Evaluation of 802.11e models under ns-2 and OPNET Modeler simulation tools in MANET networks

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Abstract

In this work we present the results of a comparative study between two well-known network simulators: ns-2 and OPNET Modeler. In particular, we focus on a performance evaluation of the IEEE 802.11e technology on Mobile Ad-hoc NETworks (MANETs) in both stationary and mobile scenarios. The paper describes the tested scenarios in detail, and discusses simulation results obtained with OPNET Modeler, comparing them with those obtained with ns-2. The performance of IEEE 802.11e in presence of legacy IEEE 802.11 stations is also analized. Due to the significant differences between both simulators, we enumerate those changes required so as to make results obtained via both simulators comparable. The results that have been reached support the conclusion that the behavior of both simulators is quite similar in general. We believe that such finding validates simulation results obtained with either of them.

1 Introduction

A Mobile Ad-hoc Network (MANET) is composed by a group of stations that communicate wirelessly with each other to form a network. These networks do not require any sort of infrastructure for support. Two of the most important factors that characterize MANETs are the routing protocol and the wireless technology employed by the stations that conform it. When referring to wireless technology we mean the combination of the physical and MAC layers.

The IEEE 802.11 standard [2] was created to provide wireless local area networks (WLANs) to different environments, such as public access networks, enterprise networks, home networks, etc. It operates in free bands such as the industrial, scientific and medical (ISM) band at 2.4 GHz or in the unlicensed 5 GHz band. The IEEE 802.11e [3] task group has finished some extensions to the IEEE 802.11 standard to provide QoS at the MAC level. The availability of a wireless technology that offers QoS support is one of the most important requirements to deploy a QoS framework in MANET environments. By enabling traffic differentiation at the MAC level it is possible to design a strategy, built on top of the IEEE 802.11e technology, that can successfully support traffic with QoS constraints. Examples of QoS traffic include VoIP, videoconference and that generated by any other real-time application.

The most of the published research about MANETs use simulation tools, but the reliability of such simulation studies has been questioned [6]. Because of this, some comparative studies have been conducted in order to validate the obtained results [8].

This paper presents a comparative analysis of two well-known network simulators in particular: ns-2 version 2.26 [11] and OPNET

Modeler release 11.5 [1]. We focus on the accuracy in simulating IEEE 802.11e technology in MANET environments. Results obtained with the ns-2 simulator have already been published in [4]. The motivation of this paper is to repeat all the experiments under the same conditions but with a different simulation tool, OPNET Modeler, in order to validate the accuracy of both simulators for some particular MANET scenarios. Similarly to that previous paper, all nodes in all scenarios of this paper run the IEEE 802.11 [2] or 802.11e [3] in the ad-hoc mode, that is, without infrastructure, and all the experiments are conducted using the Ad-hoc On-demand Distance Vector (AODV) [9] routing protocol.

Since important divergences at different levels have been found between both simulators, several changes are necessary when replicating ns-2 experiments in the OPNET models, as explained later.

The remainder of the paper is organized as follows. Annex E of the IEEE 802.11 standard is briefly presented in section 2, including an introduction to EDCA. Section 3 describes the methodology employed in conducting the different experiments, along with the divergences detected in the comparison process. The static and mobile scenarios used are described in sections 4 and 5, respectively, followed by the discussion of the obtained results. Section 6 shows results of both simulators in the presence of legacy 802.11 nodes. Finally, conclusions are drawn in section 7, along with references to future work.

2 An overview of IEEE 802.11e

The IEEE 802.11e is an improvement to the original IEEE 802.11 standard in order to support Quality of Service (QoS) at the MAC level. To achieve this, packets received from upper levels are handled in a different manner depending on their QoS requirements, meaning that IEEE 802.11e supports service differentiation. Similarly, the MAC layer also offers a differentiated treatment to packets with different QoS requirements when passing them to upper stack layers.

