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Fairness and Throughput Tradeoff in Ad hoc Networks

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Abstract

The use of IEEE 802.11 standard in ad hoc networks causes some performance problems as throughput and fairness tradeoff. The purpose of this article is to improve this tradeoff. The proposed approach is an improvement of IEEE 802.11 standard which is based on optimal contention window size and attribution of similar value contention window to all nodes. The proposed solution is validated by simulations using the simulation tool NS2 (Network Simulator 2). Our protocol is better than IEEE 802.11 standard and Miop protocol in terms of global throughput and its Jain's index is closed to 1.

Keywords: MANET, average throughput, fairness, contention window.

Introduction

The Ad hoc networks are characterized mainly by a dynamic topology and the lack of infrastructure. In these networks, the access to the channel is managed by protocols called MAC (Medium Access Control) protocols. IEEE 802.11 specifically DCF (Distributed Coordination Function) mechanism has been selected as standard MAC protocol for ad hoc networks. However, this standard presents some performance problems that result in an overall throughput decrease or in unfairness situations[1].

Several protocols have been proposed to solve these problems. Among them we can mention: Miop protocol, Idle Sense, GDCF (Gentle DCF)[2,3,4]. In Miop scheme, each node can estimate the channel utilization and the number of nodes competing by medium. The algorithm of the protocol is similar with IEEE 802.11's behavior, with the exception that when a collision occurs, all nodes use the same contention window size. Note that this protocol provides good channel access fairness, but the average throughput is not as better than Idle Sense one. Idle Sense depends on an estimate of the number of active stations in a network. The contention window of a station can be updated at any time when a specific number of transmissions occur, but it is only used for the next transmission attempt. GDCF meanwhile, preserve more approaches of the IEEE 802.11 standard. A node does not change its contention window after a successful transmission; that allows other nodes to have access to the medium. It is only after a specific consecutive number of transmissions attempts that the contention window is changed, that is to say, divided by two. However, most of these solutions do not either take into account the tradeoff between the medium access fairness and the average throughput or do not really improve the tradeoff[2].

This paper presents a new MAC protocol called FTMAC (Fairness and Throughput MAC protocol), design to improve the tradeoff between the overall throughput and fairness access in ad hoc networks. This protocol attribute for all nodes in a network, the same contention window after each transmission attempt. The rest of this paper is organized as follows. We present in section 2, the overview of our proposal. We present the results obtained from simulations in NS2 simulator in section 3, followed by a conclusion in section 4.

Methodology

Overview of the proposal: The principle of this proposal is based on different mechanisms which are the processes of sending a message, of successful transmission and failure transmission of a message. Figure-1 is a state machine illustrating the different steps.

Sending a packet: When a node has a new packet to transmit, it senses the channel activity. i. If the channel is sensed idle for a given period of time called DIFS, the node transmits the RTS packet to the channel. After sending this packet, a new size of the contention window is calculated and assigned to all nodes. It will be used at a subsequent transmission, if there is a need. ii. Otherwise, if the channel is sensed busy, the transmitter selects a random value between zero and the current size of the contention window, and this value is multiplied by the duration of a slot. After the release of the channel, the node starts a random contention period to minimize the packet collision probability. The contention counter is decremented as long as the channel is sensed idle, stopped when a transmission is detected, and resumed when the channel is sensed idle again for a period equal to a DIFS interval. The transmission only occurs when the backoff counter reaches the value zero.

When the destination receives the RTS frame, it will transmit a CTS frame after the SIFS interval, immediately following the reception of the RTS frame. The source node is allowed to transmit its packet if only it receives the CTS correctly.

