Dynamic Contention Window Selection Scheme to Achieve a Theoretical Throughput Limit in Wireless Networks: A Fuzzy Reasoning Approach

Jenhui Chen and Wenchiao Wu
Department of Computer Science and Information Engineering,
Chung Gung University, Gueishan, Taoyuan, Taiwan 333, R.O.C.
Email: jhchen@csie.cgu.edu.tw

Abstract— **In wireless local area networks (WLANs), the IEEE 802.11 medium access control (MAC) protocol has been the main element that determines the efficiency of sharing the limited communication bandwidth of the wireless channel. The performance of the IEEE 802.11 protocol could be improved by using an appropriate turning of the backoff algorithm to approach a theoretical throughput limit. However, in real case, a mobile node would not exactly know the information of network and load configurations (e.g., number of active nodes). Hence, in this paper, we propose a novel and efficient selection of backoff window size mechanism using fuzzy reasoning approach named the fuzzy backoff controller (FBC) to achieve the system throughput limit. This mechanism is developed on the following ideas: by observing the busy degree of medium and the number of neighbors, the proposed FBC could generate a proper backoff window thus reduce the probability of collisions and enhance the throughput. The obtained simulation results show that the proposed FBC not only significantly improves the performance of the IEEE 802.11 protocol but also achieves the fairness of accessing medium between nodes well.**

I. INTRODUCTION

The IEEE 802.11 wireless local area networks (WLANs) standard includes a basic distributed coordination function (DCF) and an optional point coordination function (PCF) [4]. Under DCF mode, if a station has a packet to transmit, it will check the medium status by using carrier sense multiple access with collision avoidance (CSMA/CA) mechanism. If the medium is idle for a DCF inter-frame space (DIFS), the transmission will be performed instantly. Otherwise, the medium is sensed busy (either immediately or during the DIFS), it will persist in monitoring the medium until the medium is measured idle for a DIFS. At this point, the node generates a random backoff interval before transmitting (this is the *collision avoidance* feature of the protocol) to decline the probability of collision with packets being transmitted by other nodes. However, in IEEE 802.11 medium access control (MAC) protocol, the contention window (CW) size is fixed and would not reflect the real environment accordingly. As a result, the performance of IEEE 802.11 would be degraded while in varying environment.

It is observed that once the number of active nodes increases, the throughput of IEEE 802.11 will degrade significantly because of the excessively high collision rate. In order to increase the throughput of a distributed contention-based MAC protocol, many collision resolution methods have been studied and proposed in [1], [3], [6], [7], [8]. In [8], authors proposed a MAC protocol called fast collision resolution (FCR) to improve the performance of wireless transmission in WLANs. The FCR follows the IEEE 802.11 protocol except modifying the backoff mechanism. There are three principal differences between FCR and IEEE 802.11 MAC protocol. First, the initial CW size of FCR starts at the minimum value ($CW_{\min}$ = 4 slots) and is doubled up when encoubtering a collision until reaching the maximum value ($CW_{\max}$ = 2048 slots). Secondly, FCR decreases the backoff timer exponentially fast when a prefixed number of consecutive idle slots are detected (seven slots). Thirdly, the current CW size would be doubled and randomly selected again whenever the transmitted data collides with other nodes or the medium is sensed busy.

Although FCR performs higher throughput, it would cause seriously unfairness phenomenon. This is because that FCR defers nodes who stay in the backoff states by doubling their contention window size when any collision or successful transmission is detected. As a result, the node that successfully transmits data would always gain the channel access right by its smaller contention window size. This result would not be acceptable. In [8], the FS-FCR algorithm was proposed to conquer this problem. FS-FCR uses the same operations of the FCR algorithm, except that, if a station reaches its packet transition limit in its packet transmission period, the station will set its CW size to the maximum value of CW_{max} (CW_{max} is 2048 slots). Since FS-FCR have the property of high fairness, its throughput could not be as good as FCR. Having good fairness or high throughput is really a tradeoff. Besides, up to now, although many innovative distributed contention-based MAC protocols have been proposed, very few MAC protocols satisfy all desirable properties such as high throughput and fairness as well as maintaining the simplicity of implementation in real world.