Priority	UP	AC	Designation
Lowest	1	AC_BK	Background
	2	AC_BK	Background
	0	AC_BE	Best Effort
	3	AC_BE	Best Effort
	4	AC_VI	Video
	5	AC_VI	Video
	6	AC_VO	Voice
Highest	7	AC_VO	Voice

UP = User Priority; AC = Access Category

Table 1: UP-to-AC mappings

AC	$CW_{min..max}$	AIFSN	TXOP limit
AC_BK	15..1023	7	0 ms
AC_BE	15..1023	3	0 ms
AC_VI	7..15	2	3.008 ms
AC_VO	3..7	2	1.504 ms

Table 2: Default EDCA parameter values

This new standard introduces the Hybrid Coordination Function (HCF), which defines two new medium access mechanisms to replace the legacy Point Coordination Function (PCF) and Distributed Coordination Function (DCF). These are the HCF Controlled Channel Access (HCCA) and the Enhanced Distributed Channel Access (EDCA). Concerning IEEE 802.11e enabled stations forming an ad-hoc network, these must implement the EDCA. As in this paper we focus on ad-hoc networks, we are only interested in 802.11e stations implementing EDCA.

At the Application layer, frames are assigned a priority value ranging from 0 to 7, referred as User Priority (UP). This is achieved using the first three precedence bits of the [Type of Service] (ToS) field in an IPv4 datagram header or the [Traffic class] field in an IPv6 datagram header. Depending on this UP, when a frame arrives at the MAC layer, it is classified into one of the four Access Categories (AC); the mapping between the different UPs and these four ACs is illustrated in Table 1.

Contrarily to the legacy IEEE 802.11 stations, where all MAC Service Data Units (MSDU) have the same priority and are assigned to a single backoff entity, IEEE 802.11e stations have four backoff entities (one for each AC) so that packets are sorted according to their priority. Each backoff entity has an independent packet queue assigned to it, as well as a different parameter set for medium access. Table 2 presents the default MAC parameter values for the different ACs (referred as EDCA parameters) for an IEEE 802.11a/g radio.

For IEEE 802.11 legacy stations this parameter set was fixed, and so the CWmin and CWmax where set to 15 and 1023, respectively (for IEEE 802.11a); also, the time interval between frames - interframe space (IFS) - was set to a constant value: DIFS. With IEEE 802.11e, as the values of EDCA parameters depend on the AC itself, they are referred to as CWmin[AC], CWmax[AC], AIFSN[AC] and TXOP limit[AC].

IEEE 802.11e introduces a new feature referred to as transmission opportunity (TXOP). A TXOP is defined by a start time and a duration; during this time interval a station can deliver multiple MPDUs consecutively without contention with other stations. This mechanism, also known as Contention-Free Bursting (CFB), increases global throughput through a higher channel occupation. From Table 2 we can notice that smaller values for the CWmin, CWmax, and AIFSN parameters are associated in a higher priority when accessing the channel; relative to the TXOP limit, higher values result in larger shares of capacity and, therefore, higher priority.

3 Methodology

In order to make a rigorous comparative study, the same scenarios have been tested in both ns-2 and OPNET Modeler simulators, taking special attention to the characteristics of OPNET's models and the simulation parameters used. Because of some differences have been identified between both simulators, modifications have been carry out, which can be classified into five mayor categories:

