{i=1}^K x_{ij}p_{ij}r_{ij} \quad (4.9)$$

$$\text{subject to } \sum_{i=1}^K x_{ij} = 1 \quad (4.10)$$

$$x_{ij} \in \{0,1\} \quad (4.11)$$

$$\sum_{j=1}^C x_{ij}p_{ij} = 1 \quad (4.12)$$

$$p_{ij} \in [0,1] \quad (4.13)$$

$$i \in [1, K], j \in [1, C] \quad (4.14)$$

The problem is known as the non-linear bandwidth distribution conundrum, and it is NP-hard. Increasing LUF for fairness is the main utility consideration, and increasing throughput is the secondary one.

Normally, as r_{ij} is seen as existing, allocation of bandwidth b_j is turned to relationship x_{ij} and Assignment of the transfer period p_{ij} . The equations (4.10) and (4.11) show that u_j has a single parent node connection only a_i . The equation (4.12) indicates that the duration of the transfer of a_i is 1 and the equation (4.13) indicates that p_{ij} is a variable having a range of 0 to 1. Finally, the equation (4.14) explains that i is the parent node index and j is the index of child nodes.

4.4.2 Fair bandwidth distribution

Since the non-linear bandwidth distribution is an NP-hard problem, the relationship x_{ij} is found via an approximation method and assignment of transfer period p_{ij} . A sequence of network structure creation steps fix this problem. Despite the fact that x_{ij} and p_{ij} possess the affiliation 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. The resolution of this issue involves the relationships between nodes and the distribution of resources in order to increase bandwidth utilities for throughput and fairness. As a result, this problem is divided into two smaller issues, each of which is handled in turn: the relationship calculation phase and the distribution phase. Considering child nodes are connected to parent nodes in the first phase in order to compute the relationship between child nodes, which aims to identify x_{ij} . In the second phase, the utility factor which is described as weighted sum of LUF for fairness and throughput is increased by assigning time slots. According to relationship data x_{ij} , p_{ij} is computed.

- **Relationship Computation Phase**

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

$$\max \Delta_{ij} = \zeta_1 r_{ij} / (\sum_{j=1}^C r_{ij}) + \zeta_2 I_{ij}, \forall j \quad (4.15)$$

In Eq. (4.15), Δ_{ij} is the relationship strength with regard to 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 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.

- **Distribution Phase**

Here, 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:

$$\max \lambda_1 \frac{[\sum_{j=1}^C (\omega_j \log(\sum_{i=1}^K x_{ij} p_{ij} r_{ij}))]^2}{C \sum_{j=1}^C (\omega_j \log(\sum_{i=1}^K x_{ij} p_{ij} r_{ij}))^2} + \lambda_2 \sum_{i,j=1}^C \sum_{i=1}^K x_{ij} p_{ij} r_{ij} \quad (4.16)$$

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 by using time slot assignment, p_{ij} is associated 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 transfer period of each child node is one within single parent node a_i . Figure 4.1 illustrates the algorithm of fairness bandwidth distribution process for congestion handling in WSN.

