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# 無線メッシュネットワークのための QualNet での固定バックオフ時間切替方式の実装と評価

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**あらまし** 本グループでは，柔軟で安価な大規模インターネットアクセスネットワークとして，互いに無線通信を行う複数のアクセスポイント（AP）で構成される，**無線メッシュネットワーク** *WIMNET* の研究を進めている．その中でこれまでに，マルチホップ通信に必要なリンク動作機会を確保することで，WIMNET の通信性能向上を図る，**固定バックオフ時間切替（*CSMA-FBS*）方式**の提案を行っている．本研究では，より現実的なネットワーク環境での CSMA-FBS 方式の評価のために，QualNet シミュレータに実装する．3 種類のトポロジでのシミュレーション結果を通じて，提案法の有効性を示す.

**キーワード** 無線メッシュネットワーク，固定バックオフ時間切替，CSMA-FBS，QualNet，シミュレーション

# An Implementation and Evaluation of Fixed Backoff-time Switching Method on QualNet for Wireless Mesh Network

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**Abstract** As an inexpensive and scalable access network to the Internet, we have studied the architecture, protocols, and design optimizations of *Wireless Internet access Mesh Network (WIMNET)*. WIMNET is composed of multiple access points (APs) connected through wireless links. Previously, we have proposed the *CSMA-based Fixed Backoff-time Switching (CSMA-FBS) method* for WIMNET to improve the performance by giving necessary link activation chances for multi-hop communications. In this study, we implement the CSMA-FBS method on the *QualNet* simulator for evaluations in more realistic network environments. The simulation results in three network topologies confirm the effectiveness of our proposal.

**Key words** wireless mesh network, fixed backoff-time switching, CSMA-FBS, QualNet, simulation

## 1. Introduction

The *wireless mesh network* has been extensively studied as a promising technology to flexibly and inexpensively expand the coverage area by allocating multiple wireless mesh routers on a network field [1]- [3]. As a scalable access network to the Internet using this technology, we have studied the architecture, protocols, and design optimizations of *Wireless Internet access Mesh Network (WIMNET)* [3]- [5]. As shown in Figure 1, WIMNET is composed of multiple access points (APs) as mesh routers that are connected with each other through wireless links. At least one AP acts as a *gateway (GW)* to the Internet. Any host in WIMNET can be connected to the Internet through this GW.

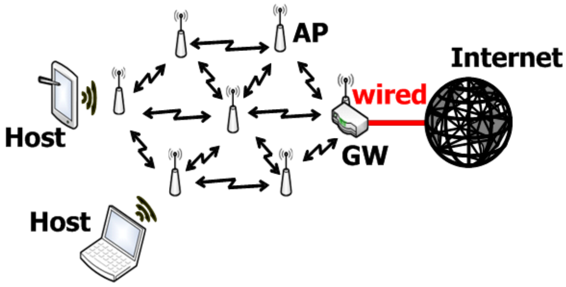



Fig 1: Outline of WIMNET.

WIMNET adopts *IEEE802.11 MAC (Media Access Control) protocols* for wireless communications [6]. To use a communication channel, a node in WIMNET employs the *CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol*. In CSMA/CA, any node possessing a packet is on standby for a random time before the data frame transmission in order to avoid frame collisions while providing the fairness among nodes. This standby time is called the *backoff-time*, and is set a certain value within the size of the *Contention Window (CW)*. When a node fails in the transmission, the CW size is increased to reduce the probability of the collision occurrence in the retransmission. When the node succeeds, it resets the CW size to the initial one.

Unfortunately, CSMA/CA can cause several problems in WIMNET. The first problem is congestions of the links around GW that can be bottlenecks of whole communications in WIMNET, because these links have to handle a lot of packets to/from GW for the Internet access. Thus, they should be activated with higher priorities than other links. The second problem is interferences among the links around GW that may not be resolved by the random backoff-time because of the limited CW size. We note that the initial value of the CW size is small. Multiple conflicting links can be activated at the same time by generating the same or similar backoff-time at the source nodes. Then, any link cannot complete the packet transmission successfully, and needs re-activations causing further conflicts.