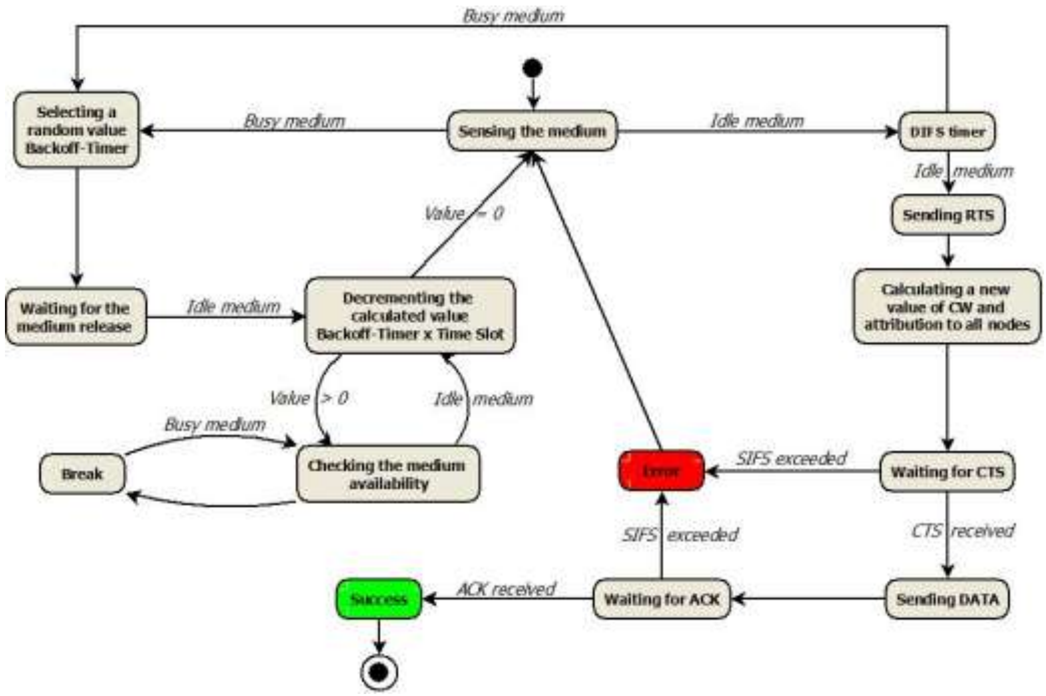

Figure-1
Principle of FTMAC protocol

Successful transmission: This procedure occurs if only the recipient receives the message and decodes it at the MAC layer. Then, it sends an acknowledgment (ACK packet) to the sender of the packet. Thereafter, the transmitter makes sure that the full message is received by the recipient. Otherwise, when the receiver cannot decode the packet and the sender does not receive an acknowledgment at the end of a SIFS period, the sender believes that the packet is lost or a collision occurred.

Transmission failed: We distinguish two (02) cases where this process can be achieved: i. If a transmitting station does not receive an acknowledgment (CTS packet) after sending the RTS packet and after a SIFS period; ii. If a transmitting station does not receive an acknowledgment (ACK packet) after sending the DATA packet and after a SIFS period. The transmitter assumes in these two (02) cases that the packet sent is lost or there was a collision. It returns the message, according to the submission process.

The principle of FTMAC is similar to the IEEE 802.11 protocol and Miop. Unlike IEEE 802.11, when there is a collision, the protocol as the protocol FTMAC Miop, allows all stations on a network to use the same contention window calculated at the end of each transmission attempt. The difference with the protocol Miop lies in the determination of the optimum size of the contention window to be assigned to the stations.

Determining the optimal size of the contention window: The optimal sizes of the contention window are determined from a standard optimization throughput based on probabilities. Consider the number of active nodes in an ad hoc network.

