Performance Analysis of IEEE 802.11 EDCA for a Different Number of Access Categories and Comparison with DCF

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Abstract. Performance analysis of the 802.11 EDCA and DCF using simulation and analytical model is presented. An impact of different number of ACs in the network performance is studied under nonsaturation and saturation network condition. Additionally, it is shown that the EDCA doesn't provide a good prioritized access in contrast to the DCF, when only one traffic type is being transmitted through the wireless network.

Keywords: wireless networks, 802.11, medium access control, DCF, EDCA, throughput analysis.

1 Introduction

IEEE 802.11 [1] standard is one of the most popular standards of wireless LANs. The wireless LAN's performance strongly depends on the transmission rate and on the design of the medium access control (MAC) protocol. Technology innovations have significantly increased the transmission rate through wireless environment. At the same time almost all wireless networks still use the same MAC protocol based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme with slotted Binary Exponential Backoff (BEB) algorithm. This MAC protocol provides contention-based access to the physical environment. As it has been shown in [2] the throughput of the 802.11 wireless LANs is bounded by the overhead of the MAC protocol. Therefore, there are many studies focused on the MAC protocol improvement and extension to maximize channel capacity and utilization.

The CSMA/CA scheme, implemented in the early versions of 802.11 MAC, is referred to as Distributed Coordination Function (DCF). Later, with significantly growing multimedia traffic and number of real-time applications that require supporting of a Quality of Service (QoS), the DCF has been improved by Enhanced Distributed Channel Access (EDCA) scheme. The EDCA scheme defines four access categories (ACs) that provide support for the delivery of prioritized traffic.

This paper is focused on the performance analysis of the EDCA scheme with a different number of ACs compared to the performance of the DCF scheme under saturation and nonsaturation network conditions.

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2 Overview of 802.11 DCF and EDCA Schemes

The distributed scheme DCF, based on the CSMA/CA, provides the basic asynchronous and contention-based shared access to the physical environment. Before a station starts transmission, it senses the wireless medium. If a station senses no transmission on the channel, it considers the channel state as idle; otherwise it considers the channel state as busy. If the medium is idle for the Distributed Interframe Space (DIFS) the station waits for a random backoff interval. Here backoff counter is uniformly and randomly chosen in the range $[0, \mathrm{CW}]$, where CW – Contention Window. If during and after backoff the medium is still sensed idle, then the node is permitted to begin the transmission process. If the medium is busy, then station postpones its transmission for a random period of time. In case of successful transmission a receiver after the Short Interframe Space (SIFS) immediately transmits a positive Acknowledgement (ACK). Thus, only one station can successfully transmit in the network at a given time. The DCF has not been developed to support prioritized traffic; therefore packets with a different priority are being processed identically.

As opposed to DCF scheme the EDCA scheme has been designed to support QoS. In EDCA, frames from the upper layers are mapped onto one of the four ACs according to their priority: background (AC_BK), best effort (AC_BE), video (AC_VI) and voice (AC_VO). Each AC has a transmission queue and the access parameters: minimal and maximal values of CW, Arbitration Interframe Space (AIFS), which is larger or equal to the DIFS. Each AC independently executes DCF scheme in order to resolve internal collision between ACs. If waiting time reaches zero simultaneously for two or more frames in different AC queues, then the frame with the higher priority gets the opportunity to be transmitted. Minimal and maximal CW as well as AIFS are shorter for higher-priority ACs. Therefore, higher-priority frames have a better chance to get transmission opportunity than lower-priority ones.

3 Performance Analysis

It is assumed that EDCA scheme can have a different number of ACs (not only four as it is defined in IEEE 802.11e). Our goal is to study the throughput variations of a wireless network for different number of ACs as a function of the number of stations in the case of saturation network condition, or as a function of the offered load in the case of nonsaturation network condition.

3.1 Simulation Setup

To perform the simulation experiments, we have developed a wireless simulator [3]. Additionally, we use an Engelstad's analytical model [4] (we call the model by the first author's name). Engelstad's model allows to simulate EDCA and DCF schemes under both saturation and nonsaturation network condition.

A simulated wireless network consists of several wireless stations and an access point, which are located within the Basic Service Set (BSS), i.e., every station is able to detect a transmission from any other station. The wireless network works in the Infrastructure mode, when all stations send and receive traffic via an access point. The channel condition is assumed to be ideal and each station operates at the transmission rate of 54 Mbit/s. The other parameter settings for MAC and physical layers are shown in Table 1.

Table 1. Parameter settings for MAC and physical layers

Frame size	2312 bytes
MAC-header	34 bytes
PHY-header	32 bytes
ACK	14 bytes
Slot time	20 μs
SIFS	10 μs
Retry limit	16

3.2 Simulation Scenarios

In order to study the impact of the number of ACs on the wireless network performance we define five scenarios:

Scenario 1. There is only one AC and the wireless network works using DCF scheme.
Scenario 2. There are two different ACs for video (AC_VI) and background (AC_BK) traffic.
Scenario 3. There are four ACs, as defined in the IEEE 802.11e standard.
Scenario 4. There are eight ACs that correspond to the user priorities defined in the IEEE 802.1D.
Scenario 5 is similar to Scenario 3, but only one of the four traffic types is present in the wireless network.