To solve these problems in WIMNET, we have proposed the *Fixed Backoff-time Switching (CSMA-FBS) method* [5]. In this method, before starting communications, the *target link activation rate*, the *active backoff-time*, and the *passive backoff-time* are assigned for each link. The target link activation rate represents the frequency to activate the link to handle the traffic properly. Different values are assigned to the two backoff-times by following the descending order of expected traffic loads of links. A larger value than any active backoff-time is set for the passive backoff-time so that the link should be preferentially activated by using the active backoff-time.

During communications, the *actual link activation rate* is observed by counting the numbers of link activation chances and actually activated times for each link and taking their fraction. If this value is smaller than the target one, the active backoff-time is used for the preferential activation. Otherwise, the passive backoff-time is used. Because of the different backoff-times among links, conflicts among interfered links can be avoided. However, only the outline of the CSMA-FBS method was presented and evaluated through our simple network simulator, where it was not implemented as a protocol.

In this paper, we present an implementation of the CSMA-FBS method on a well-known network simulator *QualNet* [8]. It is known that QualNet adopts a more realistic physical model than other simulators such as ns-2 [9]. Before the implementation on hardware, the evaluation using a realistic network simulator is significant to refine the details of our method. We show simulation results using three network topologies, where they confirm the effectiveness of the CSMA-FBS method.

The rest of this paper is organized as follows: Section 2. reviews some related works. Section 3. introduces our proposed CSMA-FBS method. Section 4. presents the implementation on QualNet. Section 5. shows evaluation results. Section 6. concludes this paper.

## 2. Related Works

In [10], Xu et al. raised the question: Can the IEEE 802.11 work well in wireless ad hoc networks? They concluded that the protocol was not designed for multihop networks. Although it can support some ad hoc network architecture, it is not intended to support the wireless multihop networks such as ad hoc networks and wireless mesh networks, where the connectivity is one of the most prominent features.

In [11], Minooei et al. proposed an efficient backoff mechanism for ad hoc networks using DCF. It decreases the contention window size by 1 unit at the successful transmission after failures, instead of resetting the small initial value. For this purpose, the backoff-time $bt$ is given by:

$$bt = rand\left[CW_{\min} \times 2^{m-1}, CW_{\min} \times 2^{m}\right] \qquad (1)$$

where $CW_{min}$ represents the initial contention window size, $m$ does the number of consecutive transmission failures, and the function $rand[x, y]$ returns a uniformly randomized integer between $x$ and $y$. The simulation results show the higher end-to-end throughput than the conventional IEEE 802.11 MAC protocol. In [12], Wu et al. modify the backoff time by considering the frame collision probability of each node for multihop ad hoc networks.

In [13], Nakamura et al. proposed the fixed backoff-time for wireless LANs. By simulations, they showed that it can reduce collisions and idle duration to improve the throughput and delay performance. However, their method is based on PCF, whereas WIMNET is based on DCF.

## 3. Proposed CSMA-FBS Method

In this section, we briefly describe the proposed CSMA-FBS method with the outline of the MAC protocol.

### 3.1 IEEE802.11 MAC protocol

The IEEE802.11 MAC protocol makes it possible for several nodes to share the same physical medium or channel by detecting or avoiding data frame collisions. Figure 2 illustrates the timing chart for the data transmission. After the channel becomes idle, the source node waits first for the DIFS period, and then, for the backoff-time that is randomly selected between 0 and the CW size. Then, if it does not detect transmission from other node, it starts the transmission. The backoff-time is used to stagger the transmission timing among nodes to avoid collision. If collisions occur, the CW size is doubled as the binary exponential backoff scheme to avoid further collisions. If the transmission succeeds, the CW size is reset to the initial one $CW_{min}$.

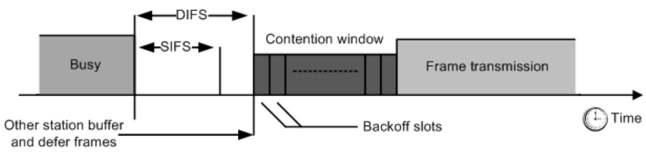



Fig 2: Timing chart for data transmission.

