Performance of IEEE 802.11 in Wireless Mesh Networks

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Abstract – **This paper addresses the performance of the IEEE 802.11 MAC protocol in a wireless mesh network. The aim is to assess under which conditions the protocol's performance might be acceptable, in particular for delay sensitive traffic. A number of different scenarios is considered, with varying number of gateways, different sizes for the group of users, as well as different transmission and carrier sensing ranges. It is shown that the IEEE 802.11 performs poorly on heavy traffic, in particular for data flows subject to multiple hops. In addition, the protocol fails to dispense the available bandwidth fairly to the requesting nodes. Improvements can be obtained by minimizing the number of hops required for the traffic to reach its destination. This can be achieved by increasing the number of gateways. Another alternative is to increase the transmission range, at the cost of spatial reuse. However, the latter option only translates into better performance if the carrier sense range is also decreased.**

***Index terms* – Wireless LAN, IEEE 802.11, Ad-hoc Network, Mesh Network.**

I. INTRODUCTION

Many studies and deployments of wireless mesh ad hoc networks have adopted the IEEE 802.11 Medium Access Control (MAC) [1] as the de facto standard for the medium access layer, despite its well known poor performance in such networks, especially in multihop mode [2]. However, a detailed analysis of the IEEE 802.11 MAC in multihop networks shows that an acceptable performance may be achieved, depending on the network configuration. In this paper, we investigate the performance of the IEEE 802.11 MAC in a wireless mesh network. The aim is to determine the conditions under which the protocol's performance might be acceptable. In this investigation, we select scenarios with varying number of gateways, different sizes for the group of users, as well as different transmission and carrier sensing ranges. The results with one gateway confirm the well known unfairness problem with the IEEE 802.11 MAC. When the number of gateways is increased, a performance improvement is observed, which can be explained by the reduced number of hops between a node and its gateway. We also show that the commonly used values for transmission range and carrier sensing range (*250*m and *550*m) are not the best choice for multihop transmission.

The remainder of this paper is organized as follows: In Section 2 presents the scenarios studied in this paper; in Section 3 the results are presented and analyzed; finally, Section 4 concludes the paper.

II. SIMULATION SCENARIOS

In order to evaluate network performance using gateways, a *7x7* regular grid scenario is selected, in which each node has an effective transmission range of *250*m, and the distance between nodes is *200*m. Considering the fact that each node may interfere with the data reception at another node, even though they are beyond the transmission range, a *550*m carrier sense range is used in the simulations. The two-ray ground channel model is adopted.

For performance analysis, FTP and CBR traffics are used in the simulations. In both cases, a maximum *2* Mbps channel transmission data rate is set in the simulator. When simulating FTP, a *512*-byte packet size and a *32*-byte TCP Receiving Window are used. The CBR simulation uses data rate of *50* kbps and *125*-byte packet size.

The results presented here represent an average of *10* runs, each one lasting *180* seconds of simulation time. Network performance is analyzed by the average throughput and average packet delay.

III. RESULTS

A. Single gateway

In this case, the gateway is at the center of the grid and 16 terminals (out of 48) are generating/receiving data, as shown in Fig. 1. Considering this scenario and using CBR traffic, we have obtained an average throughput of *2* kbps at the application layer. Throughputs for individual nodes are shown in Fig. 2. One may notice that nodes *7* and *10* perform better than the other nodes. The reason for this is

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that both terminals are close to the gateway, and therefore they do not face high level of contention.

The average overall delay obtained is *8.05*s, a figure that is unacceptable for most applications (e.g., VoIP). Fig. 3 shows the average packet delay for each node.

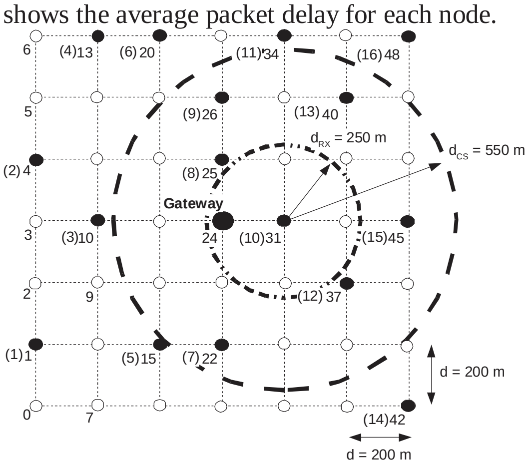

Fig. 1: Simulation scenario – the dark dots correspond to the traffic generating terminals and are numbered (in parenthesis) from 1 to 16.