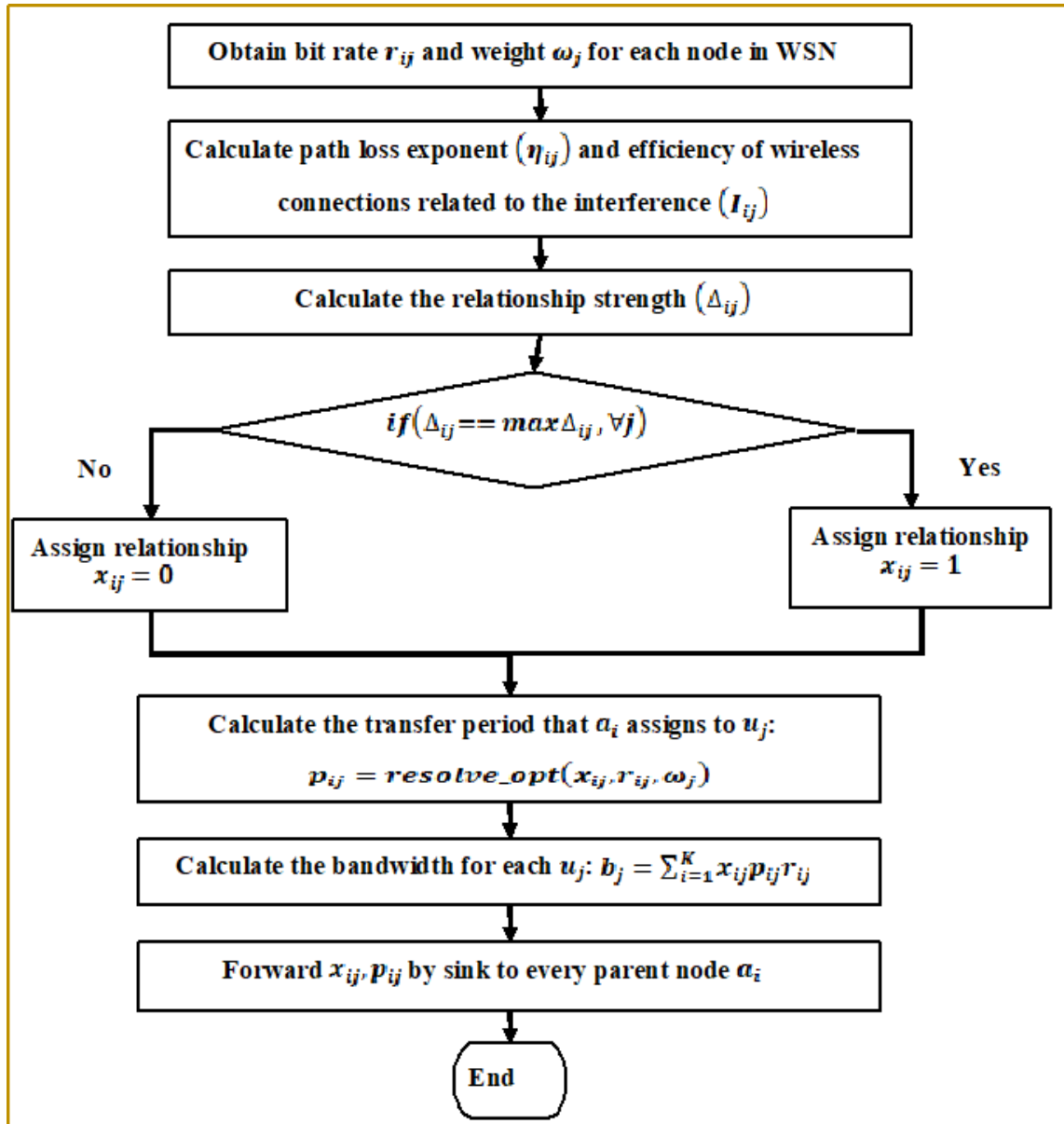


Figure 4.1 Flow Diagram of Fairness Bandwidth Distribution Process

Algorithm 4.1 Fairness Bandwidth Distribution Process

Input: Rate of bit r_{ij} between i and j , weight ω_j for every node

Output: Bandwidth for each child node, duration of transmission, and relationship information

Get input r_{ij} and ω_j ;

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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
         $x_{ij} = 0;$ 
    end if
end for
end for
 $p_{ij} = \text{resolve\_opt}(x_{ij}, r_{ij}, \omega_j);$ 
Bandwidth for every  $u_j$ :  $b_j = \sum_{i=1}^K x_{ij} p_{ij} r_{ij};$ 

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Forward x_{ij}, p_{ij} through each parent node's sink

$a_i;$

This algorithm was split into 2 stages. First, the relationship computation was completed which was considered as a branch bounding approach in the entire algorithm. It chooses a branch where it had highest Δ and lessens unwanted branches for minimizing the computational difficulty. Thus, the congestion through the network was controlled by using traffic priority and fair bandwidth distribution.

4.5 SIMULATION RESULTS

The proposed PRC-FBA method was implemented and its performance was evaluated using various metrics. The results for packet loss of PRC and PRC-FBA were depicted by varying times. Packet loss, throughput, queue size, End-to-End (E2E) latency and source data transfer rate adjustment were the parameters used in the analysis.

4.5.1 Throughput

The throughput of PRC and PRC-FBA was compared with definite number of iterations. Throughput values for the proposed PRC-FBA and the PRC model with the number of iterations was compared in Table 4.1.