### 3.2 Overview of CSMA-FBS Method

Unlike the conventional MAC protocol, the CSMA-FBS method uses the two fixed backoff-times. Specifically, the *active backoff-time* and the *passive backoff-time* are adopted for each link to avoid the simultaneous activations of conflicting links. Either of them is used by comparing the *target link activation rate* and the *actual link activation rate*. Any backoff-time is assigned a different value from each other so that no pair of conflicting links may be activated at the same time. Besides, the backoff-time for a link with the larger traffic load is assigned a smaller value than that for a link with the smaller load, so that congested links can be activated more frequently than less-congested links. Furthermore, any active backoff-time is assigned a smaller value than a passive one, so that links using active ones have larger priorities in activations than links using passive ones.

During communications, every time an AP holding packets detects that the channel is clear, it calculates the actual activation rate. If it is smaller than the target activation rate, it selects the active backoff-time, judging that the activation rate of this link is not enough to handle the traffic. On the other hand, if it is larger, it selects the passive backoff-time so that other links selecting active backoff-times can be activated with higher priorities. The link with the passive backoff-time can be activated only if any conflicting link with the active backoff-time does not hold packets.

#### 3.2.1 Target Activation Rate

Before communications, the target activation rate is calculated for each link by dividing the number of assigned time-slots for link activations in the TDMA cycle with the TDMA cycle length [5]. The TDMA cycle can be given by the link scheduling algorithm in [7]. The target activation rate $rt_{ij}$ for link $l_{ij}$ from $AP_i$ to $AP_j$ is given by:

$$rt_{ij} = \frac{ts_{ij}}{TL} \quad (2)$$

where $TL$ represents the TDMA cycle length, and $ts_{ij}$ represents the number of assigned time-slots for link $l_{ij}$.

### 3.3 Active/Passive Backoff-time

The two fixed backoff-times for each link are calculated. First, the number of hosts $T_{ij}$ using link $l_{ij}$ for the Internet access, and the link priority $p_{ij}$ are calculated by the following procedure:

(1) Initialize $T_{ij}$ by 0.

(2) Add the number of hosts associated with $AP_k$ if the route between GW and $AP_k$ includes $l_{ij}$ for $k = 1, \cdots, N$.

(3) Sort every link in descending order of $T_{ij}$ where the tiebreak is resolved by the number of links relaying packets of the link.

(4) Assign $p_{ij}$ for $l_{ij}$ by the sorted order.

Then, the two fixed backoff-times for each link are given by using the link priority. The active backoff-time $ta_{ij}$ and the passive one $tp_{ij}$ for link $l_{ij}$ are given by:

$$\begin{aligned} ta_{ij} &= p_{ij} \times \delta \\ tp_{ij} &= (P + p_{ij}) \times \delta \quad (3) \end{aligned}$$

where $\delta$ represents the unit backoff-time, and $P$ does the largest priority among the links.

## 4. Implementation of CSMA-FBS Method

In this section, we describe our implementation of the CSMA-FBS method on QualNet.

### 4.1 Actual Activation Rate

The actual activation rate for each link is obtained by dividing the number of actually transmitted packets with the number of possibly activating chances in the link:

$$ra_{ij} = \frac{pn_{ij}}{ac_{ij}} \quad (4)$$

where $ra_{ij}$ represents the actual activation rate for link $l_{ij}$ that transmits packets from $AP_i$ to $AP_j$ ($i = 1, \cdots, N$ and

$j = 1, \cdots, N$), $pn_{ij}$ does the number of packets that have been successfully transmitted through link $l_{ij}$, and $ac_{ij}$ does the number of possibly activating chances of link $l_{ij}$.

In the CSMA protocol, $ac_{ij}$ is hard to be obtained. One reason is that unlike the TDMA protocol where the link activations are synchronized by a single clock, the timing of counting the number of activating chances is not clear in the CSMA protocol. Another is that the link activation chances resulting in transmission failures should not be counted, because they are not considered in the calculation of the target activation rate.

In our implementation, we neglect the effect of transmission failures for simplicity. Thus, $ac_{ij}$ is counted every time $AP_i$ detects the opening of the channel where no node is using the same channel. Then, $pn_{ij}$ is counted every time link $l_{ij}$ starts transmitting a packet, where the success or failure is not considered. In QualNet, we add a necessary variable *dot11−>chance* in the function:
*MacDot11AttempToGoIntoWaitForDifsOrEifsState*
for $pn_{ij}$, and increase the value every time this function is called. Then, for $ac_{ij}$, we get the value from the variable *dot11->pktsToSend*. By using two variables *node->nodeId* and *dot11->currentNextHopAddress*, we obtain the link index $ij$ of link $l_{ij}$.

