Fairness and QoS in Ad-Hoc Networks

Amine BERQIA
ILAB, FCT-DEE
Universidade Algarve
Portugal
bamine@ualg.pt

Blaise ANGOMA
Laboratoire LAGI
ENSIAS
Morocco

Noufissa MIKOU, Youssef DEHBI
Laboratoire LE2I
Université de Bourgogne
France
{nmikou,youssef.dehbi}@u-bourgogne.fr

Abstract—**IEEE 802.11 is a standard for Wireless Local Area Networks. Recent works show that this standard has bad performances in ad-hoc mode. In this paper, we analyze the algorithm used by the standard to manage contentions and propose an alternative algorithm to resolve fairness issues observed in the Hidden terminal scenario. Using NS-2 simulator we show that our algorithm has better throughput management based on fairness between nodes under QoS constraints required by each node.**

Keywords-IEEE 802.11, Ad-hoc, Mobility, QoS, Fairness

I. Introduction

Wireless networks have become very popular because they can be used in many environments (home, offices, airports…). They can also be useful in emergency cases due to their rapid setup in ad-hoc mode.

In the IEEE 802.11 WLAN (Wireless Local Area Network) standard, the Distributed Coordination Function (DCF) method is implemented at the Medium Access Control (MAC) Layer in order to manage the access to the communication channel. However, it has bad management of throughput when it deals with many nodes in contention. Indeed, even if that contention is resolved by the back-off algorithm, in some network configurations the channel is attributed almost totally to some nodes while others have very small throughput. This is a fairness issue that decreases IEEE 802.11 performance.

The back-off algorithm has then to be adapted to assure a fair access for all nodes under QoS constraints.

In this paper, we show the weaknesses of the back-off algorithm in an IEEE 802.11 environment and we propose an improvement to solve the fairness issue in the case of hidden terminals.

The rest of this paper is organized as follows: First, we present ad-hoc networks and IEEE 802.11 standard. Then we present different issues. Finally we propose an algorithm to manage contentions rather than the standard algorithm and using NS-2 simulation results, we compare performances of both algorithms.

II. IEEE 802.11 Ad-Hoc Networks

An ad-hoc network is a set of stations having a wireless LAN card without the presence of any access point, unlike infrastructure networks.

As other 802.x standards, IEEE 802.11 covers both physical layer and data link layer. IEEE 802.11 MAC layer uses the Distributed Coordination Function (DCF) for accessing the medium in ad-hoc mode.

DCF is basically a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism which works as follows:

A station wishing to transmit packets senses the medium, if the medium is busy then it defers. If the medium is free for a time called DIFS (Distributed Inter Frame Space) then the station is allowed to send. The receiving station will send an ACK (Acknowledgement) message if the packet is well-formed. If the sender does not receive ACK, it will retransmit until it gets ACK or abort after a given number of retransmissions.

In order to reduce the probability of collisions, IEEE 802.11 uses the RTS/CTS mechanism. A node sends an RTS (Request To Send) message to reserve the channel. The destination node replies with a CTS (Clear To Send) message if the channel is free. Other nodes which receive RTS and/or CTS set a NAV (Network Allocation Vector) to the given duration contained in CTS and RTS messages.

To resolve contention between different stations, DCF uses a back-off algorithm [6], where each node chooses a random back-off time uniformly in the range [0,CW-1] as in (1), CW being the Contention Window size. The node waits then for this back-off time before accessing the medium.

$$\textit{Back-off time} = \textit{Random}(0,\mathrm{CW}-1) \times \textit{SlotTime} \qquad (1)$$

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SlotTime is the duration of one slot (9 µs in IEEE 802.11).

Back-off time decreases by one slot in the following cases:

- When the station senses the medium before the first transmission of a packet and if the medium is busy
- After each retransmission
- After a successful transmission

The only case when this mechanism is not used is when the station decides to transmit a new packet and the medium has been free for more than DIFS.

Thus to send a packet, a station must wait until the medium becomes free and then wait for DIFS followed by back-off time. After that, if the channel is still free the station sends its packet.

If the medium becomes busy before Back-off time expiration, the station waits again until the medium becomes free, then it waits for a period DIFS and the rest of the previous Back-off time before emitting.

If two stations are emitting at the same time, a collision is detected due to the non reception of an ACK and the new contention window CW is increased exponentially to reduce the collision probability as in (2).

$$CWnew = min(2 \times CWold + 1 \text{ , } CWmax) \tag{2}$$

III. IEEE MAC LAYER ISSUES

IEEE 802.11 MAC layer is responsible for decreasing the number of collisions, increasing the use of the channel, assuring fairness between different network nodes and guaranteeing QoS.

However MAC layer cannot solve in a satisfactory way all these issues. IEEE 802.11 suffers from throughput problems.