Therefore, in this paper, we provide original contributions as we first use the fuzzy reasoning approach to design an appropriate dynamic CW generator named *fuzzy backoff controller* (FBC), which could determine an adequate CW size according to the observation of 1) the channel access ratio of the medium and 2) the number of active nodes around itself. Furthermore, instead of increasing CW size passively when encountering a

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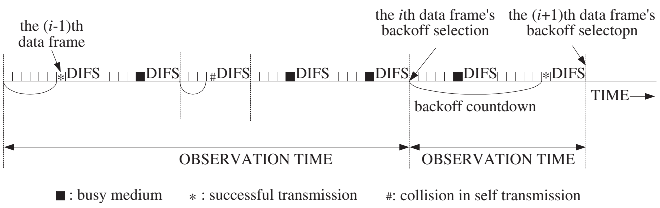

Fig. 1. An illustration of observation time in FBC. Once the node gets into backoff procedure and sets its backoff timer, observation time must be reset (accumulated from zero), but if the backoff timer did not make the transmission success, observation time will not be reset.

collision, the FBC would dynamically adjust the CW size to adapt current state in varying environment.

The remainder of this paper is organized as follows. Section II describes the detailed operations of proposed FBC scheme. The performance evaluation of FBC are presented and investigated in Section III. Finally, we give some conclusions and remarks in Section IV.

II. The Fuzzy Backoff Controller

A. Observation Time

The FBC needs the information of observing the channel status to estimate an appropriate CW size for contending the channel access. But it is a thorny problem that how long the observation time should be taken to monitor the channel status, which represents the network conditions relatively, since the outcome of observation would not reflect the real network conditions if a longer observation window is taken, and vice versa. Consider the illustration of channel access in Fig. 1, the observation time of the ith data frame in FBC is defined as the time interval between the backoff countdown period of the $(i-1)$th data frame and the time that starting to select a CW size of the ith data transmission. The observation time would be expended and continued in counting when the node encounters a collision in its data transmission. After its successful transmission, the new observation time will be refreshed and gets start from the time that latest choosing backoff countdown to present.

B. The Fuzzy Model of FBC

In our FBC, we use the zero-order Sugeno fuzzy model as our FBC's model. The Sugneo fuzzy model was proposed by Takagi , Sugeno, and Kang[9], [10] in an effort to develop a systematic approach to generating fuzzy rules from a given input-output data set. A typical fuzzy rule in a Sugeno fuzzy model has the form if x is A and y is B then $z = f(x, y)$ where A and B are fuzzy sets in the antecedent, while $z = f(x, y)$ is a polynomial in the input variables x and y. The $f(x, y)$ can be appropriately described the output of the model within the fuzzy region specified by the antecedent of the rule. The resulting fuzzy inference system is called *zero-order* Sugeno fuzzy model if the $f(x, y)$ is a zero-order polynomial (i.e., constant). The output of a zero-order Sugeno fuzzy model is a smooth function of its input variables as long as the neighboring membership functions (MF) in the antecedent have enough overlap. The smooth characteristic of the zero-order Sugeno fuzzy model is in our expected, this is why we adopt zero-order Sugeno fuzzy model.

TABLE I

The IF-THEN fuzzy rule of FBC

1.	IF α is NB and β is S THEN CW size = K_1.
2.	IF α is NB and β is M THEN CW size = K_6.
3.	IF α is NB and β is L THEN CW size = K_7.
4.	IF α is SO and β is M THEN CW size = K_3.
5.	IF α is SO and β is S THEN CW size = K_7.
6.	IF α is SO and β is L THEN CW size = K_8.
7.	IF α is B and β is S THEN CW size = K_6.
8.	IF α is B and β is M THEN CW size = K_9.
9.	IF α is B and β is L THEN CW size = K_{10}.
10.	IF α is VB and β is S THEN CW size = K_9.
11.	IF α is VB and β is M THEN CW size = K_{10}.
12.	IF α is VB and β is L THEN CW size = K_{10}.

C. Input and output of FBC

The FBC needs two input parameters for further inference: the busy-degree α and the number of active nodes β. The busy-degree is measured as the times that medium is sensed busy divided by the times that medium is sensed busy plus idle slots and given by

$$\alpha = \frac{\text{the times of busy}}{\text{Obsertvation Time}}$$

The number of active nodes is measured by monitoring each transmitted data frame within the transmission range. The node checks out the transmitter address (TA) field in the MAC header and records it into their active neighbor table. The output of the FBC is the CW size.