### 4.2 Backoff-time Modification

For very crowded links that can often happen around the GW in WIMNET, even different backoff-times among the links in the CSMA-FBS method cannot avoid collisions of interfered links due to propagation delays in wireless links. In such situations, the difference of backoff-times among links should be enlarged to further stagger their transmission timing. Besides, the waiting time before starting the transmission should be long enough to detect activations of conflicting links as in [12]. Therefore, any backoff-time is randomly selected between the minimum and the maximum that satisfy the constraints for the backoff-time in the CSMA-FBS method:

- Any active backoff-time must be smaller than any passive backoff-time.
- The backoff-time for a link with the higher priority must be smaller than that for a link with the lower priority.

Actually, the active backoff-time $ta_{ij}$ for link $l_{ij}$ with the priority $p_{ij}$ are given by:

$$\begin{aligned} amin_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{p_{ij}-1}{P}\right), \\ amax_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{p_{ij}}{P}\right), \\ ta_{ij} &= rand\left[amin_{ij}, amax_{ij}\right], \end{aligned} \tag{5}$$

and the passive backoff-time $tp_{ij}$ is given by:

$$\begin{aligned} pmin_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{P+p_{ij}-1}{P}\right), \\ pmax_{ij} &= CW_{\min} \cdot \left(2^{m-1} + 2^{m-2} \cdot \tfrac{P+p_{ij}}{P}\right), \\ tp_{ij} &= rand\left[pmin_{ij}, pmax_{ij}\right]. \end{aligned} \tag{6}$$

The number of consecutive transmission failures $m$ is saturated by 6. Once these backoff-times are generated, they are fixed subsequently in our implementation.

For the implementation in QualNet, we added the above-mentioned procedures in the function
*MacDot11StationSetBackoffIfZero*.

## 5. Evaluation by Simulations

### 5.1 Simulation Environment

For evaluations of our implementation of the CSMA-FBS method, we prepare three network topologies with static routing in Figure 3, namely, 1) Line, 2) Grid 5x3, and 3) Grid 3x3. The IEEE802.11b protocol is adopted for any node where the nominal bit-rate is $5.5 Mbps$ and the nominal wireless range is $250m$.

Each host performs CBR as a real-time UDP application and FTP as a TCP application. For CBR, 20 packets are transmitted from the source node to the GW for each second, where the packet size is changed from 160 bytes to 2560 bytes. For FTP, files with 160 bytes to 2560 bytes are transmitted from the source host to the GW at every 0.05 sec. The network simulation is executed for 30 min., and the average result throughout the simulation is used in evaluations. The simulation environment is summarized in Table 1.

表 1: Simulation environment.

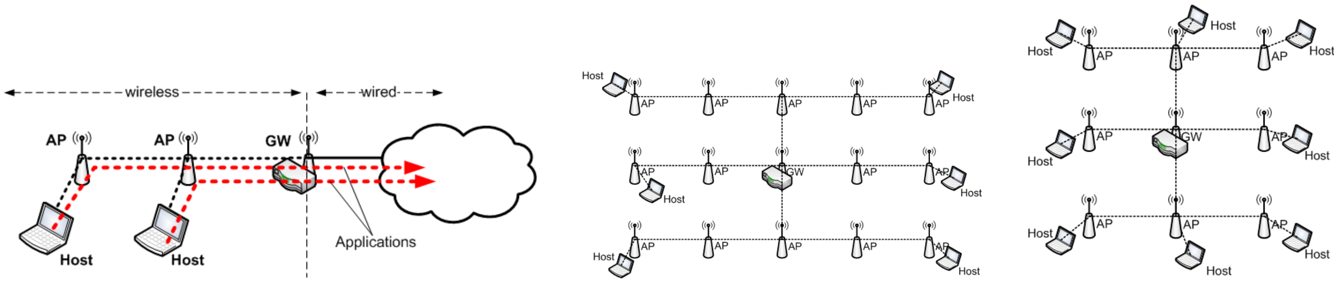
| **Parameter** | **Value** |
|---|---|
| Interface | IEEE802.11b |
| Nominal bit-rate | 5.5 Mbps |
| Channel Frequency | Backbone: 2.484 GHz<br>Host: 2.412, 2.437, 2.482 GHz |
| Network simulation time | 30 min. |
| Application | CBR for UDP<br>FTP Generic for TCP |
| packet rate for CBR | 20 packets/sec |
| packet size for CBR | 160, 320, 640, 1280, 2560 bytes |
| File size for FTP | 160, 320, 640, 1280, 2560 bytes |

