Performance evaluation of QoS in wireless networks using IEEE 802.11e

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***Abstract*— The increase demand for Quality of Service (QoS) in computer networks and the recent popularization of wireless networks required a standard to bring QoS to such networks. The IEEE 802.11e, a complement to the 802.11 family, answers to these requirements implementing such QoS mechanisms.**

The main contribution of this work is to provide an evaluation of the final IEEE 802.11e standard. Using the ns-2 simulator, we compare it against IEEE 802.11a with a FIFO queue, as well as priority and round robin arbiter queues. We also consider different scenarios, both in ad hoc and infra-structure modes.

Our results show that the IEEE 802.11e can improve the QoS of a wireless network in all scenarios.

***Keywords*— QoS, IEEE 802.11e, Simulation, MANET, Ad Hoc, Wireless**

I. Introduction

The growth of Internet as a tool for video and audio streams caused concern to the user's quality of experience. Guaranteeing metrics such as latency and jitter is fundamental for such applications to fulfill their objectives. The *QoS* (Quality of Service) term has been introduced in this context, as the adoption of features to improve this metrics [1]. Some schemes have been proposed [2], [3] to meet these needs, achieving quite expressive results.

More recently, wireless networks have become common both in domestic and business applications, especially because of high costs to build wired networks, but also to allow mobility in the environment. Wireless networks are more sensitive in terms of quality, because of interferences from other sources and mobility. In a particular situation, ad hoc networks make the challenge even bigger, mainly due to rapid change of topology and the absence of a central point of coordination.

The IEEE 802.11e standard [4] intends to provide QoS in wireless networks. This papers compares IEEE 802.11e protocol against the IEEE 802.11a MAC protocol. Since the standard behavior of the IEEE 802.11a is associated with a regular FIFO queue, we decided to broaden our experiments by varying the queue disciplines. Besides the FIFO queue, we also use a Priority Queue and a Round Robin (DRR) queue. These scenarios were chosen to allow us to understand how IEEE 802.11e improves the QoS of a network, using as metrics throughput, average delay and jitter.

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The Priority Queue works simply by letting traffic with higher priority pass before those with lower priority. The Round Robin scheme does not take into account any priority. Each traffic has a slot of time to go through, after this time is finished, the next one will transmit. Finally, the FIFO queue uses the arrival time as metric, packets arriving first will be delivered first.

The main contribution of this paper is to provide an evaluation of the final IEEE 802.11e standard, comparing it against regular IEEE 802.11a and also different queue policies. Different scenarios have been used to enrich the discussion. To the best of our knowledge, these results, or similar, have not been published in such a complete way.

The rest of this paper is organized as follows. In Section III, the IEEE 802.11e is presented and its features are discussed. The scenarios used in our simulation are presented in Section IV, and in the following section we show the results of these simulations, while providing some analysis of them. Finally, Section VI concludes the paper.

II. Related Work

Previous work presents performance evaluation of the IEEE 802.11e, but they generally do not cover a large number of scenarios. For instance, Rushabh *et al.* [5] evaluate a draft of the MAC mode. They use two scenarios, both in infra-structured mode, with different priority flows. The analysis and results were focused on finding the best parameters of link layer protocol in both scenarios for the 802.11e.

Grilo and Nunes [6] also evaluate a draft of 802.11e using an initial scenario that is infra-structured with one access point and two sessions transmitting either video flow or VoIP flow. It has used delay as the only metric and variates the number of clients consuming background data, which was modeled as HTTP bursty traffic.

Carlson *et al.* [7] compare IEEE 802.11e with Dynamic Resource Allocation (DRA), only one ad hoc scenario is used, and conclude the second choice gave better results in the simulated scenario. This work used the last version of IEEE 802.11e, but the reduced number of scenarios may have favored the DRA scheme.

Gu and Zhang [8] evaluates the final standard in a simple ad hoc single hop scenario. Their results take into account medium access time and throughput for different classes of flows. As the previous one, this work lacks of diversity, both in number of scenarios and in comparison against previous standards, thus allowing limited view of IEEE 802.11e.