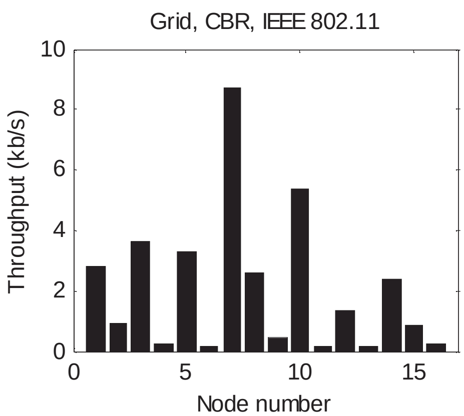

Fig. 2: Average throughput per node in kbps for CBR traffic.

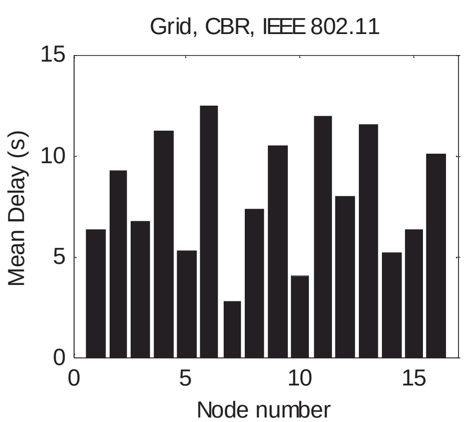

Fig. 3: Average delay per node in seconds for CBR traffic.

Again, nodes *7* and *10* have better performance when compared to the other nodes. It is important to note that although node *8* is also close to the gateway, it does not perform as well as nodes *7* and *10* because it forwards significantly more packets than the latter nodes.

For FTP traffic, the performance results are better when compared to the case when CBR traffic is used, as shown in Figs. 4 and 5. Again, nodes located near the gateway perform better, both in terms of packet delay and throughput. Similar to what is observed for the CBR traffic, these figures suggest that the channel occupation is highly unfair.

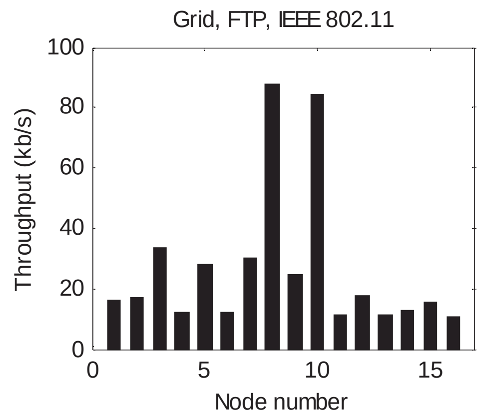

Fig. 4: Average throughput per node in kbps for FTP traffic.

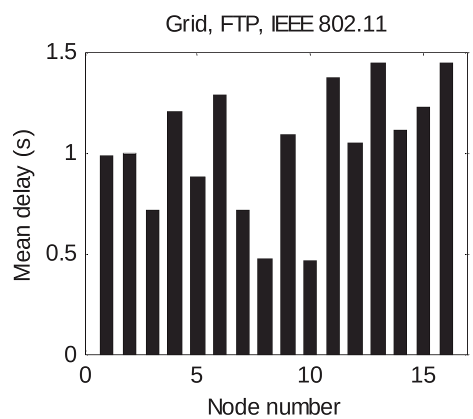

Fig. 5: Average delay per node in seconds for FTP traffic.

B. Multiple gateways

The single gateway scenario used above showed that the existence of traffic bottlenecks greatly reduces the average throughput. One way around such a problem is the deployment of multiple gateways and the partition among them of the expected traffic. Using more than one gateway is desirable because:

- Offers redundancy and increases system reliability;
- Network bottleneck problem is reduced;
- Decreases the number of hops between source and the gateway.

The simulation scenario considered here has five gateways, deployed as shown in Fig. *6*. All the simulation parameters remain the same, except that here only the CBR traffic is considered.

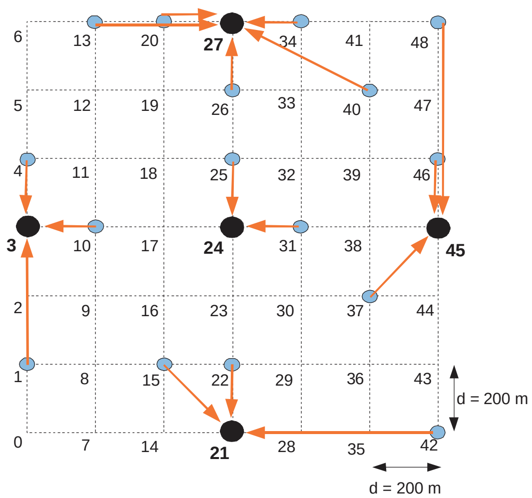

Fig. 6: Simulation scenario using five gateways. The arrows show which gateway each transmitting node is connecting.