Probability of packet transmission: P_e is the probability that a node attempts to transmit in a given slot. When all stations use the same contention window, P_e is considered as a function of a window and is[5]:

$$P_e(CW) = \frac{2}{CW+1} \quad (1)$$

Throughput: D is the normalized throughput of the system that represents the optimal utilization of channel. It has been defined as the ratio between the period of use (transmission) of the medium and the expected contention duration[5]. To calculate the throughput, the following probabilities are expressed[3]:

Only one node must transmit on the channel, in the absence of all others for a successful transmission. Then, the probability of successful transmission if nodes want to access the medium is:

$$P_t = NP_e(1 - P_e)^{N-1} \quad (2)$$

The probability P_s of an idle slot is:

$$P_s = (1 - P_e)^N \quad (3)$$

The probability Pc that a collision occurs during a slot can be expressed as:

$$P_c = 1 - P_t - P_s \quad (4)$$

The throughput D is expressed as follows:

$$D = \frac{P_t s_d}{P_t T_t + P_c T_c + P_s T_s} \quad (5)$$

Time values of the throughput expression: These parameters depend on Physical and MAC layers, in accordance with IEEE 802.11 standard extensions [3]. The values presented here are specific to 802.11b. T_t represents the average duration of a transmission and is $1363\ \mu s$; T_s defines the time slot that is to say the duration of a slot is $20\ \mu s$; T_c is the average duration of a collision. This duration is the same as that of a transmission $1363 \mu s$; sd corresponds to the average size of a given frame. It is $1500\ bytes$.

The normalized throughput D must be maximized in order to find the optimal size of the contention window.

Maximizing throughput is equivalent to minimizing the following cost function[3] (equation-6):

$$Cost(P_e) = \frac{\frac{T_c}{T_s} P_c + P_s}{P_t} \tag{6}$$

By replacing the expression probabilities and deriving the equation-6 with respect to the probability, we obtain the equation-7:

$$1 - NP_e - \left(1 - \frac{T_s}{T_c}\right)(1 - P_e)^N = 0 \tag{7}$$

The solution of equation-7 by the numerical analysis method of Newton-Raphson, we obtain the optimal probability for which the normalized throughput is maximized. The optimal size of the contention window is determined by equation-8.

$$Peopt = \frac{2}{CW_{opt} + 1} \tag{8}$$

Results and Discussion

To study and analyze the operation and behavior of our proposal, we used Network Simulator 2 (NS2). Simulations have been made to show a comparison between our proposal, IEEE 802.11 and Miop protocol. We have simulated configurations with a different number of stations (3, 6, 9, 15, 30, 45). Each transmitting node has always a frame to transmit. The purpose of these simulations is to see the behavior of our proposal when the number of nodes increases. The parameters used in the simulations are described in table-1.

Table 1
Simulation parameters

Parameters	Values
Data rate	$11\ Mbps$
Type of traffic	CBR
Packet size	$1500\ octets$
Time slot	$20\ \mu s$
SIFS	$10\ \mu s$
DIFS	$50\ \mu s$
EIFS	$364\ \mu s$

Average throughput: The overall throughput of a network is the average of the throughput of all active nodes in the network [3]. The throughput of our proposal, in all simulations is better than IEEE 802.11 standard and Miop protocol ones.

Medium access fairness: The comparisons between the three (03) protocols, in terms of fairness in networks of 3 and 45 stations are presented respectively in figure-3 and figure-5. We evaluated the fairness by using the Jain fairness index [6, 7].

Figure-2 compares the average throughput achieved by each protocol, after each simulation based on the number of stations in the network. These figures show that our proposal presents a better Jain index than the IEEE 802.11 standard and a very close index to Miop's one (figure-4 shows an enlargement of the Jain index for a network of 3 stations).