In a recent work [9], the performance of the IEEE 802.11e is analyzed in a infra-structured network, with two access points and six clients. Three traffics with different priorities are used. The results achieved shows the performance of IEEE 802.11e, but no other scheme is used to compare the results. The comparison is made between EDCA and DCF schemes only.

III. IEEE 802.11E STANDARD

The IEEE 802.11e [4] is the standard to support applications with QoS over wireless networks; it is a complement standard to the 802.11 family, as well as the whole 802.11 family this is a second layer (MAC) protocol. Regular IEEE 802.11a defines two MAC mechanisms: DCF (Figure 1-a) and PCF (Figure 1-b). Distributed Coordination Function (DCF) is used in ad hoc scenarios and Point Coordination Function is used in infra-structured scenarios.

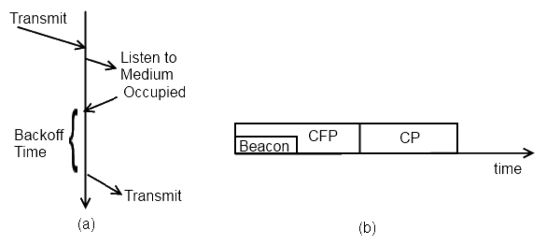

Fig. 1. a) Distributed Coordination Function is the default mode to ad hoc communication under IEEE 802.11. A *Collision Avoidance* scheme is used to optimize medium utilization. b) Point Coordination Function is the default mode in infra-structure IEEE 802.11. A coordinator makes use of *beacons* to synchronize communication.

IEEE 802.11e defines two additional modes: Enhanced Distributed Channel Access (EDCA) and Hybrid Coordination Function (HCF) Controlled Channel Access (HCCA), derived from the original version HCF and Enhanced Distributed Channel Function (EDCF) [10].

The HCCA (Figure 2) is based on the PCF mode, from the non-QoS IEEE 802.11. In PCF, a *superframe* is the combination of a *Contention Free Periods* (CFP) and its following *Contention Period* (CP). The CFP, and as a consequence a superframe, starts with a *beacon*. In HCCA, the start of a CFP during the CP phase is possible, this special CFP is called Controlled Access Phase (CAP), which allows an Access Point (AP) to start transmission or reception in a contention-free fashion.

EDCA is defined to ad hoc scenarios, the basic principle is that any node wanting to transmit waits a certain amount of time. This waiting period is longer if the traffic has lower priority. In addition, shorter Contention Window (CW) and Arbitration Inter-Frame Space (AIFS) are also used for higher priority traffic.

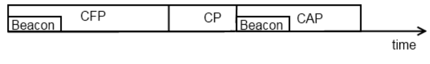

Fig. 2. Hybrid Coordination Function Controlled Channel Access is one of the IEEE 802.11e modes to provides QoS to wireless networks. It is based on the PCF mode, but beacons can be used at any time to better control of the traffic.

It is important to notice that the IEEE 802.11e has, in general, a probabilistic behavior, and so it does not guarantee QoS. It works by improving the probability that a priority flow will be delivered, but no resource allocation or reservation is made.

IV. SIMULATION

This simulation was performed with *ns2* simulator [11], the module 802.11e [10] was used to simulate the IEEE 802.11e mode.

The scenarios can be divided in two classes; in the first (Scenarios 1 and 2), an infra-structured like mode was used. In the second an ad hoc topology was simulated.

A variable, but small, number of flows is used, depending on the scenario, but they all belong to one of 3 classes: a FTP download; a video stream and an audio stream (voice). Both FTP and video flows use 200Kbytes/s, while the audio stream uses 2Kbytes/s. The voice traffic has the highest priority and the FTP the lowest. Table I shows the mapping of these flows into IEEE 802.11e Classes of Services (CoS), and Table II shows the parameters used to each CoS. Senders and receivers are chosen at random, so not all the nodes send/receive a flow, but they may be part of the routing.

TABLE I
SUMMARY OF SIMULATION FLOWS AND THEIR MAPPING INTO IEEE 802.11E COS.

Flow Tipe	Band	IEEE 802.11e Class of Service
Audio Stream	2 Kbytes/s	Voice
Video Stream	200 Kbytes/s	Video
FTP download	200 Kbytes/s	Background

TABLE II
SIMULATION PARAMETERS TO EACH CLASS OF SERVICE.

