Achieving Fairness by Using Dynamic Fragmentation and Buffer Size in Multihop Wireless Networks

Jalaa Hoblos(✉)

Penn State, Behrend College, Erie, PA 16562, USA
jxh83@psu.edu

Abstract. Wireless Networks are error-prone due to multiple physical changes including fading, noise, path loss and interferences. As a result, the channel efficiency can be severely degraded. In addition, in saturated multihop wireless networks, nodes with multiple hops away from the destination suffer additional throughput degradation signified by high collisions resulting in high packet loss. It has been shown that packets fragmentation and buffer size play an important role in improving performance. In this work, we propose a technique to dynamically estimate appropriate buffer size and fragmentation threshold for individual nodes across the network in reference of their locality from the gateway and on their traffic load. The results show that nodes far from the gateway incur significantly higher throughput. The technique also results in better fairness across all nodes. Furthermore, it enhances the total network throughput while lowering the end to end and MAC delays.

Keywords: 802.11g · Wireless multihop networks · Throughput · Fairness · Fragmentation · Buffer size

1 Introduction

CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) [10] protocol used in Wireless Multihop Wireless (WMNs) have been studied mostly on single hop networks, however, their performance on multihop networks is still debatable.

In WMNs the throughput between sender and receiver stations in MWNs depends on several factors. Among them, their location from the gateway, their transmission power, and interferences [17]. In addition, the end to end throughput decreases further more in congested networks.

The work in [28] showed that 802.11 MAC protocol does not work well in MWNs. In [21], the authors showed that, in large ad-hoc networks, if the distance between sender and receiver grows the nodes capacity decreases rapidly. The authors in [8] studied TCP performance over MWNs. They showed that

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when load increases, links in these networks exhibit high packets drop rate due to increased link contention. As indicated in [12], in WMNs higher rate nodes are adversely influenced by other nodes with low rates thus decreasing their throughput. In addition, they also decrease the entire network throughput.

Research showed that packet size highly affects the network performance [1,25]. Although, researchers [4,5,19,24,26,29] have conveyed the impact of fragment sizes on the entire network, not much is found on the impact of the fragmentation and packet size on the fairness problem on these types of networks.

In this work, we introduce a Fragmentation and Buffer Size Estimation Technique (FBET) capable of assigning dynamically appropriate fragments and buffer sizes to various stations in the network depending on two main factors: their position in distinction to the gateway and their traffic load. Once these two factors become known, FBET then uses them to estimate the blocked and relayed traffic probabilities of each node across the network using Erlang-B [7]. Furthermore, FBET generates fragmentation thresholds and buffer sizes for individual nodes based on the estimated probabilities. Last, FBET sends the suggested values back to the nodes so they can dynamically adjust their attributes. We show that by using FBET, we reduce the unfairness problem, and increase the throughput of underprivileged nodes. Additionally, FBET enhances the network throughput and lowers the end to end and MAC delays.

This article is organized as follows: in Sect. 2, we briefly review previous work done in this area. Section 3 explains the network model and the methodology of the problem. Section 5 presents the simulation outcomes. Last, Sect. 6 examines future work, open questions and the conclusion.

2 Previous Work

The authors in [19] proposed dynamic fragmentation scheme to enhance throughput. The technique was able to increase the network throughput. However, the work only considered uniformly distributed networks where the hidden and exposed nodes problem does not exist. The authors in [23] were able to improve fairness in MWNs by assigning various contention window sizes to stations depending on their rates.

The authors in [27] introduced a protocol that enables stations to find alternative routes to various access points depending on their traffic loads. The protocol however suffered multiple shortcomings as noted in the paper.

The authors in [9] proposed a distributed link layer method on top of the TCP to attain fairness between TCP streams in mesh networks.

In [5], the authors proposed various adaptive fragmentation algorithms able to change the fragmentation size dynamically based on the channel quality in wireless networks. The network throughput was improved but the effect of the proposed algorithms was not studied on individual nodes.

In [20], the authors showed that packet size customization in the application layer may highly increase the channel utilization for wireless networks under harsh conditions.

The authors in [29] created mathematical models, with unlimited traffic loads, to calculate the network throughput in 802.11b using Markov chain. They used in their work packets fragmentation method.

Chang et al. [4] presented an algorithm capable of selecting optimal size packets based on the dynamic channels. The algorithm showed substantial throughput increase.

The paper in [24] introduced an analytical model of the work of 802.11 MAC taking into consideration hidden terminals and interferences. They concluded that by using optimal fragment size, the throughput could be increased significantly.