### 5.2 Performance Evaluation for Real-time Application

First, we evaluate the performance improvement by the CSMA-FBS method from the conventional CSMA/CA method in a real-time application using CBR.

#### 5.2.1 Throughput

First, we compare the throughput between two methods when only CBR is used. Figure 4 shows the throughput where the packet size is changed from 160 bytes to 2560




(a) Line (b) Grid 5x3 (c) Grid 3x3

Fig 3: Simulated network topology.

bytes. This result indicates that as the traffic load is low at 160 bytes or 320 bytes, their throughputs are similar, and when the traffic load is high at 1280 bytes or 2560 bytes, the CSMA-FBS method improves the throughput by about 10% from the conventional one.

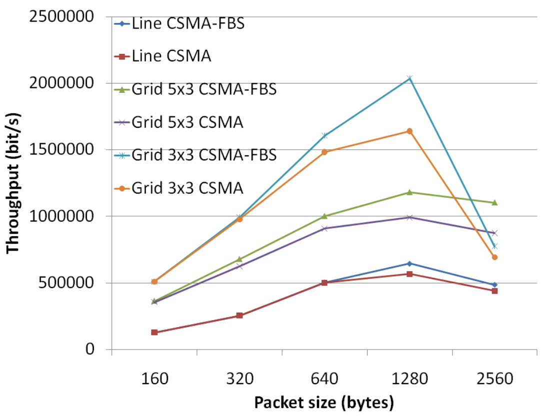



Fig 4: Throughput.

### 5. 2. 2 Packet loss

Then, we compare the packet loss during communications between them. Figure 5 shows the number of lost packets for the different packet size. The result indicates that as the traffic increases, the packet loss increases in both methods, and the CSMA-FBS method can reduce it. We note that packets are lost at the intermediate (relay) nodes, but not at sources.

### 5. 2. 3 End-to-end delay

Then, we compare the end-to-end delay from the source (host) to the destination (GW) between them. Figure 6 shows the average delay from one host to the GW among all the hosts and packets for the different packet size. The result indicates that as the traffic increases, the delay increases in both methods, where the CSMA-FBS method can reduce it by about 10%.

### 5. 2. 4 Average queuing time

Then, we compare the queuing time at a node between them. Figure 6 shows the average queuing time among all the nodes and packets for the different packet size. The result indicates that as the traffic increases, the queuing time increases in both methods, where the CSMA-FBS method can reduce it by about 10%.

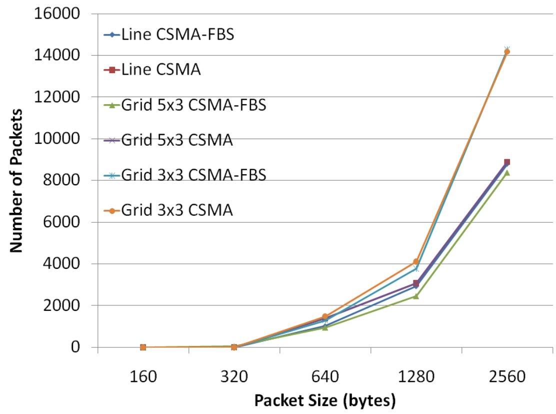



Fig 5: Number of lost packets.