D. Fuzzification

Once the two variables, α and β, are obtained by FBC, they are fuzzified against the appropriate linguistic fuzzy sets. The parameter α is interpreted as the linguistic variables, {not busy (NB), so so (SO), busy (B), very busy (VB)}, as shown in Fig. 2(a). The parameter β is interpreted as the linguistic variables, {small (S), middle (M), large (L)}, as shown in Fig. 2(b). Since MFs of input values: the *busy degree* and the *number of active nodes* had been mapped out, we need to establish the MFs of output value: CW size. Follow the zero-order Sugneo Fuzzy Model, the fuzzy rules has the form if x is $\mathcal{A}$ and y is $\mathcal{B}$ then $z = k$, where k is a constant, so all consequences MFs are represented by a singleton spikes as shown in Fig. 2(c).

E. Rule Evaluation

Rule evaluation is to take the fuzzified inputs and apply them to the antecedents of fuzzy rules. In our FBC, the fuzzy operator AND is used to obtain a single number that represents the result of antecedent evaluation. This number is then applied to the consequence MF. Tab I shows fuzzy rules of FBC and Fig. 3 is the overall intput-output surface of FBC.

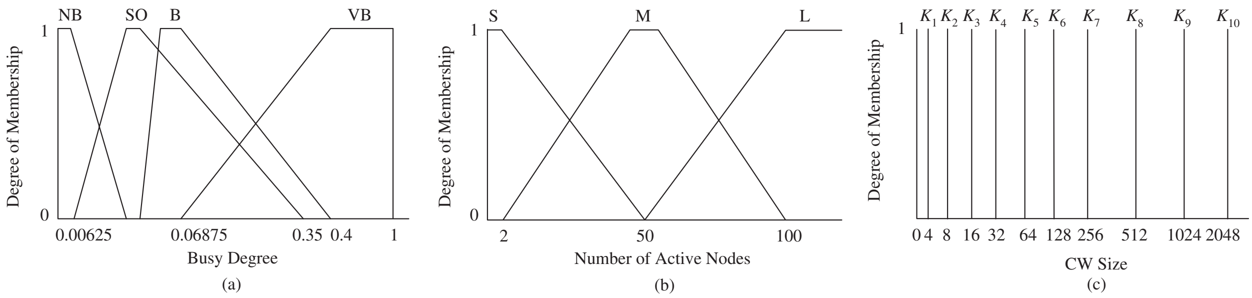

Fig. 2. (a) MFs of busy degree, we define all of them are trapezoidal MFs, the MF of linguistic value NB is defined by trapezoid (0, 0, 0.00625, 0.0375), the MF of linguistic value SO is defined by trapezoid (0.00625, 0.0375, 0.05625, 0.35), the MF of linguistic value B is defined by trapezoid (0.05625, 0.06875, 0.1, 0.4), and the MF of linguistic value VB is defined by trapezoid (0.06875, 0.35, 1, 1). (b) MFs of the term set T(the number of active nodes). The MF of linguistic value S is defined by trapezoid (0, 0, 2, 50), the MF of linguistic value M is defined by trapezoid (2, 45, 55, 100), and the MF of linguistic value L is defined as an open right MF. (c) The MFs of CW size. We devide CW size into ten levels here.

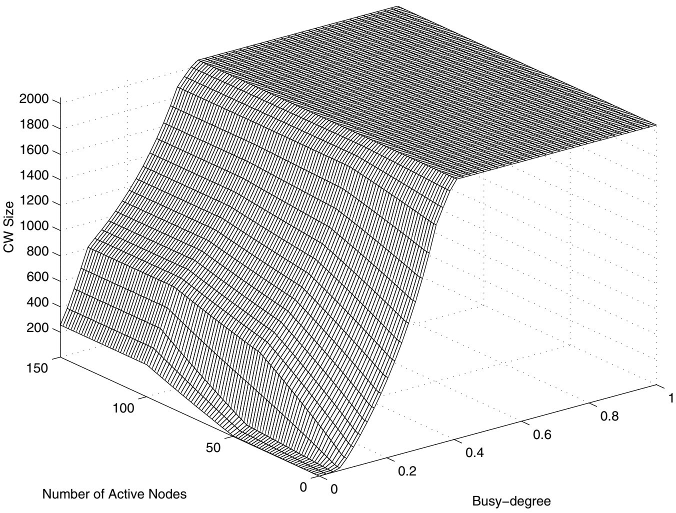

Fig. 3. The overall input-output surface for FBC.