As the number of nodes in the same sensing carrier area increases, the global throughput decreases. That is because the channel is shared by many nodes in competition [7]. Also, the throughput between two nodes decreases according to the distance separating them. The packets are no longer correctly received due to the attenuation of signal power [7].

Many research has been done on IEEE 802.11 standard as we can see in [11] [10] [5] [3] [1] and [7].

The problem of the back-off mechanism is the exponential increase of CW [11]. A node having collisions while transmitting will have its CW increased exponentially after each calculation of Back-off time [8] and will quickly reach its maximum value CWMax. The choice of CW is fundamental in order to obtain good performances. A node having a small value of CW has more chance of accessing the channel and sending its packets. Whereas a node having great value of CW will have less chance of accessing the channel if its neighbors have smaller values of CW.

Then, there is a problem of fairness and we have to change the way of calculation in (1), which implies the design of a new algorithm in order to have a linear increase of CW rather than an exponential increase. CW attribution must also guarantee fairness in bandwidth usage by penalizing the node occupying the most of the channel. This can be done by giving it a high value of CW relative to nodes having less chance of accessing the channel.

In the next section we propose an enhanced back-off algorithm that tries to satisfy these constraints. Our algorithm in the following will be called Enhanced Back-off (E-back-off).

IV. ENHANCED BACK-OFF

The Contention Window is central for most IEEE 802.11 MAC layer problems [2]. Some research [2] [7] [11] has proposed solutions to enhance CW taking into account some network parameters. Thus, to reach a good performance of MAC layer, two methods are often used:

The first method tries to enhance existing packets and adds new packets containing relevant information in order to assure a fair access to the channel [10] [11]. The second method uses the state of the network and collects some information to help decision making.

To avoid free bandwidth decrease, we have chosen the second method which does not overload the network. The idea of our algorithm is to adjust CW taking into account the size of the node neighborhood. Also we take into account the state of channel occupation in order to guarantee a fair access to the communication support to all nodes in competition. This fairness notion can be quantified by a fairness index and the decision made based on this metric will influence considerably the channel access.

Even if the fairness index proposed by Z.Y Fang et al [4] is interesting, it presents however some shortcomings according to our estimations because the node computes many times the same packet. Also the node does not know precisely the size of a packet sent by a node when it receives the corresponding ACK from a neighbor. Thus to calculate this index, we proceed as follows: The idea is that each node do an accounting of packets it sends (resp. receives) Ws (resp. Wr) in terms of time occupation of the medium. We define the Fairness Index metric FI as follows:

$$FI = Ws/Wr \tag{3}$$

The time is divided into intervals, called COLLECT_TIME. At each one, a node computes Ws (bits) and Wr for the same period. Then it computes the Fairness Index FI as in (3). FI, Ws and Wr values are initialized at each COLLECT_TIME. A node that had occupied the channel the most relative to its neighbors will have Ws greater than Wr. Otherwise its Ws will be smaller than Wr.

The Fairness Index computing is done at each node level in the network. This will help decision making to increase or decrease CW. In the standard version of the algorithm, CW is increased every time a collision occurs, or the channel is busy, or a sent RTS/DATA packet is lost. In these conditions, a node will have a limited access to the communication support compared to its neighbors because its CW will increase until reaching its maximum value.

The algorithm we propose modifies CW according to collected information in the previous COLLECT_TIME.

If FI is greater than a threshold called C, the node occupies more of the channel. If FI is less than 1/C, the node occupies less of the channel.

In order to solve the problem of the exponential increase of CW, we have chosen an arithmetic progression of CW.

If FI is greater than C, the node increases its CW by a fixed value which depends on its neighborhood size K. The new value of CW is greater than the old CW by one or two slots. If FI is less than 1/C, the window is reduced geometrically by two or four slots based on the neighborhood size. This is because a node having been penalized by its neighbors in the last COLLECT_TIME has to decrease its CW rapidly to facilitate the channel access.

Thus we will have a balanced share between the different nodes of the network. This algorithm exploits the number of neighbors a node has, as well as the state of its channel occupation during a period COLLECT_TIME. A very good choice of C and K constants will assure fairness between different nodes in contention.

E-BACK OFF ALGORITHM

```
IF (FI>C)
    IF (NB_NEIGB >= K)
        CW=max(CWold+2,CWmax)
    ELSE
        CW=max(CWold+1,CWmax)
    END IF
END IF
IF (FI<1/C)
    IF (NB_NEIGB >= K)
        CW=min(CWold/4,CWmin)
    ELSE
        CW=min(CWold/2,CWmin)
END IF
```

We will present in the next part of this paper through simulation results the performances of E-Back-off algorithm compared to its standard version used in the IEEE 802.11 standard.