The authors in [6] discussed a phenomenon they called "symmetrical unfairness". They noticed that stations with the same distance from the gateway also experienced throughput discrepancies. They then presented a distributed routing method capable of enhancing symmetrical unfairness while preserving the overall throughput of the network.

In [18], the authors investigated the advantages and disadvantages of various queuing mechanisms to study the fairness in MWNs.

They observed that without a MAC layer that differentiates priorities, the ideal bandwidth utilization can not be obtained.

Bisnik et al. [2] demonstrated that the largest attainable throughput in ad hoc networks is highly affected by the node distance, its traffic load and its interferences.

In [11], the authors pertained mathematically the existence of deprivation in a simple line topology of two nodes.

In [22], the authors proposed a rate-limiting technique to those nodes closer to the gateway to achieve fairness in MWNs. Their proposal however involves complex computing.

In [13], the authors proposed a method that assigns various contention windows to nodes based on their location from the gateway and on their interferences. However, the method showed only slight improvement in the context of throughput and delay.

In [14], the authors showed that better fairness is achievable by choosing appropriate packet and contention window sizes.

The authors in [16] proposed a distributed scheme to allow nodes to collect information about their neighbors enabling them to make a better decision on staying or leaving the channel.

3 Methodology and Network Model

The authors in [15] studied the throughput decay in a simple linear network of size four. They used Erlang-B to compute the traffic blocking probabilities among nodes in mesh networks. Erlang [3] is a unit of traffic used in telephony as a measure of offered load on telephone circuits or switching. The telephone circuits used in Erlang are comparable to the number of channels available to nodes in a network to transmit their traffic. The blocking probability is shown in

Eq. 1, assuming P_b is blocking probability, m is the number of channels and ρ is traffic load in Erlang. This probability represents the possibility that a customer is denied service due to lack of resources.

$$P_b = \frac{\rho^m}{m!} \Bigg/ \sum_{j=0}^{m} \frac{\rho^j}{j!}, \qquad 0 < \rho < 1 \tag{1}$$

The authors also computed the blocking and relay probabilities for individual nodes as shown in Fig. 1. In this linear network, it was assumed that node 1 is the gateway and does not send traffic, only nodes 2, 3 and 4 send traffic. Additionally nodes 3 and 4 forward traffic coming from nodes along the path to the gateway. The computations are represented in Eq. (2)

$$\begin{cases} P_{b(2)} = \frac{3\,\rho+2\,\rho^2+\rho^3+1}{3+5\,\rho+3\,\rho^2+\rho^3} \\ P_{b(3)} = \frac{2+2\,\rho+\rho^2}{\rho^2+2\,\rho+3} \\ P_{b(4)} = \frac{2+5\,\rho+3\,\rho^2+\rho^3}{3+5\,\rho+3\,\rho^2+\rho^3} \end{cases} \begin{cases} P_{t(2)} = \frac{2+2\,\rho+\rho^2}{3+5\,\rho+3\,\rho^2+\rho^3} \\ P_{t(3)} = \frac{1}{\rho^2+2\,\rho+3} \\ P_{t(4)} = \frac{1}{3+5\,\rho+3\,\rho^2+\rho^3} \end{cases} \tag{2}$$

where the number of channels m is assumed to be 1. Thus the relayed probability is given by $P_t = 1 - P_b$.

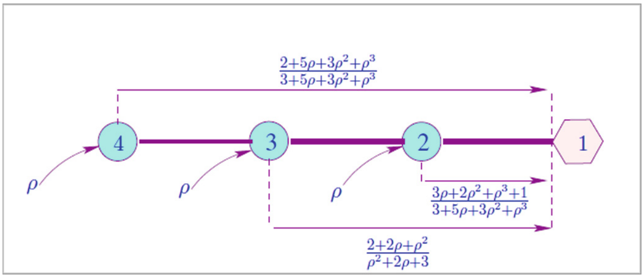

Fig. 1. A Simple linear MWN

4 Fragmentation and Buffer Size Estimation Technique (FBET)

As discussed in Sect. 2, appropriate packet fragmentation and buffer size have positive effect on performance in MWNs. That is because large packets have a better chance of being corrupted and dropped out in congested networks and where interference is factor. Inspired by this phenomenon, we want to be able to award nodes, with multiple hops away from the gateway, with smaller fragments and larger buffer sizes. The intuition behind this idea is as follows: smaller size packets have higher chances to be delivered and in case the transmission fails, nodes are provided with larger buffers to be able to store these packets and retransmit them at a later time. However, we need a to be able to properly estimate these values. One way to do so, is by using the probabilities discussed above. These values without doubt will give us a clearer insight into the degree of throughput disparities between various nodes. Since the equations were generated on a linear network of size four, we decide to use similar scenario as shown in Fig. 2 to test our technique on.