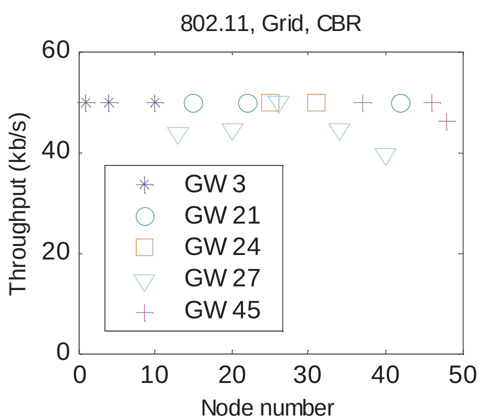

Fig. 7: Average throughput per node in kbps for CBR traffic and five gateways.

Figs. 7 and 8 show the simulation results. When compared to the single gateway case, it can be easily seen that the network performance is greatly improved by the use of multiple gateways.

For instance, it can be noticed that the packet delay times are drastically reduced. Some reasons behind the improvement are the reduced number of hops, the reduced traffic forwarding, and lesser amount of channel contention.

C. Influence of traffic load

Let us now consider the network behavior when traffic demand increases. Using the single gateway scenario shown in Fig. 1, we have established four groups of active nodes for the simulation, as shown in Table I. The average throughput and packet delay are monitored as a function of network load. The results are in Table II.

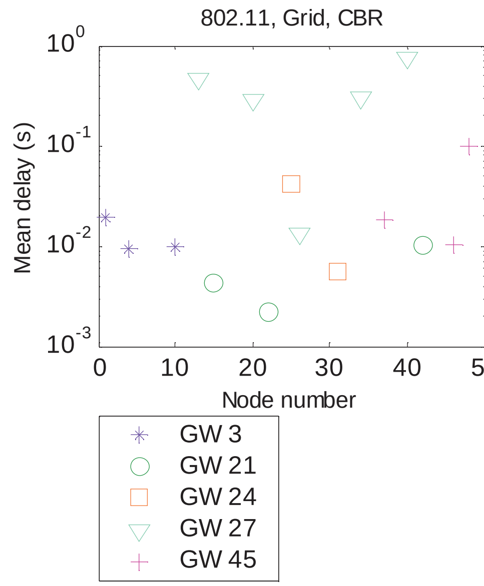

Fig. 8: Average delay per node in seconds for CBR traffic and five gateways.

TABLE I:
USER GROUPS

Group	No. of active nodes	Node numbers
G1	*1*	*1*
G2	*2*	*1, 48*
G3	*3*	*1, 26, 48*
G4	*5*	*1, 4, 26, 37, 48*
G5	*16*	See Fig. 1

TABLE II:
SIMULATION RESULTS

Parameter	Group	Results
Average Delay	*G1*	*12 ms*
	G2	*16 ms*
	G3	*1,9 s*
	G4	*4,4 s*
	G5	*8,0 s*
Average Throughput	*G1*	*50,0 kbps*
	G2	*50,0 kbps*
	G3	*27,1 kbps*
	G4	*7,4 kbps*
	G5	*2,1 kbps*

For the particular scenario and groups of active nodes used here, performance for delay sensitive applications might be acceptable when we have up to two active nodes. The network performance rapidly degrades when the number of active nodes increases beyond two.

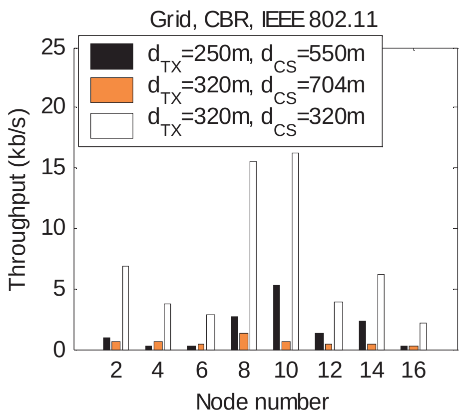

Fig. 9: Average throughput per node for various transmission and carrier sense ranges (CBR traffic).