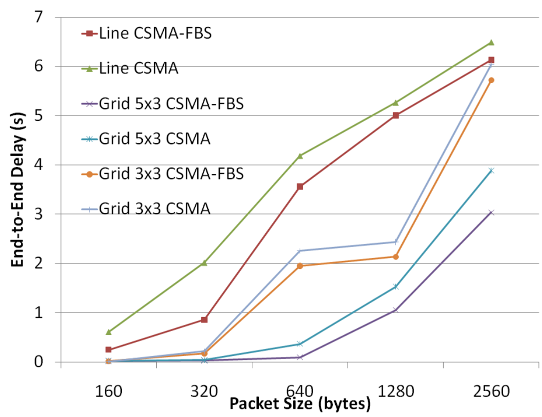



Fig 6: End-to-end delay.

## 5. 3 Fairness Evaluation for TCP Application

In WIMNET using the conventional CSMA/CA method, it has been observed that hosts closer from the GW in terms of hop counts dominate more bandwidth than hosts far from the GW. Thus, a host may receive unfair services depending on the location in WIMNET in terms of the hop count from the GW. This unfairness is another serious problem in WIMNET.

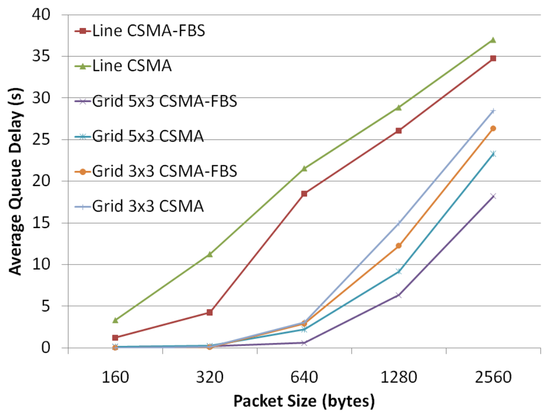



Fig 7: Average queuing time.

In order to evaluate the improvement in this unfairness by the CSMA-FBS method, we observe the difference between the highest throughput and the lowest throughput among the hosts when all of them are executing FTP. Figure 8 shows the highest and the lowest throughputs among the hosts for each topology for the different packet size. The results indicate that the CSMA-FBS method reduces the difference between them in any instance by lowering the highest throughput and raising the lowest throughput. Thus, the CSMA-FBS method can contribute to the improvement of the unfairness problem in WIMNET.

## 6. Conclusion

This paper presented an implementation of the CSMA-based Fixed Backoff-time Switching (CSMA-FBS) method for wireless mesh networks on the QualNet simulator, and evaluation results through simulations in three network topologies. The performance comparisons between the CSMA-FBS method and the conventional CSMA/CA method in the IEEE 802.11 protocol confirm the superiority of our method in the throughput, the packet loss, the delay, and the fairness. Our future works include the refinement of actual activation rate and backoff-time calculations, and the implementation of the CSMA-FBS method on hardware for evaluations in real networks.

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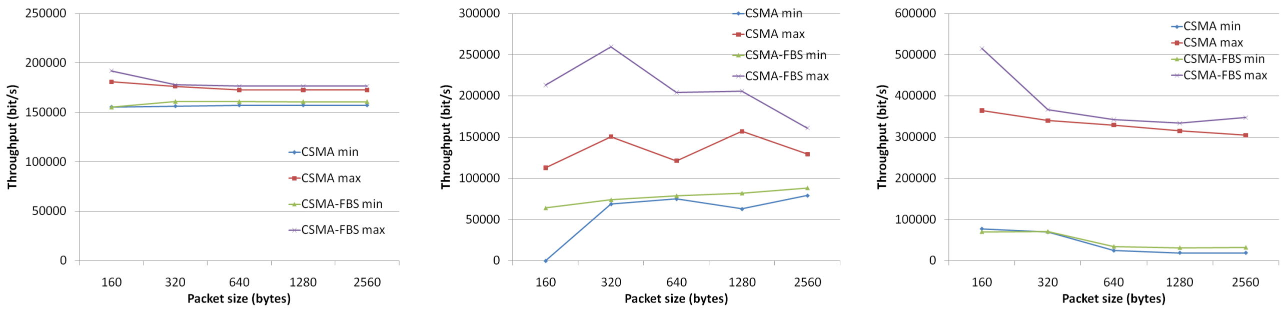


(a) Line　　(b) Grid 5x3　　(c) Grid 3x3

Fig 8: Fairness for TCP application.