CoS	CWmin	CWmax	AIFS	Max TXOP (ms)
Voice	7	15	2	3.264
Video	15	31	2	6.016
Background	31	1023	7	0

The MAC layer bandwidth was limited to 2Mbits/s in order to create competition for the medium. Each scenario has four variations: Priority Queue, Round Robin, regular 802.11a (FIFO) and 802.11e (using EDCA).

Infra-structured scenarios are simulated 20 times for each variant and ad hoc scenarios are simulated 50 times for each variant and the average of the values is used. The simulation time is 50 seconds.

The intention is not to stress (and saturate) to the limit the network, but rather evaluate the performance under normal (but still with high resource occupation) scenarios.

A. Infra-Structured Scenarios

These scenarios emulate a regular home application of a wireless network, or a small business environment. In these scenarios, one flow per client node and single hop are used. All nodes are within the others range. An Access Point is not formally defined, because the 802.11e module implements

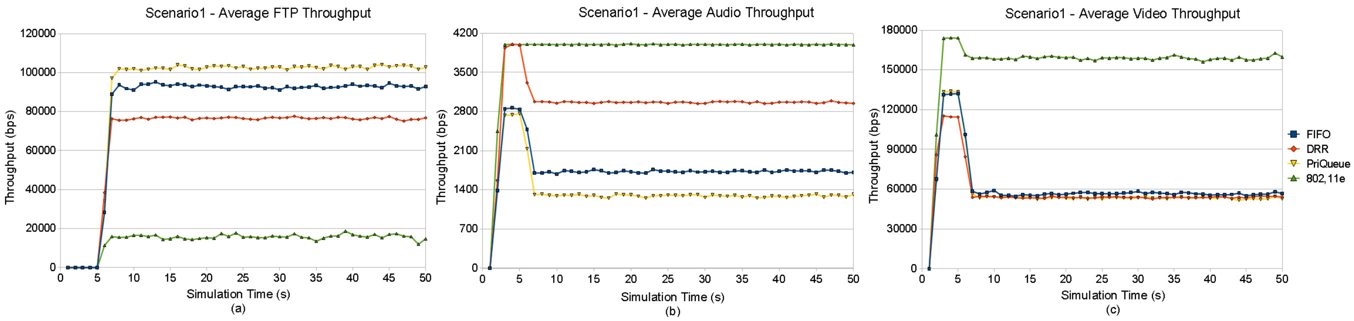

Fig. 3. The average FTP (a), Audio (b) and Video (c) throughputs in Scenario 1 to the different proposed schemes.

only the EDCA mode, but all the flows come from a single node.

Scenario 1 has 5 flows (and clients): two FTPs, a video stream and two VoIPs. Scenario 2 has 10 clients. Five more background FTP flows are used.

The order of the flows does not have any influence on the simulation, as all the nodes are within the others ranges.

B. Ad Hoc Scenarios

The second simulation class (Scenarios 3 and 4) uses an ad hoc multi-hop environment. Sources and destinations nodes are randomly chosen, with the constraint that they cannot be repeated. As routing is a third layer issue, we have choosen to isolate routing related issues from the QoS mechanisms, thus static routing was used; this was made with the Static Route for Wireless Protocol implementation (*FixRT*) [12]. The fixed routes move first diagonally, when possible, and them vertically or horizontally. The routes are not necessarily the same in both ways.

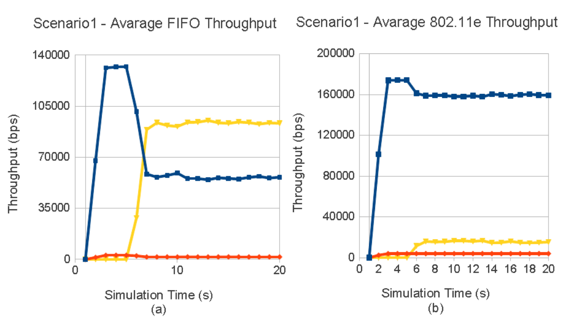

Fig. 4. Scenario 1 average throughput for all the flows truncated to 20s plotted in the same graphic, for the FIFO queue (a) and IEEE802.11e (b).