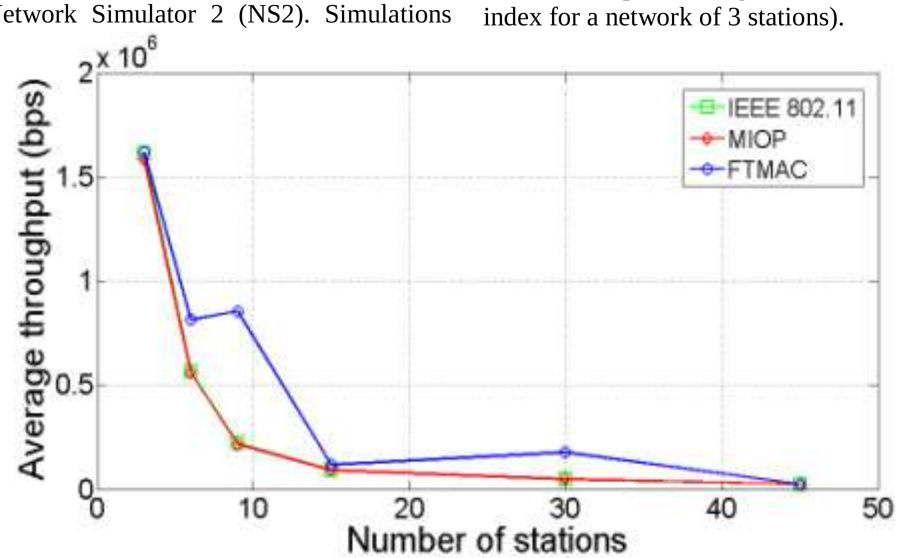

Figure-2
Average throughput for different network nodes.