1. Some default simulation parameters does not match in both simulators, for example, the default transmission range in OPNET is 371m for a data rate of 54 Mbit/s, which is significantly higher than the default in ns-2 (250m).
2. Routing priority. The routing traffic of the AODV protocol was set to a higher priority (AC_VO) according to the recommendations in annex E of the IEEE 802.11 standard [2]. Besides being the recommended procedure, it will also improve the overall network performance (see [5] for details).
3. Internal collisions. Unexpectedly, the firsts results obtained with OPNET showed high variability, and the ranking of ACs in terms of throughput seemed to be chosen randomly in most cases. This was due to the internal node collisions at the MAC layer. For dealing with this problem, instead of each source node generate traffic in all four ACs, as with ns-2, each node in a group of four source nodes was set to generate traffic in only one distinct AC.
4. A critical difference detected between both simulators is the meaning of some important metrics, namely, *load* and *throughput* per Access Category (AC), which are usually evaluated on the source node and on the destination node, respectively. However, OPNET evaluates these parameters in a different way, considering all nodes of the network, not only the end nodes. This severely affects the comparability of the final results, changing the relative ranking among those statistics per AC. To solve this problem we defined new statistics on OPNET's 802.11 and 802.11e MAC models.
5. A critical difference has been found when legacy 802.11 and 802.11e nodes coexist in a same scenario. In the original IEEE 802.11 standard [2] there is no support for service differentiation. With ns-2, an intermediate 802.11 node is *transparent* in the sense that if that node receives a packet from a 802.11e node, although the

Parameter	Static scenario	Mobile scenario
Size	1900m x 400m	
Commun. range	250m	
Nodes		
+ Nb. of nodes	[8..15]	50
+ Placement	See Fig. 1	Random
+ Legacy nodes	0 %	[0..100] %
Traffic		
+ Load per AC	[0.125..6]	0.2 Mbit/s
+ Nb. of sources	4	[4..48]
Mobility	No	[No,Yes]
+ model	-	RWM
+ speed	-	5 m/s
+ pause time	-	0 s

RWM = random waypoint model

Table 3: Simulation parameters

QoS information of the incoming packet is not processed, it is preserved when the packet is forwarded to the next hop, which could be 802.11e or not. On the other hand, this information is lost with OPNET since intermediate nodes automatically set the ToS field of the IP packet header to zero before retransmission.

The modified models have been debugged and validated using several test-bench scenarios prior to running all simulation sequences. The implemented scenarios can be divided into two types: static and mobile scenarios, and several experiments where conducted in each one, as described in the next sections. Table 3 shows the more important simulation parameters. In order for mobility models to converge, statistics are collected after an initialization period of 60 seconds, mitigating the initial transient problem [10]. In all cases, the offered traffic is generated at a constant bit rate (CBR) using UDP fixed size packets of size fixed of 512 bytes for all four ACs.

The obtained results involve the following metrics:

- *Throughput*: the amount of data traffic successfully delivered to a final destination node for a certain data flow.
- *Latency* or *end-to-end delay*: the average amount of time measured from the instant a data packet is originated until the packet is successfully delivered to the final destination.
- *Average number of hops*: number of router nodes in the end-to-end path (source not included).
- *Routing overhead*: total number of routing packets/bytes .
- *Bandwidth share per AC*: percentage of the total throughput obtained by a certain AC.

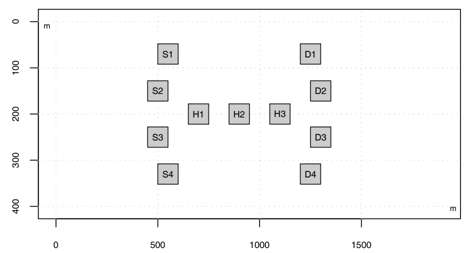

Figure 1: Static scenario

4 Static scenario

4.1 Description

The static scenario consists of several fixed nodes, placed as shown in Figure 1, adjusting the transmission range to 250m so that the average number of hops from each source to each destination was of four. This scenario have four source/destination pairs (S_i,D_i) i=1..4, and three cases are considered. Firstly, with an average number of hops of four, increasing the offered traffic per AC from 0.125 to 6 Mbit/s. In the second case the offered traffic is set to a fixed value (3 Mbit/s), varying the average number of hops from 1 to 8. Thirdly, the AC_VO and AC_VI traffic were fixed at a data rate of 0.5 Mbit/s and 1.0 Mbit/s, respectively, while varying the low priority ACs traffic.