The fact that the unfairness problem manifests mainly in high traffic networks, we compute the blocking probabilities given a high load of $\rho = 0.9$. The values returned for *mobile_node_0*, *mobile_node_1* and *mobile_node_2* are: 0.91, 0.82175 and 0.56750 respectively. Thus, their relay traffic probabilities are: 0.093, 0.178 and 0.432 respectively. The computed values confirm the claim stating that individual nodes' throughput decreases exponentially with the number of hops away from the gateway under heavy traffic. These values are subsequently normalized and used to estimate the fragments and buffer sizes of nodes as described later. In our work, F denotes the default fragment size and B is the default buffer size. In addition, $F(i)$ and $B(i)$ represent the fragment threshold and buffer size, of node i, respectively. The Fragmentation and Buffer Size Estimation Technique (FBET) is described in Algorithm 1.

Algorithm 1. Fragmentation and Buffer Size Estimation Technique (FBET)

Assumption 1. *Nodes are aware of their location from the gateway*

Assumption 2. *Nodes send their traffic load periodically (every window time T) to the gateway*

1: Nodes relegate their location to the gateway
2: **for each** T **do**
3: Nodes consign their traffic load to the gateway
4: Calculate $P_t(i)$ $\forall$ i {where i is the number of stations}
5: Send F and B to the node with $P_t(min)$ { the node with *minimum* relay traffic probability}
6: Calculate $R(i)= P_t(i)/P_t(max)$ {normalize relayed values}
7: Calculate $F(i)=$ F/$R(i)$ and $B(i)=$ B*$R(i)$ $\forall i$ s.t $P_t(i) \neq P_t(min)$
8: Send the computed values back to the nodes
9: **end for**

We claim that the gateway is able to implement FBET. Once the nodes send their locations and traffic loads, the gateway will be able to estimate the appropriate fragmentation thresholds and buffer sizes and sends them back to the nodes.

5 Simulations Results

We apply FBET on the linear network shown in Fig. 2. The number of nodes generating traffic is 3. We assume that *mobile_node_3* is the gateway. *mobile_node_0*, *mobile_node_1* and *mobile_node_2* generate traffic. In addition, *mobile_node_1* and *mobile_node_2* relay their neighbors' traffic it to the gateway. Thus, *mobile_node_1* generates its traffic and forward *mobile_node_0* traffic. The same way, *mobile_node_2* sends and forward both *mobile_node_0* and *mobile_node_1* traffic. We assume that the gateway does not generate any packets and it serves as a router enabling traffic to flow in and out the network.

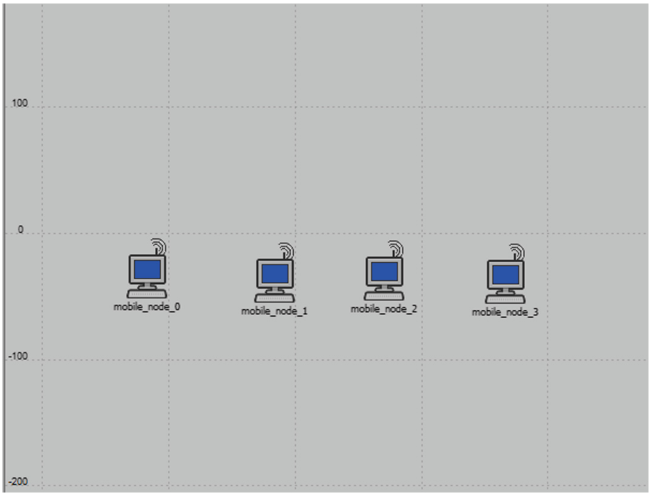

Fig. 2. Multihop wireless network

We call the default scenario *Default* and the scenario that we implement FBET on, is called *Frag*. The buffer size B of all nodes in the default network is set to 1024000 bits and all nodes' default fragmentation threshold F is set to 256 bytes.