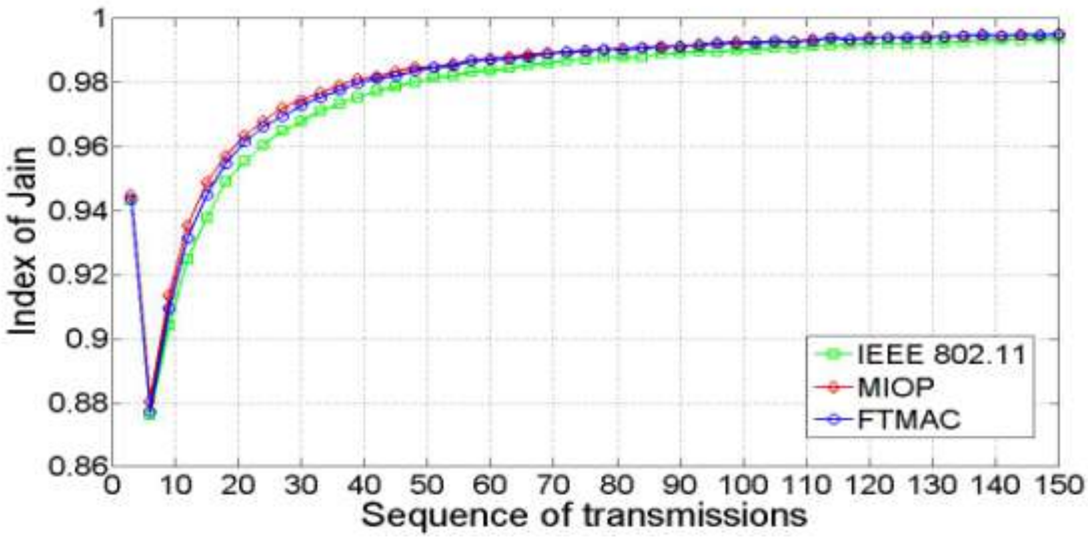

Figure-3
Jain's index for a network with 3 stations

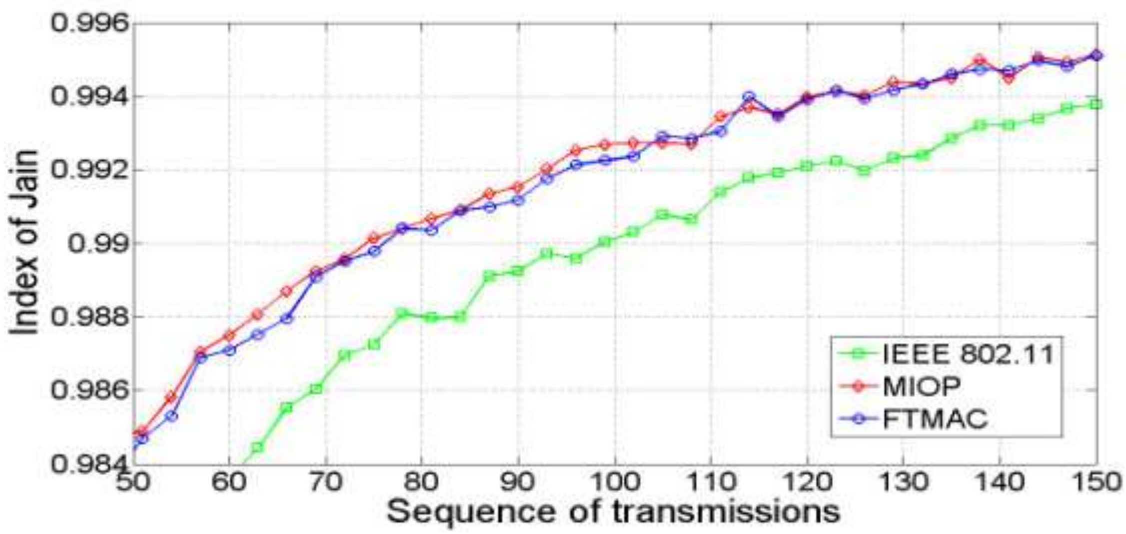

Figure 4
Enlargement of the Jain's index for a network with 3 stations in the interval [0.984; 0996]

The index of Jain of IEEE 802.11 standard in figure-3 is very different from the one in figure-5. This decrease confirms the unfairness of the standard when the number of stations increases. The fairness slightly lower of our protocol compared to the Miop's one is due to the improvement of the overall throughput of FTMAC compared to other protocols and, therefore, the improvement of the tradeoff between throughput and fairness.

Packet delivery ratio: The Packet Delivery Ratio is the ratio between the number of packets received by recipients in the network and the number of packets transmitted in the network. Figure-6 shows the rate for the three (03) protocols. The packet delivery ratio of FTMAC is superior to the IEEE 802.11 one and is around the Miop one. The average rate of FTMAC, the IEEE 802.11 and Miop protocol are respectively 97.29 %, 90.66 % and 97.41 %.

The throughput of our proposal in all simulations is much higher than the throughput of IEEE 802.11 and Miop protocol. The access fairness of our protocol, is better than the standard's one, especially when the number of active stations increases. But the Jain's index of FTMAC and Miop protocol are much closed.