Each simulation last 360s, and the number of iterations was 10 (different seeds).

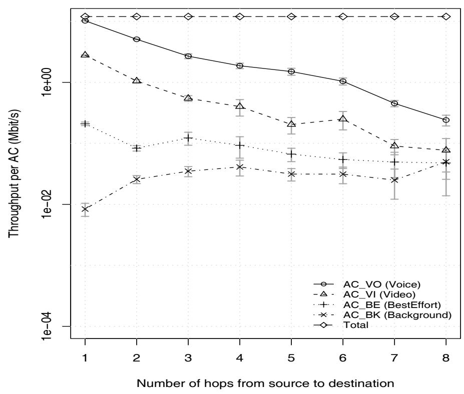

Figure 4: Throughput achieved without CFB

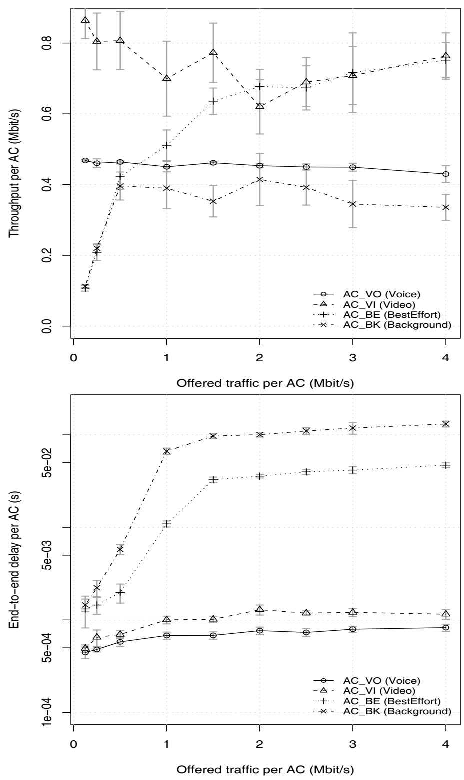

Figure 5: Throughput (top) and end-to-end delay (bottom) without CFB

ure 4, as average number of hops increases, throughput decreases quickly, although relative rankings are maintained according to their priority. Again, activating the CFB mechanism has clearly a favorable impact for the Video AC, similarly to ns-2, at the expense of Voice AC.

Finally, in the last experiment we examine the stability of AC_VO and AC_VI traffics when varying the data rate of the lower priority ACs. From Figure 5, AC_VO is not affected at all in terms of throughput, although AC_VI is slightly affected; with ns-2, neither of both were affected. As similar than ns-2, activating the CFB mechanism has no impact on the results, and variations suffered in terms of end-to-end delay are quite similar.

5 Mobile scenario

5.1 Description

In this section, a suite of ten randomly generated scenarios is considered, each composed of 50 mobile nodes randomly placed on a rectangular scenario sized 1900m x 400m. The model was first simulated without mobility, and then with a predefined trajectory assigned to each node within the working area using the random waypoint model (RWM) [7]. In both cases, the CFB functionality was disabled, and the generate traffic was CBR/UDP with a bit rate of 0.2 Mbit/s per AC. The number of communicating pairs is variable, ranging from 4 to 48. The purpose of this experiment is to evaluate the impact of node mobility on the different metrics, and all results are presented in the following section.