F. Aggregation of the Rule Outputs

Aggregation is the process of unifying the outputs of all rules. In other words, we take the MFs of all rule consequences into a single fuzzy set. Thus, the input of the aggregation process is the list of consequence MFs, and the output is one fuzzy set for output variable.

G. Defuzzification

The input for defuzzification process is the aggregate output fuzzy set and the output is a single number. FBC defuzzify the aggregation of the rule output to a single output via weighted average method as the following formula:

$$\frac{W_1 \times K_1 + W_2 \times K_2 + \ldots + W_n \times K_n}{W_1 + W_2 \ldots + W_n}$$

Fig. 4 shows an example of the operations of our proposed FBC, where the busy-degree is 0.02 and the number of active nodes is 2. The inputed busy-degree (=0.02) has the degree 0.56 in NB and the degree 0.44 in SO. The inputed the number of activr nodes (=2) has the degree 1 in S. Then evaluate the rules to find the corresponding rules, and aggregate the rule

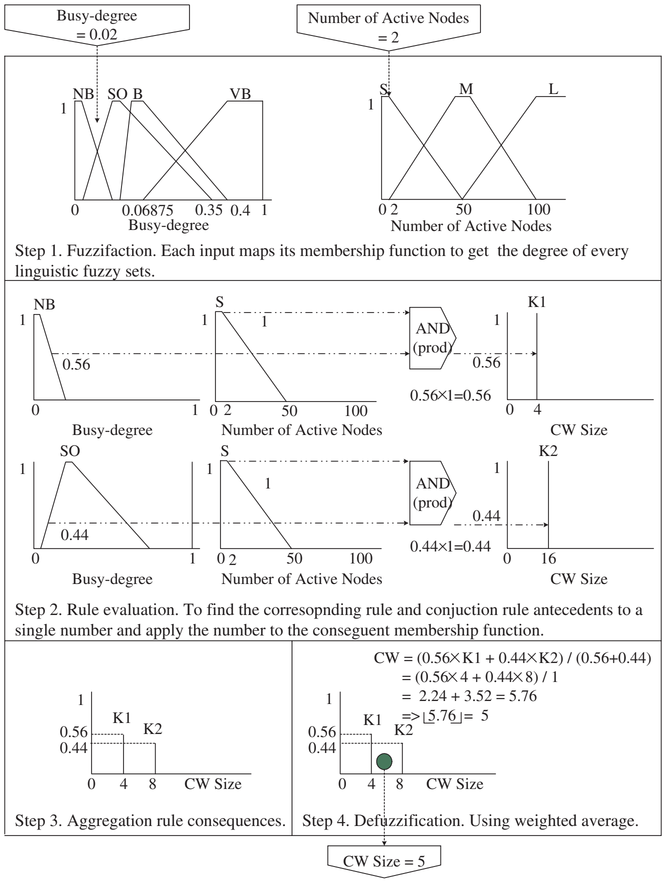

Fig. 4. An example of proposed FBC operations, the inputed busy-degree is 0.02 and the number of active nodes is 2.

consequences. Finally, defuzzify the overall output to a single value.

III. Simulation Model and Results

In this section, we present the simulation for the proposed FBC and the IEEE 802.11 using direct sequence spread spectrum (DSSS) specification. The parameters used in the simulations are shown in Table II. We use Possion distribution

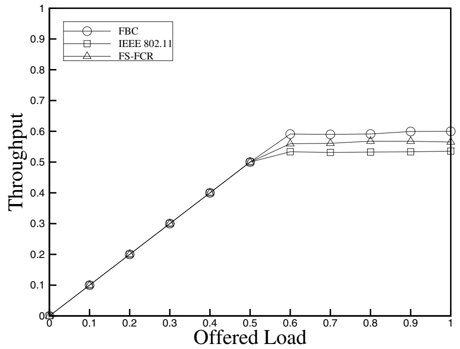

Fig. 5. The comparison of the FBC, IEEE 802.11, and FS-FCR in throughput while the number of nodes is 10 and the packet size is 500 bytes.