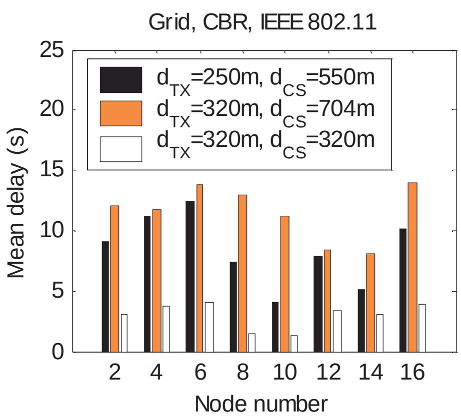

Fig. 10: Average delay per node for various transmission and carrier sense ranges (CBR traffic).

D. Influence of transmission range and carrier sense range

The performance in a multihop ad hoc wireless network relies on the MAC protocol ability to allow spatial channel reuse and to avoid collisions. These are associated with transmission range (d_{TX}, the maximum distance from the transmitter's antenna that a packet can still be correctly received) and carrier sense range (d_{CS}, the maximum distance that a packet transmission can sill interfere with other nodes transmissions).

In this analysis, network performance is observed as a function of both carrier sense and transmission ranges. The scenarios are:

- d_{TX} = *250m* and d_{CS} = *550m*: the same values used in all previous simulations (d_{CS} / d_{TX} = *2.2*);
- d_{TX} = *320m* and d_{CS} = *704m*: in this case, eight neighboring nodes are within transmission range (see Fig. 1) and d_{CS} / d_{TX} is still *2.2*;
- d_{TX} = *320m* and d_{CS} = *320m:* again, eight nodes are within transmission range but d_{CS} / d_{TX} = *1*.

Both CBR and FTP connections are being analyzed. The results are shown in Figs. 9, 10, 11 and 12.

As one can see, the best results for CBR are obtained when d_{CS} / d_{TX} =*1*. Similar results are presented in [3]. Also it is observed that when d_{CS} / d_{TX} = *2.2*, the network performance is worse when the transmission and carrier sense ranges are greater because channel reuse is reduced. For the FTP traffic, the results are slightly different. While the delay performance is better when d_{CS} / d_{TX} = *1*, the throughput is better when d_{TX} = *250m* and d_{CS} = *550m*.

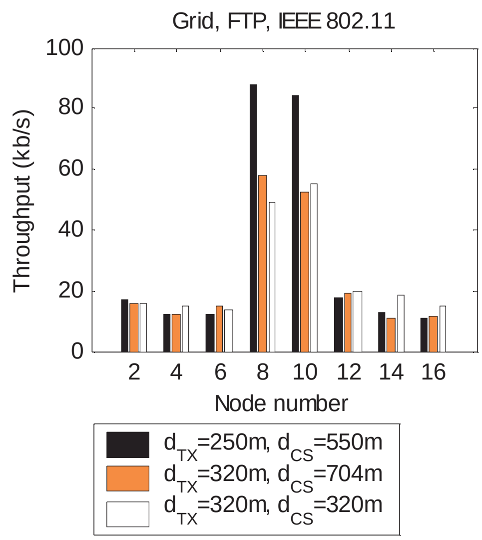

Fig. 11: Average throughput per node for various transmission and carrier sense ranges (FTP traffic).

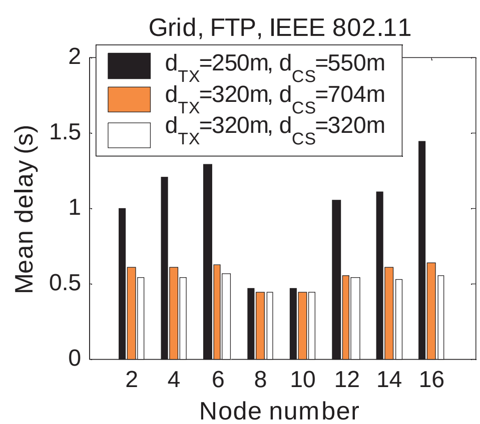

Fig. 12: Average delay per node for various transmission and carrier sense ranges (FTP traffic).

IV. Conclusion

The work presented here considers the use of the IEEE 802.11 MAC protocol in an ad hoc multihop network. It is shown that the IEEE 802.11 performs poorly on heavy traffic, in particular for data flows subject to multiple hops. In addition, the protocol fails to dispense the available bandwidth fairly to the requesting nodes.

Improvements can be obtained by minimizing the number of hops required for the traffic to reach its destination. This can be achieved by increasing the number of gateways. Another alternative is to increase the transmission range, at the cost of spatial reuse. However, the latter option only translates into better performance if the carrier sense range is also decreased.

References

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