For both scenarios (i.e. networks),we use Riverbed Modeler (version 17.5) simulator to assess the conduct of FBET. we utilize IEEE 802.11g protocol. We presume that the traffic is homogeneous. In addition, we also assume that the traffic and the packet size are exponentially distributed. The simulation time is set to 55 min. Table 1 shows other attributes we use in our simulation.

Table 1. Both networks simulation attributes

Attribute name	Value
Data Rate	5.5 Mbps
Inter_arrival time	32 ms
Packet Size	2048 Bytes
On Time	100 s
Off Time	0.01 s

Additionally, Table 2 shows the fragments and buffer sizes obtained by FBET. All other attributes not-shown here are left unchanged (we use the default values set by the simulator).

Table 2. Buffer and fragment sizes returned by FBET.

Nodes	Buffer sizes (bits)	Fragmentation thresholds (bytes)
mobile_node_0	1024000	256
mobile_node_1	422039	621
mobile_node_2	222126	1181

As shown in Figs. 3, 4 and 5, *mobile_node_0* when implementing FBET is able to send ≈21% more compared to its counterpart in the default network. *mobile_node_1* also sent about 10% more and *mobile_node_2*'s sent traffic **decreased** by about 7.5%.

Figures 8 and 7 clearly show better fairness when using FBET. The overall throughput is also increased by ≈24% when using FBET as shown in Fig. 6. The traffic sent using FBET increases by ≈11% and the received traffic also increases by ≈8%.

The end to end delay and the MAC delays are both lower when implementing FBET as shown in Figs. 9 and 10 respectively.

Last, Tables 5, 4 and 3 summarize the major findings described in this Section.

Table 3. Ratios of sent and received traffic across all nodes

Nodes	Default network	Network with FBET
mobile_node_0	0.43	0.52
mobile_node_1	0.557	0.56
mobile_node_2	0.73	0.68

Table 4. Overall network performance when Using FBET

Network parameters	Measurement
Throughput	↑ 24 %
Traffic Sent	↑ 11%
Traffic Received	↑ 8%
Delay	↓ 50.32%