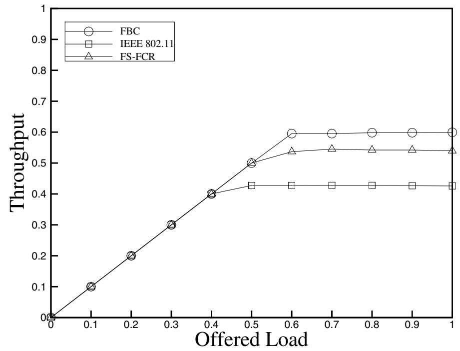

Fig. 6. The comparison of the FBC, IEEE 802.11, and FS-FCR in throughput while the number of nodes is 50 and the packet size is 500 bytes.

as traffic generator. All simulation are performed for 60 second simulation time.

TABLE II

PARAMETERS USED IN THE SIMULATION

Parameters	Values
aSlotTime	20 μs
aSIFSTime	10 μs
aDIFSTime	50 μs
aPreambleLength	144 μs
aPLCPHeaderLength	48 bits

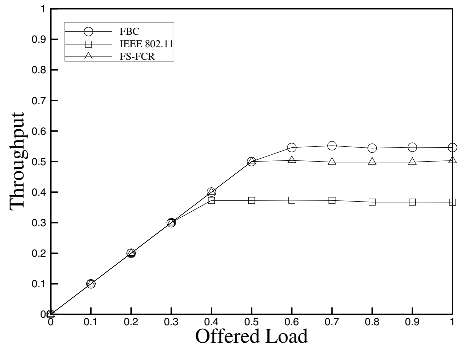

Fig. 7. The comparison of the FBC, IEEE 802.11, and FS-FCR in throughput while the number of nodes is 100 and the packet size is 500 bytes.

Fig. 5, Fig. 6, and Fig. 7 compare the throughput versus offered load of the IEEE 802.11, the FS-FCR, and the FBC when number of node is 10, 50, and 100 and the packet size is set 500 bytes, respectively. We can see that, from Fig. 5, Fig. 6, and Fig. 7, our proposed FBC improves the throughput of IEEE 802.11 since the fuzzy reasoning approach considers the network condition in advance to adjust its contention window size. The throughput of the FBC sustains about 0.6 whether in 10 nodes, 50 nodes or 100 nodes conditions. On the contrary, the throughput of IEEE 802.11 will decrease as increasing the number of neighbors. This is because that the initial CW size of IEEE 802.11 always starts at 32 slots and increases its CW size exponentially until reaching the maximum CW size 1024. The inadequate backoff window selection scheme would not reflect the real network conditions and improve the performance of transmission in WLANs. We also note that the FBC outperforms FS-FCR whether the number of neighbors is few or large. This is because that the transmission throughput of FS-FCR would not take advantage of fast counting down the backoff to even though the FCR utilizes the method: fast countdown backoff to retrench the idle slots since the collision probability also increase when the number of nodes increases. On the contrary, the FBC gets the balance of idle slots and collision probability as the network conditions.

In Fig. 8, Fig. 9, and Fig. 10, we investigate the effect of packet size to the throughput when enlarging packet size to 1200 bytes. From Fig. 8, we can see that the throughput of our proposed FBC reaches about 0.8 when offered load is 0.8. This is because that the FBC could decrease the collision probability than other schemes. In the case of 50 nodes, since our methods forecasts the number of active nodes and busy degree by observing channel access status to get the proper CW size, the FBC even does well than the IEEE 802.11 about 20%. Even in the case of 100 nodes, the FBC outperforms the IEEE 802.11 about 25%.

Fig. 11, Fig. 12, Fig. 13 show the throughput of the FBC, IEEE 802.11, and FS-FCR by varying the packet size from 50 to 1250 bytes under different number of nodes. In Fig. 11, we could not see the obvious throughput difference between FBC, FS-FCR, and the IEEE 802.11 while packet size is small, but the gap becomes larger while the packet size is increased. This is because that when packet size is small, whether the FBC, FS-FCR or IEEE 802.11 has too much control overhead. This results show that the proposed FBC improves the throughput more as increasing the packet length and gets higher throughput enhancement in large nodes environment.