Scenario 3 is composed of 9 nodes distributed in a 3x3 regular grid. The signal of each node reaches only the adjacent nodes, including diagonally, making it a two hop network.

We use one FTP flow, one Video stream and a VoIP traffic. So, there is a total of six nodes sending or receiving data, the other may be part of the route, depending on where the senders and receivers are.

Scenario 4 has 25 nodes in a 5x5 regular grid. This creates a four hop network. It has 5 traffics: a video stream, two audio streams and two FTP flows.

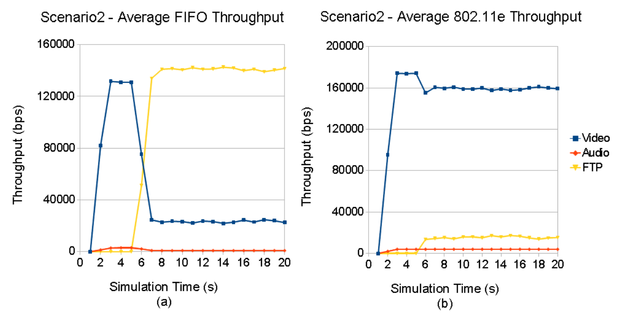

Fig. 6. Scenario 2 average throughput for all the flows plotted in the same graphic and truncated to 20s, for the FIFO queue (a) and IEEE 802.11e (b).

V. RESULTS AND ANALYSIS

In this section, the results of the simulations and a discussion are presented. Different perspectives are given to enable a better understanding of the results. First, the results for each simulated scenario and flow are given. In these graphics it is possible to compare the performance of the different schemes used. Then, concurrent flows are put together, showing the overall results of a scenario. This latter comparison is only made for two cases (FIFO and 802.11e), as theses cases are the most relevant ones. Average jitter and end-to-end delay are shown separated, by flow, scenario and scheme.

Figure 3 shows the average throughput to the Scenario 1, in Figure 3-a (resp. Figure 3-b and Figure 3-c) the FTP (resp. voice and video) throughput to all schemes is shown. Then, Figure 4 brings another perspective to same results: all the flows for both FIFO queue (Figure 4-a) and IEEE 802.11e (Figure 4-b) are plotted in the same graphic.

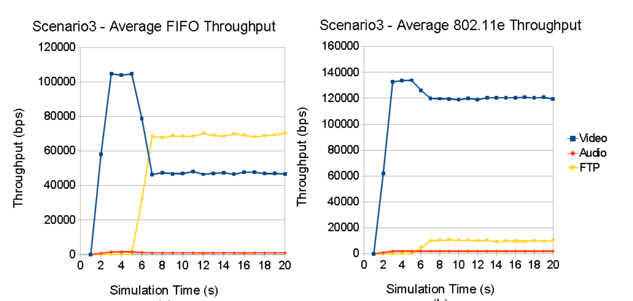

Fig. 8. Average throughput of all the flows plotted in the same graphic and truncated to 20s, for the FIFO queue (a) and IEEE 802.11e (b) in Scenario 3.

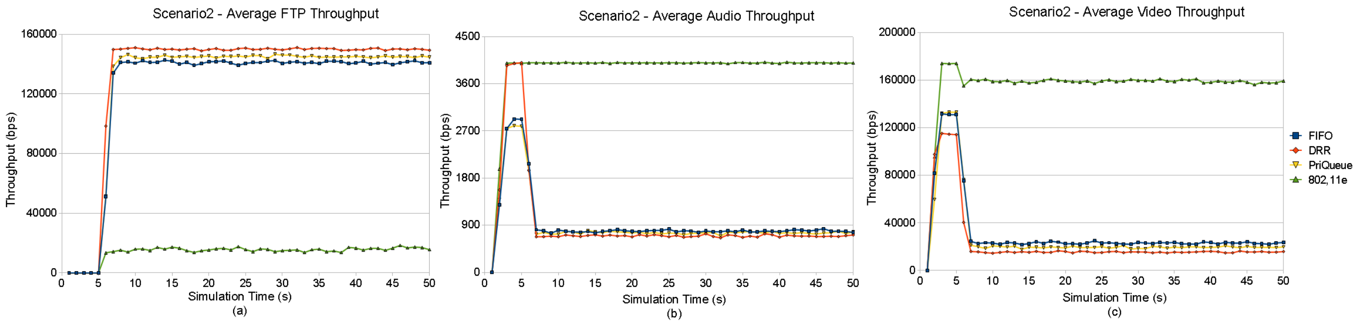

Fig. 5. The average FTP (a), Audio (b) and Video(c) throughputs in Scenario 2 to the different proposed schemes.