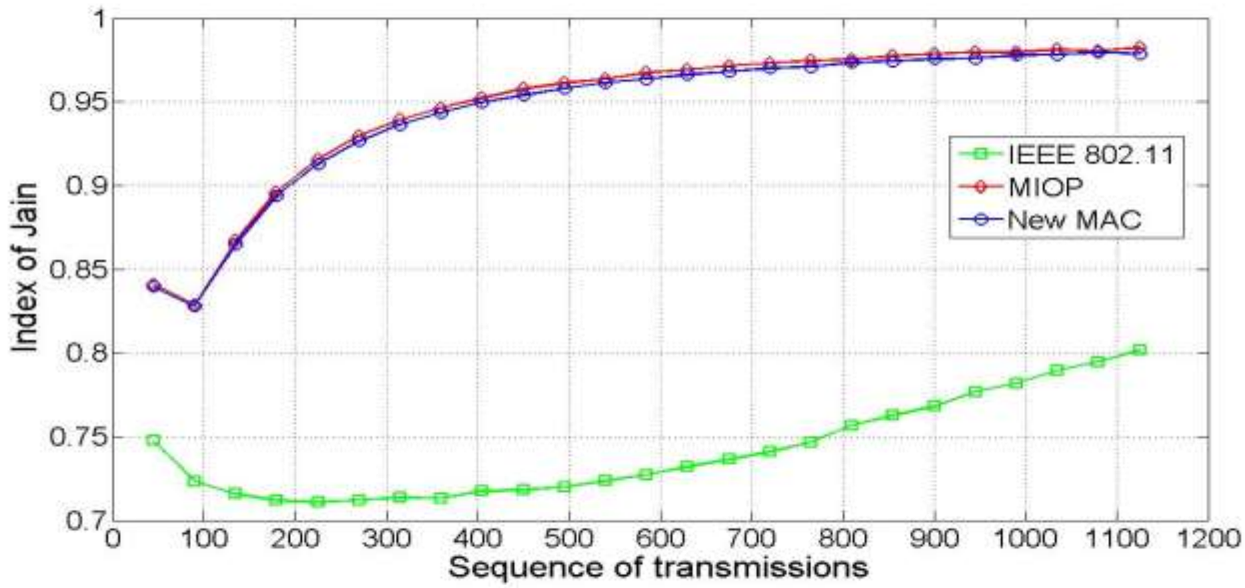

Figure 5
Jain's index for a network with 45 stations

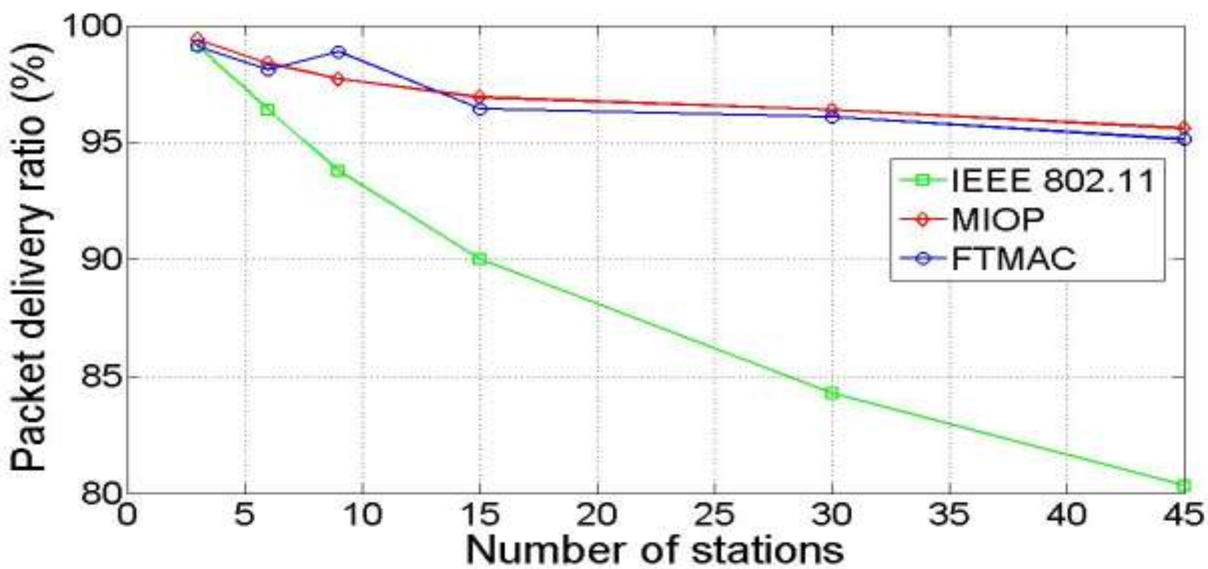

Figure 6
Packet delivery ratio for different network nodes

To this end, we found that the index of Jain of FTMAC is close to that of Miop and close, respectively, 8.10^{-4} and 2.10^{-3} for the Jain index networks 3 and 45 stations. This confirms that our protocol has a fair access to the channel substantially equal to that Miop. In addition, our proposal is reliable, with 97.29 % of packets successfully delivered.

Overall, our proposal manages better the fairness-throughput tradeoff than IEEE 802.11 standard and Miop protocol.

Conclusion

In this paper, we proposed a new MAC protocol, FTMAC, improving the tradeoff between fairness and throughput in ad hoc networks. This protocol is a modification of the principle of IEEE 802.11 DCF mechanism; it is more precisely based on the contention window size according to the number of stations in a network. The evaluation of our proposal with the NS2 simulator shows a significant improvement of the fairness-throughput tradeoff compared to the IEEE 802.11 standard and Miop protocol, and an average packet delivery of 97.29 %.

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