5.2 Results

For the static scenario, the results obtained (not shown here) were quite different. First, the throughput achieved by each AC does not approach the network load, as with ns-2. Secondly, and contrarily to ns-2, this metric shows a slightly ascending trend for both AC_VO and AC_VI when the number of sources increases. On the other hand, the throughput

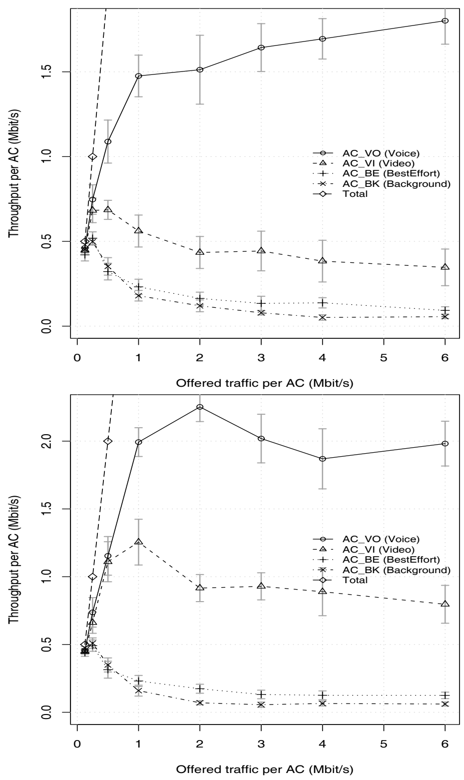

Figure 2: Throughput achieved without CFB (top) and CFB activated (bottom)

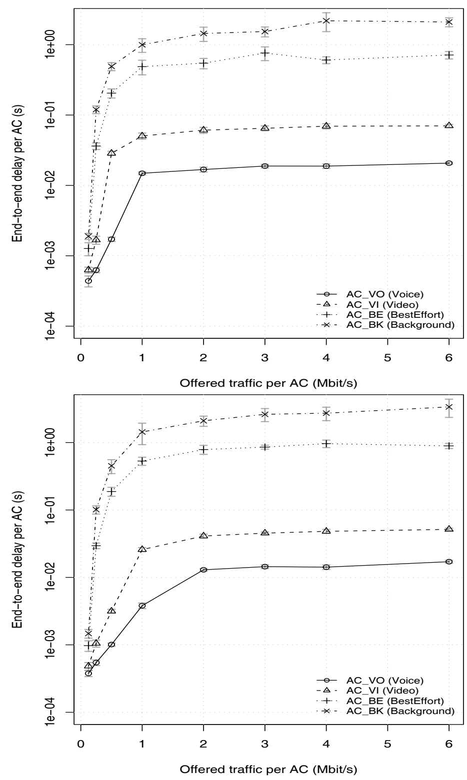

Figure 3: End-to-end delay achieved without CFB (top) and CFB activated (bottom)

4.2 Results

This section presents the results collected during the simulation of the scenario described above using the OPNET Modeler simulator, comparing them with those from ns-2 [4]. When varying the offered traffic, comparison of throughput per AC results shows a similar trend, though different absolute values with both simulators (see Figure 2). When increasing network load the throughput per AC stabilizes, and the relative ranking among throughput per AC matches with the priorities assigned to each traffic. However, the total throughput obtained is lower than that for ns-2. As expected, activating the CFB in both simulators clearly favors to the Video AC throughput. Contrarily to ns-2, best-effort and background traffics keep a minimal throughput as the load increases; in ns-2, both suffered starvation for an offered load above 4 Mbit/s. In terms of end-to-end delay (see Figure 3) the obtained results are, in general, similar in both simulators, with low priority ACs experiencing higher delays. However, the absolute values are quite different, especially when the load is high: delays values with ns-2 are higher compared to OPNET.

In a second experiment we vary the average hop count between source and destination. We observe similar results for 1 or 2 hops. As the number of hops increases, the throughput decreases in all ACs, being this decay more pronounced in OPNET that in ns-2. From Fig-