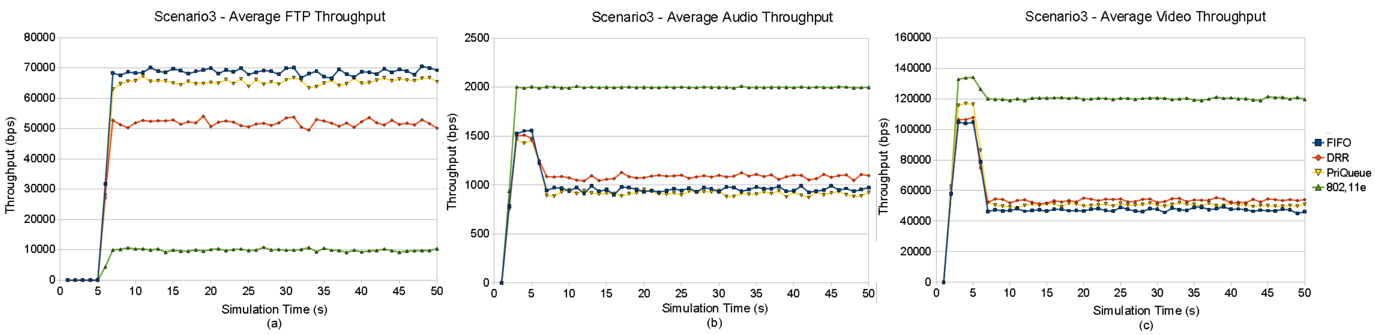

Fig. 7. The average FTP (a), Audio (b) and Video (c) throughputs in Scenario 3 to the different proposed schemes.

This first scenario shows an ideal case, a small number of clients and flows, the network is not stressed. Still, it is possible to see the better performance of IEEE 802.11e over the concurrents. The throughput for the VoIP application is almost flat during time for IEEE 802.11e, and the video throughput drops slightly. The background traffic is substantially reduced, to compensate the others. The surprise goes for the Priority Queue, which have worse results than the regular case (FIFO).

Similar results are achieved in Scenario 2. As one can find in Figures 5 and 6, IEEE 802.11e is able to maintain the audio throughput almost flat, while the audio throughput has only a small decrease. The main difference from Scenario 1 is that the other schemes have similar behavior, all of them being worse than in the previous scenario, this is explained by the additional medium contention. Jitter and delay, for both scenarios are shown in Table III. IEEE 802.11e improves these metrics to the audio flow, causing both video's and FTP's metrics to be worsened.

The main conclusion in these scenarios is that IEEE 802.11e is capable of achieving good QoS metrics. One disadvantage is the great decrease in the background traffic metrics.

In Figures 7 and 8 the throughput for Scenario 3 is shown, first by flow and then by scheme. This scenario keeps the tendency of the previous ones, as the number of hops is still small. The presence of only three flows makes the performance (of all schemes) better than Scenario 2.

Scenario 4 is the most stressed case. As visible in Figures 9 and 10, the throughput is more volatile than the other schemes. Jitter and delay for the last two scenarios are also in Table III. One can notice that delays are longer, due to the multi-hop environment.

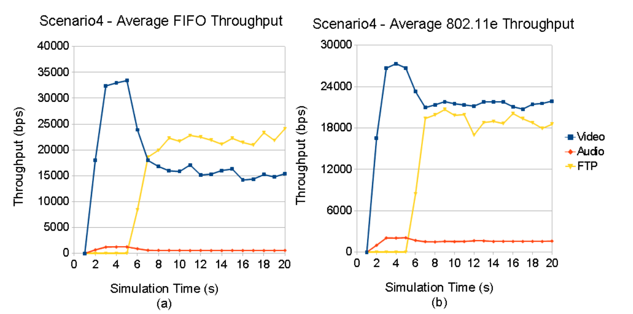

Fig. 10. Average throughput of all the flows plotted in the same graphic and truncated to 20s, for the FIFO queue (a) and IEEE 802.11e (b) in Scenario 4.