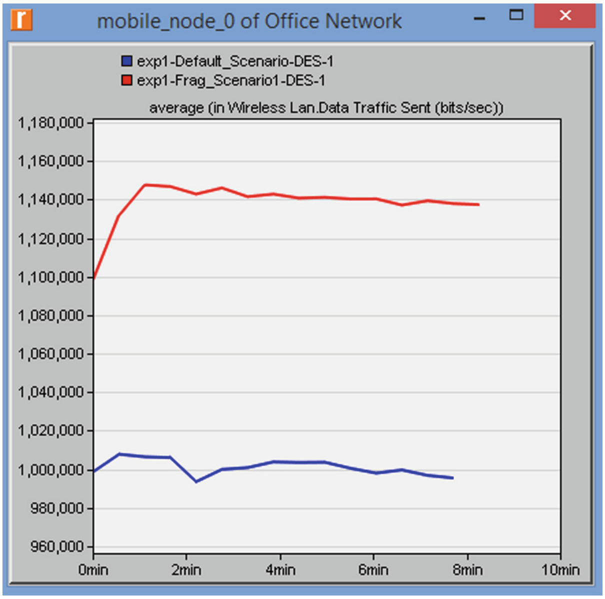

Fig. 3. *mobile_node_0* Traffic Sent

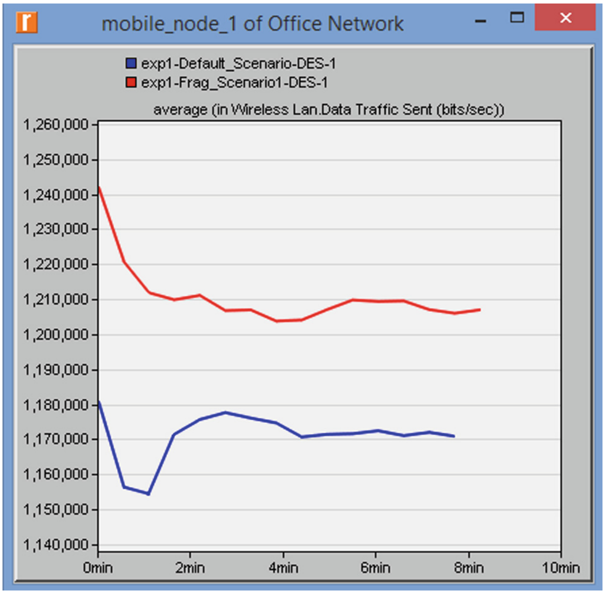

Fig. 4. *mobile_node_1* Traffic Sent

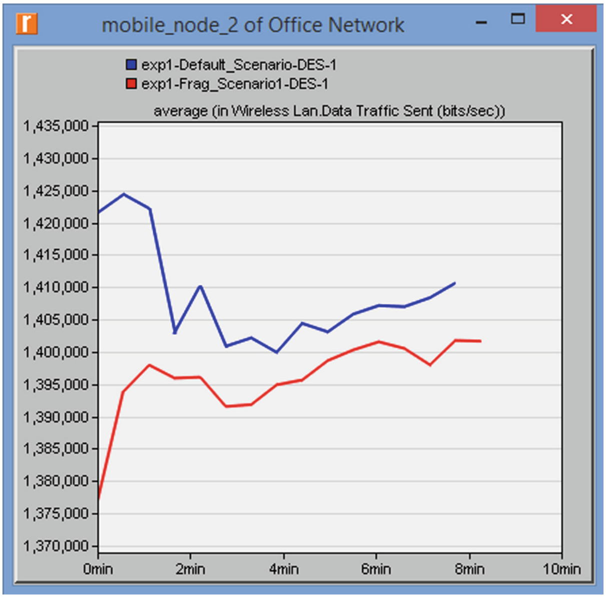

Fig. 5. *mobile_node_2* Traffic Sent

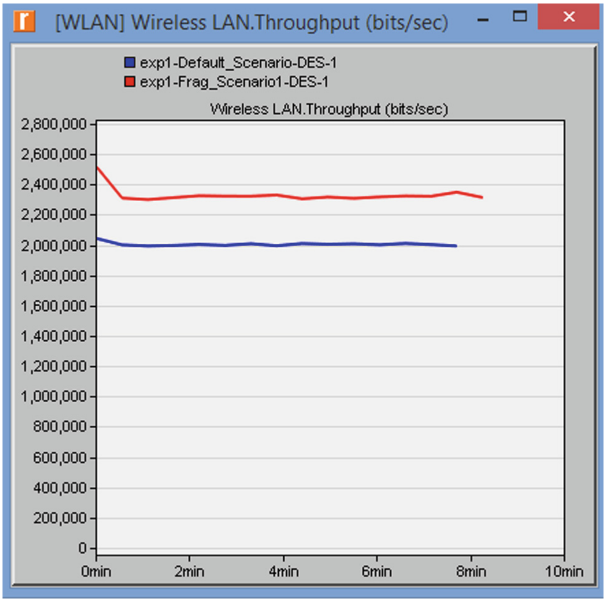

Fig. 6. Throughput w and w/o FBET

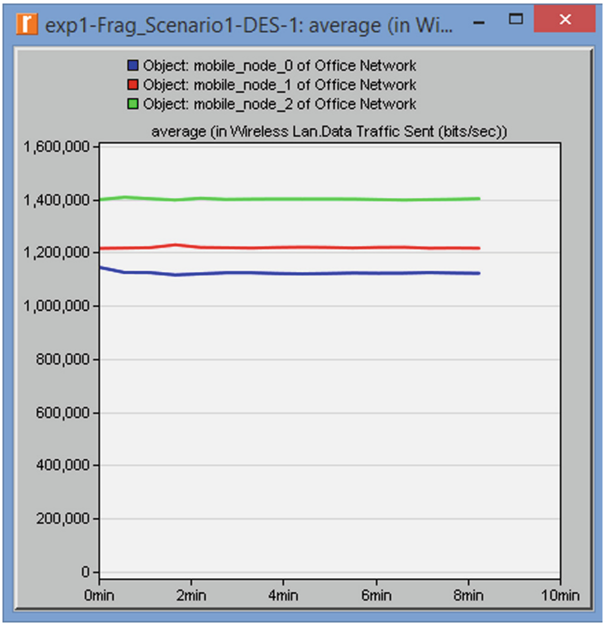

Fig. 7. Traffic Sent by all nodes using FBET

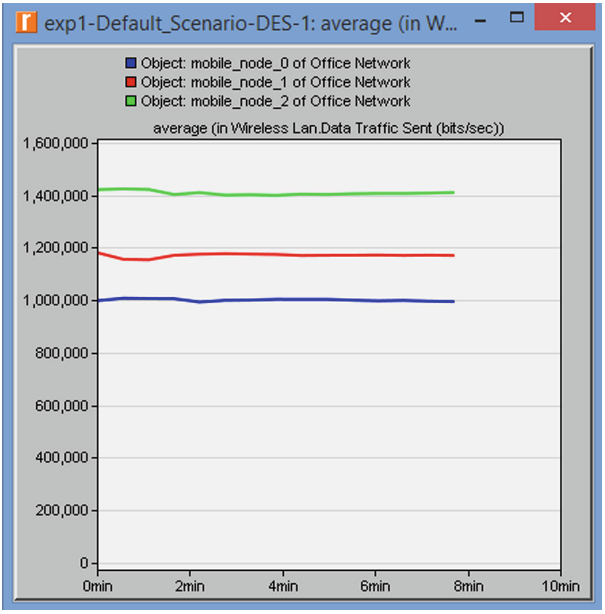

Fig. 8. Traffic Sent by all nodes in the default scenario

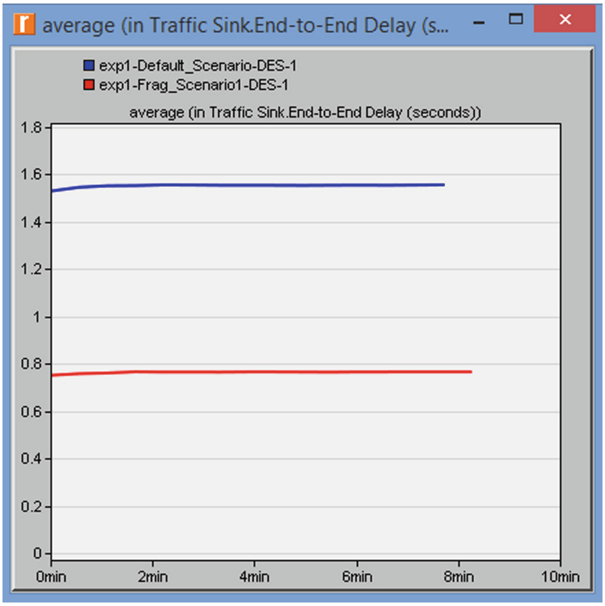

Fig. 9. End-to-End delay in networks w and w/o FBET

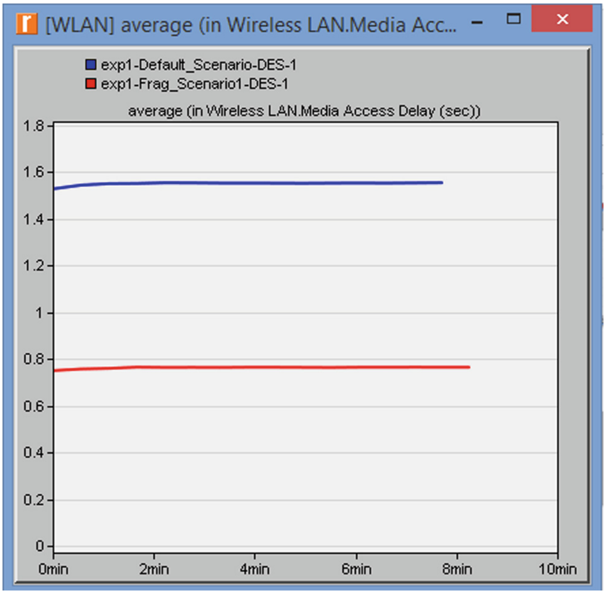

Fig. 10. MAC delay in both networks w/ and w/o FBET

Table 5. Individual nodes throughput when using FBET

Nodes	Traffic sent using FBET
mobile_node_0	↑ 21 %
mobile_node_1	↑ 10%
mobile_node_2	↓ 7.5%

6 Conclusion and Open Issues

Nodes in WMNs suffer from throughput degradation relatives to their locality, interferences and traffic load. To enhance fairness, we propose FBET, a technique capable of estimating fair packets fragmentation thresholds and buffer sizes for all nodes proportional to their physical location and their traffic load. We show that FBET increases fairness and network throughput. It also lowers the end to end and MAC delays. The findings are promising but need further investigation. We acknowledge that FBET was implemented on a simple network of four nodes and needs to be tested on more complicated networks. We also assumed that the nodes are immobile in the network. However, we believe that FBET can be equally implemented on mobile nodes. Since we assume that nodes periodically send their estimated traffic loads to the gateway, they can send their new location, if changed, at the same time. One limitation of FBET is the computation complexity required to be done by the gateway. Analysing the time complexity is part of our future work. In addition, we will be testing FBET on larger, more realistic networks where mobility is also supported.

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