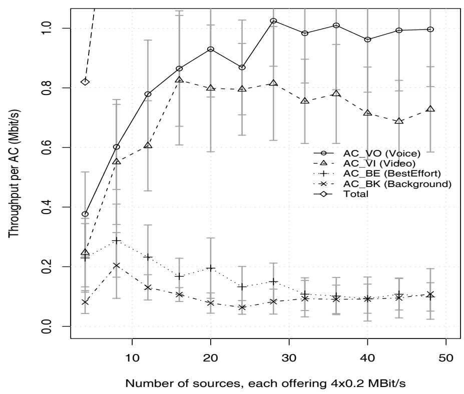

Figure 6: Throughput achieved with mobility

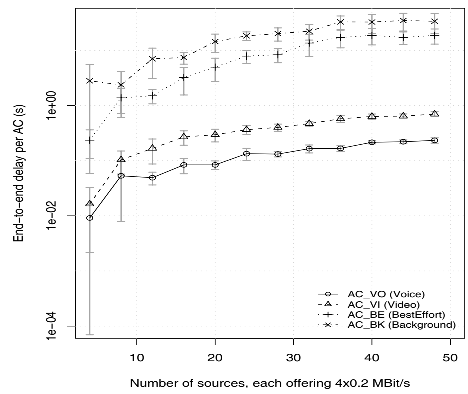

Figure 7: End-to-end delay achieved with mobility

achieved is higher for all 4 ACs when nodes have mobility than when they are static, for any number of sources, as illustrated in Figure 6. Also, saturation limits are reached for a higher number of sources. As stated in [4], this is a direct consequence of the fact that there are a great number of available paths in the mobile scenario. However, the absolute values are lower than in ns-2. Furthermore, these results indicate that the positions of the nodes have a great importance, as can be deduced from the large confidence intervals shown in the plot. As shown in Figure 7, end-to-end delay are very similar for both simulators when increasing the number of sources, both in terms of general trend and absolute values. However, the rate of growth in OPNET is more constant and progressive than in ns-2.

6 Heterogeneous scenario

6.1 Description

In this analysis the number of sources is set to a fixed value (4) varying the percentage of randomly chosen legacy stations. Our main goal is to analyze the decay in QoS support in presence of 802.11 stations.

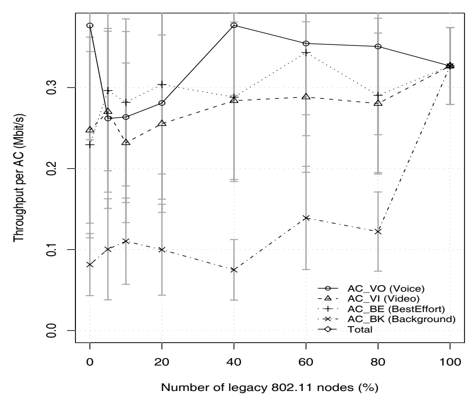

Figure 8: Throughput achieved with mobility

6.2 Results

Contrarily to the results obtained with ns-2, network performance not only does not drop but throughput shows a stabilized or slightly ascending trend in all four ACs as the number of legacy 802.11 nodes increases, as shown in Figure 8. Before applying the last modification referred in section 3, throughput in AC_BE grew significantly as the number of 802.11 stations increases. Although not shown, similar end-to-end delay values are obtained in both simulators, whereas the increase is more progressive in OPNET than in ns-2.

7 Conclusion

In this paper, a comparative study between two common network simulator tools have been carried out, namely, ns-2 and OPNET Modeler, involving several static and mobile MANETs scenarios using IEEE 802.11g/e. Some important differences between the simulators have been reported, and the corresponding modifications to deal each of them are presented. After describing the scenarios, the obtained results using OPNET are shown, comparing them with the previously published results using ns-2.

Results showed that the referred modifications are necessary in order to address such critical differences and to obtain similar results. The conclusions based on the simulation results for the different MANET scenarios are that the trend of all the metrics in both simulators were rather consistent, although in certain experiments absolute values are different.

At sight of the above results we can conclude that more comparisons between network simulators in general, and between ns-2 and OPNET Modeler in particular could be done. Specifically, we will carry more experiments comparing both simulators under different topology parameters, signal propagation models, complex traffic patterns, or the behavior of different routing protocols, like DSR, OLSR, etc.

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