Table 4.1 Throughput Comparison

Simulation Time(sec)	PRC (Kbps)	PRC-FBA(Kbps)
20	375	396
40	408	421
60	429	444
80	450	473
100	472	497
120	490	515

For a 120-second simulation time, PRC-FBA throughput outperforms PRC approaches by 5.1%. This was made possible by allocating varying priorities to different kinds of traffic in each virtual queue and distributing the available bandwidth equitably among all network nodes.

4.5.2 Packet Loss

The packet loss of PRC and PRC-FBA was compared with definite number of iterations. Table 4.2 provided the comparison values of packet loss for proposed PRC-FBA and PRC algorithm with the number of iterations.

Table 4.2 Packet Loss Comparison

Simulation Time(sec)	PRC (%)	PRC-FBA (%)
20	4.4	3.2
40	6.4	5.5
60	10.6	9.1
80	15.1	13.8
100	19.5	17.6
120	25.2	23.7

It was appeared that PRC-FBA achieves lower packet loss than the compare to PRC methods. Simulations were shown that PRC-FBA reduces packet loss by 6% compared to standard PRC methods while executing for 120 seconds. Hence, PRC-FBA packet loss was attributed to its use of virtual queues and each node's fair bandwidth distribution in relieving WSN congestion.

4.5.3 End-to-end Delay

For various simulation times, the E2E latency (in ms) for the DHSSBA, PRC, WPDDRC, PRC and PRC-FBA methods (in sec). A lower E2E delay was achieved with PRC-FBA compared to the other method. With a 120-second simulation time, PRC-FBA has a 6% lower E2E delay than the PRC methods. Because of this, higher throughput and lower packet loss are correlated with shorter E2E times. The E2E latency (in ms) for PRC and PRC-FBA approaches under different simulation times (in sec) is shown in Table 4.3.

Table 4.3 E2E Delay Comparison

Simulation Time(sec)	PRC(ms)	PRC-FBA(ms)
20	83	71
40	101	90
60	130	119
80	142	132
100	170	157
120	183	172

It was observed that in comparison to the other methods, the PRC-FBA produced a lower E2E latency. The E2E delay of PRC-FBA was 6% smaller than that of PRC techniques if the simulation duration was 120 seconds. Thus, the highest throughput and the least amount of packet loss was correlated with the lowest E2E delay.

4.5.4 Queue Size

The queue size of PRC and PRC-FBA was compared with definite number of iterations. Table 4.4 provides the comparison values of Queue Size for proposed PRC-FBA and PRC algorithm with the number of iterations.

Table 4.4 Queue Size Comparison

Simulation Time(sec)	PRC (Pkts)	PRC-FBA(Pkts)
20	5	3
40	8	6
60	11	9
80	14	11
100	18	15
120	22	18

The average queue size for PRC and PRC-FBA systems with varying simulation times (measured in seconds) in terms of packets. As compared to the other methods, it was found that the PRC-FBA approach results in shorter average queue lengths (mean queue sizes). Assuming a simulation time of 120 seconds, PRC-FBA reduces the average queue size by 18.2% compared to traditional PRC methods. Raising the minimum queue length was aid in lowering end-to-end latency and packet loss. PRC-FBA stabilizes the queue length around a desired value and evidently, provides superior stability for the mean queue size.

4.5.5 Data Transfer Rate

A fixed-number-of- iterations comparison was made between the data transfer rate adjustments of PRC and PRC-FBA. Data transfer rates (in packets/second) for PRC and PRC-FBA methods at different elapsed simulation times was shown in Table 4.5.

Table 4.5 Data Transfer Rate Comparison

Simulation Time(sec)	PRC(Pkts/s)	PRC-FBA(Pkts/s)
20	375	396
40	408	421
60	429	444
80	450	473
100	472	497

Lowering packet loss and end-to-end delay was achieved by increasing the minimum queue length. Clearly offering better stability for the mean queue size, PRC-FBA keeps the queue length centered around a targeted value. PRC-FBA was provided a 5.9% greater data rate at 120 seconds of simulation time than conventional PRC methods. It had been noted that the PRC-FBA was lower the data transfer rate compared to the nodes initial transfer rate. Thus, before lowering the transfer rate, the highest priority traffic classes was correctly transmitted without any congestion.