In this last scenario it is not possible to say that IEEE 802.11e brings QoS to the network, as metrics are far from ideal. But it is still visible that it improves them. In a real scenario, considering movement and actual routing protocols, this problem might be still worse.

VI. Conclusion

This paper has made an analysis of 4 different schemes for QoS simulating 4 different scenarios with single and multi-hops in wireless network. In those scenarios is necessary to provide QoS in order to enable watching a video, listening to an audio stream or talking in a telephone with acceptable quality.

IEEE 802.11e reaches its objectives by fairly improving delay for the most prioritary flow and throughput for high prioritaries flows in limited scenarios. It is also capable of

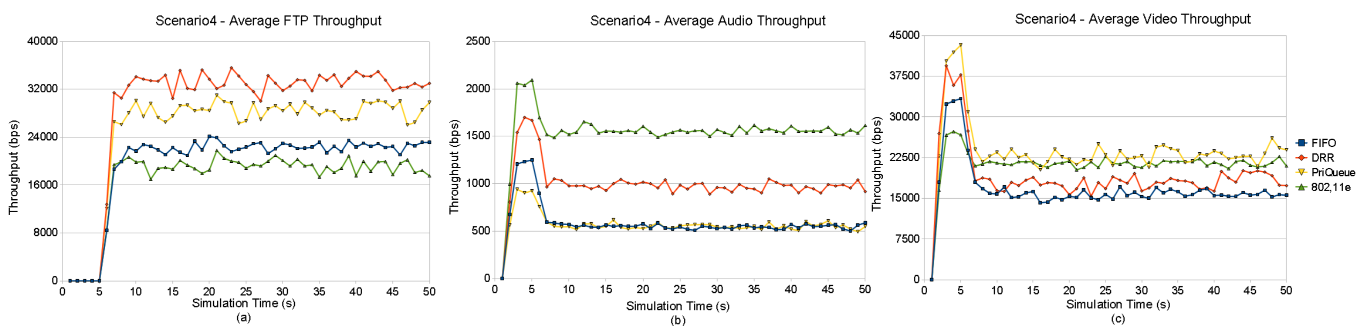

Fig. 9. The average FTP (a), Audio (b) and Video (c) throughputs in Scenario 4 to the different proposed schemes.

TABLE III

AVERAGE END TO END DELAY AND JITTER TO ALL SCENARIOS, ALL VALUES IN MILLISECONDS.

Scenario		FIFO	DRR	PriQueue	802.11e
1	FTP	214 ± 9	45 ± 1	229 ± 8	3.0k ± 0.7k
1	Audio	198 ± 30	51 ± 25	201 ± 38	5 ± 4
1	Video	203 ± 30	63 ± 29	210 ± 35	299 ± 45
2	FTP	246 ± 10	22 ± 2	248 ± 9	3.1k ± 0.8k
2	Audio	213 ± 43	61 ± 43	209 ± 49	5 ± 4
2	Video	209 ± 49	74 ± 40	206 ± 48	299 ± 47
3	FTP	1.0k ± 0.2k	205 ± 50	1.0k ± 0.2k	6.3k ± 1.9k
3	Audio	1.1k ± 0.6k	4.2k ± 1.9k	1.3k ± 0.7k	10 ± 10
3	Video	1.2k ± 0.7k	192 ± 55	1.2k ± 0.6k	460 ± 61
4	FTP	3.6k ± 1k	504 ± 241	3.4k ± 1k	15.1k ± 7k
4	Audio	2.5k ± 1.6k	4.5k ± 2.3k	2.4k ± 1.5k	968 ± 730
4	Video	1.9k ± 1.1k	487 ± 471	1.9k ± 1k	2.2k ± 1k

improving these metrics on more complex cases, but there is loss on quality of communication in theses cases.

It would be interesting, as a further investigation, to understand how IEEE 802.11e performs over a mixed (wireless and wired) network and to compare its performance versus other more elaborated schemes, such as MPLS or DiffServ. Adding movement to the simulations is an important evaluation on future works.

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