V. COMPARING STANDARD BACK-OFF ALGORITHM TO E-BACK-OFF

In this section, we use the discrete event network simulator NS-2 [9] to simulate our work. Simulation results show that our algorithm has better performances than the standard back-off algorithm.

Tab. I summarizes the parameters used in NS2. We have opted for a sensing range equal to the sensing interferences range to avoid the problem of EIFS (Extended IFS), a well known issue which is not the subject of our work. Parameters C and K were chosen empirically after having been varied in different simulations and comparing algorithm throughputs.

TABLE I. SIMULATION PARAMETERS

Parameter	***Value***
Slot Time	20 µs
ACK	20 bytes
RTS	25 bytes
CTS	20 bytes
DATA	1000 bytes
DIFS	40 µs
SIFS	10 µs
CWmin	31
CWmax	1023
Throughput	2 Mbits/s
Sensing Carrier	250 meters
Transport Protocol	UDP
C (threshold of FI)	1.1
K (threshold of neighbors)	3
COLLECT_TIME	1 second

We simulate the three pair scenario, a well-known problem of the IEEE 802.11 standard. We have three pairs of nodes (1,2), (3,4) and (5,6) as we see in Fig. 1.

The channel is continuously busy for the central pair (3,4) because the RTS that node 1 sends informs node 3 that the channel is busy. Once the channel becomes free, the central pair senses that it is still busy because the pair (5,6) is in communication or node 1 sets its CW to 0 due to the successful transmission of a packet.

As we see in Fig. 2, the central pair (3,4) sends almost nothing. Its throughput is null whereas other pairs occupy almost all the bandwidth.

Fig. 3 shows the results after using E-Back-off algorithm. As the nodes are in communication, progressively the channel access becomes fair to all nodes in contention. The central pair no longer has a null throughput as in the case of standard back-off algorithm. This is because the nodes choose the new CW taking into account the last activities and the state of their neighbors. This method offers a chance to all nodes, whether in hidden node situation or not to access the channel with fairness.

Curves in Fig. 4 (resp. Fig 5) are an interpolation of the curves in Fig. 2 (resp. Fig. 3). These allow us to clearly see the throughput evolution of the three pairs.