IV. CONCLUSIONS

In this paper, we designed a dynamic contention window selection mechanism named fuzzy backoff controller (FBC) to enhance the throughput in IEEE 802.11 WLANs. The FBC considered the medium status in advance to adjust CW size by time. The FBC got the balance between the collisions and idle slots well. Simulation results showed that the FBC is flexible and efficient mechanism to adapt dynamic wireless

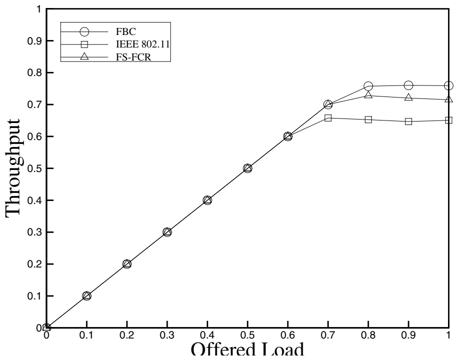

Fig. 8. The comparison of the FBC, IEEE 802.11, and FS-FCR in throughput for 10 nodes.

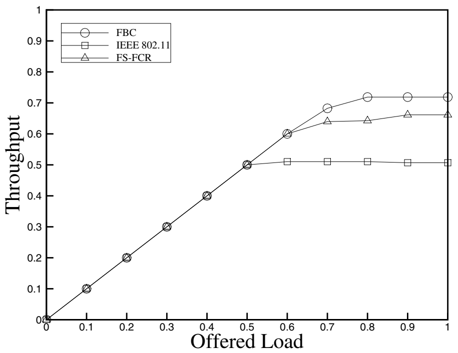

Fig. 9. The comparison of the FBC, IEEE 802.11, and FS-FCR in throughput for 50 nodes.

environment and get higher throughput than the ordinary IEEE 802.11 and FS-FCR.

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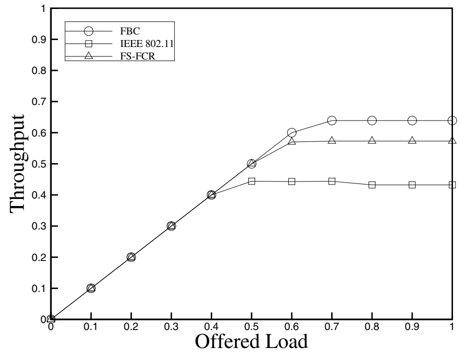

Fig. 10. The comparison the throughput of the FBC, IEEE 802.11, and FS-FCR for 100 nodes.

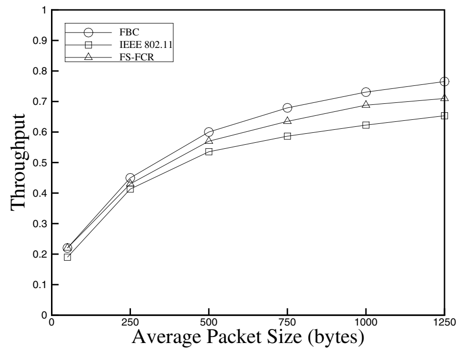

Fig. 11. The comparison of the throughput of the FBC, IEEE 802.11, and FS-FCR for 10 nodes.

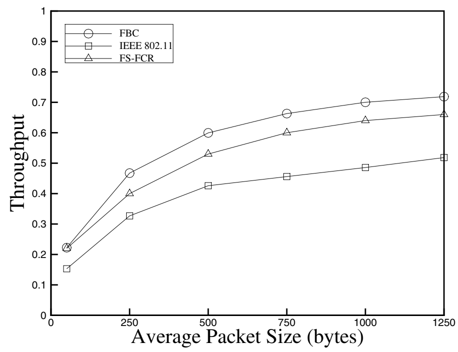

Fig. 12. The comparison of the throughput of the FBC, IEEE 802.11, and FS-FCR for 50 nodes.

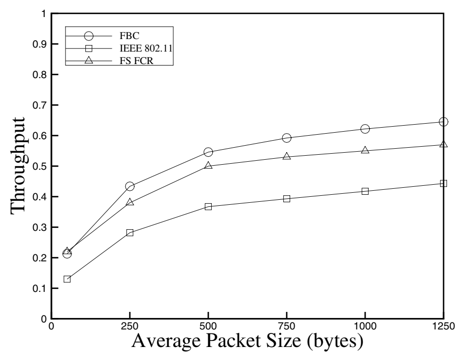

Fig. 13. The comparison of the throughput of the FBC, IEEE 802.11, and FS-FCR for 100 nodes.

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