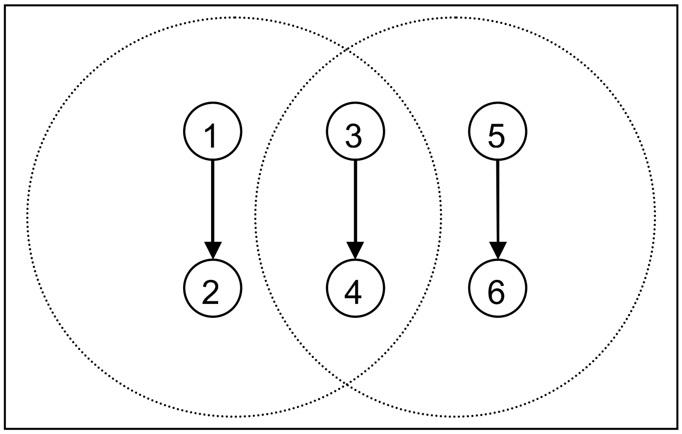

Figure 1. Three pair configuration

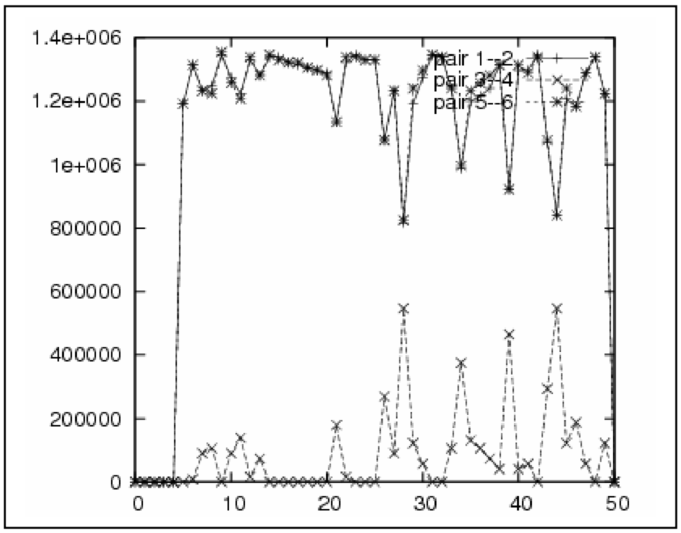

Figure 2. Throughput of three pairs. Case of IEEE 802.11 standard algorithm

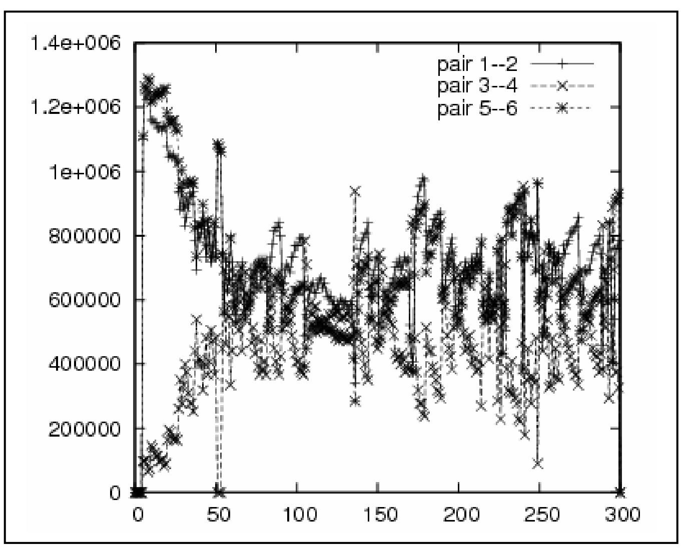

Figure 3. Throughput of three pairs. Case of enhanced algorithm

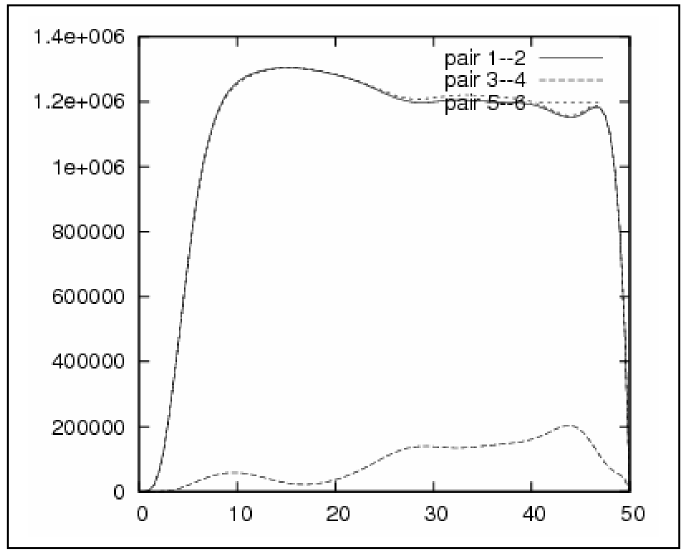

Figure 4. Interpolated throughput of three pairs. Case of IEEE 802.11 standard algorithm

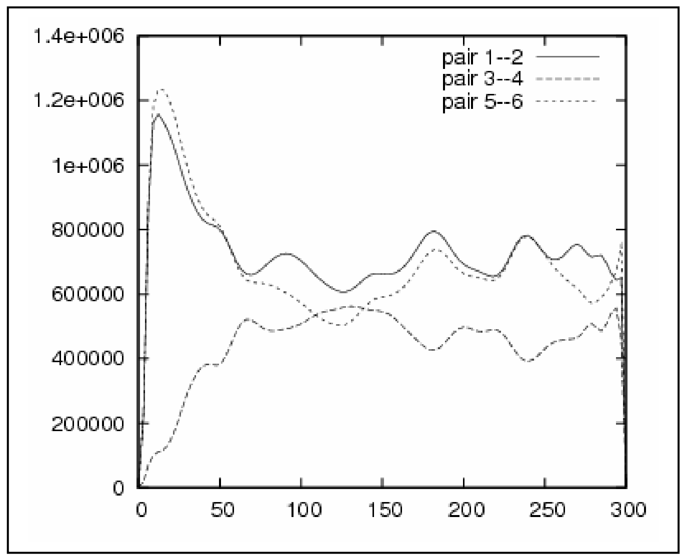

Figure 5. Interpolated throughput of three pairs. Case of enhanced algorithm

VI. CONCLUSION

The back-off algorithm proposed in IEEE 802.11 to manage the contention has many anomalies notably the exponential increase of CW. There is a fairness problem in some configurations because nodes having the smallest CW have more access to the communication support relative to their competitors. The E-Back-off algorithm solves this fairness problem and limits also the exponential increase of CW. We have included in our algorithm the neighbors of a node and the observation of different states of the network by computing the amount of information a node and its neighbors send. This helps decision making to achieve fairness in the network. Simulation results obtained using NS-2 shows the enhancement added by the E-Back-off algorithm in terms of fairness. We consider that the choice of the optimal thresholds C and K will allow better management of throughput based on fairness between nodes under QoS constraints required by each node. However, as the neighborhood changes frequently in a mobile environment, these thresholds depend on the type of configurations used. In future work, we will further investigate the optimization of C and K and simulate our E-Back-off algorithm in a multi-hop mobile environment. Another possible way that can enhance the QoS in IEEE 802.11 is to exploit advantages that routing protocols offer in neighborhood construction.

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