The AC parameters for each scenario are shown in Table 2. The higher number the AC has the higher-priority traffic it corresponds to. Traffics for each AC type are equally generated by station.

3.3 EDCA Performance under Saturation Network Condition

Simulations using the simulator and the analytical model have been done for each scenario where the number of the ACs changes from 1 to 8.

Our goal is to simulate the throughput variations of the wireless network as a function of the number of stations. Additionally, we compare them with the results obtained from the analytical model.

Table 2. AC parameters for five scenarios

Scenario	1	2		3 and 5				4			
AC	0	0	1	0 (AC_BK)	1 (AC_BE)	2 (AC_VI)	3 (AC_VO)	0,1	2,3	4,5	6,7
CWmin	31	31	15	31	31	15	7	31	31	15	7
CWmax	1023	1023	31	1023	1023	31	15	1023	1023	31	15
AIFS (μs)	50	150	50	150	70	50	50	150	70	50	50

Fig 1 shows the total normalized throughput of the saturated wireless network, when a station always has frames, which are ready to be sent, for Scenarios 1–4 is shown.

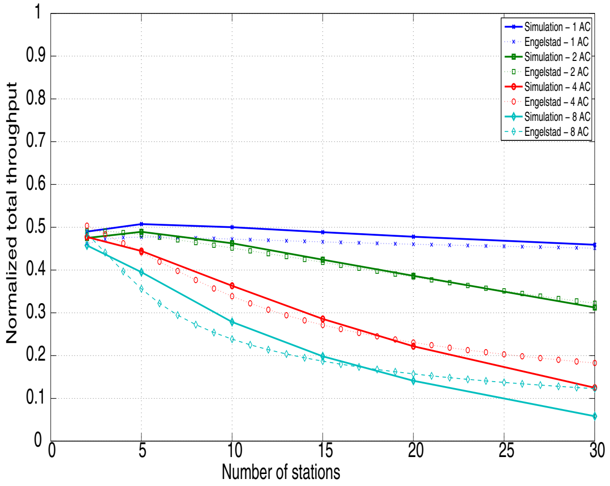

Fig. 1. Normalized total throughput as a function of the number of stations

In each scenario the total normalized throughput decreases with increasing the number of stations in the network. For a small network (number of stations is less than 5) the normalized throughput varies in the range 0.4–0.5. For larger networks the difference between the throughputs increases with increasing the number of stations. For example, in the case of 15 stations the throughput difference between network with 1 and 2 ACs is 0.06. For the network with 4 ACs the total normalized throughput is approximately one half of the total normalized throughput for the network with 1 AC. And in the case of the network with 8 ACs the total normalized throughput is bounded by the value 0.2. If the number of stations in the network is increased to 30 then the total normalized throughput for the networks with 2, 4 and 8 ACs is 1.5, 3.7 and 7.9, respectively, i.e., less than the normalized throughput for the network with 1 AC, that is DCF scheme.

Hence, we can conclude that an increase in the number of ACs in the saturated network may significantly decrease the total throughput. In the worst case – up to 8 times, and in the case of the 802.11e standard – up to 3.7 times. Also, the total throughput dramatically decreases with increasing the number of stations in the network. One of the reasons of such dependency may be the use of collision avoidance mechanism. Fig 2 shows collision probability as a function of the number of stations and the number of ACs in the network.

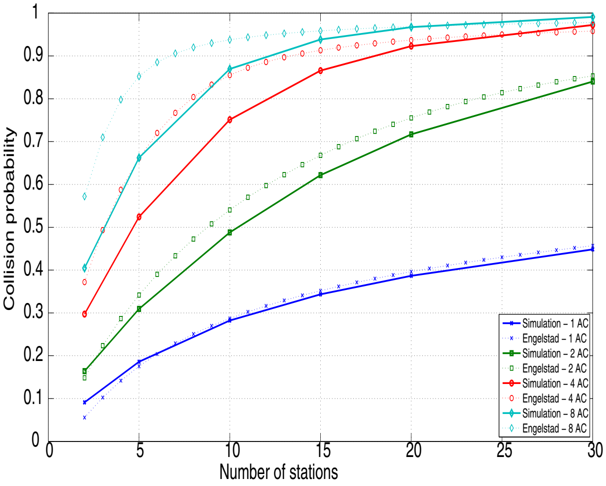

Fig. 2. Collision probability as a function of the number of stations

The collision probability for the network with 1 AC is approximately one half of the collision probability for the networks with 4 and 8 ACs. For the large networks with 4 and 8 ACs the collision probability tends to 1. Hence, a station wastes time applying the mechanism of collision avoidance instead of successful transmitting.

If we analyze the normalized throughput for each AC (Fig. 3), then we can see that the network with 2 ACs provides quality of services for the higher-priority frames under saturation condition. Even for the large network the normalized throughput is approximately 0.3, as opposed to the networks with 4 and 8 ACs. The network with 4 ACs provides good priority-access for the higher-priority frames only in small networks. The performance efficiency decreases with increasing the number of stations. For 30 stations the normalized throughput of the highest-priority traffic is bounded by the value 0.1, whereas for the network with 2 ACs this value is 0.3. For the network with 8 ACs the best throughput for the higher-priority frames (approximately 0.14–0.16) is provided if the network size is small. Otherwise the throughput is significantly low for each type of traffics.

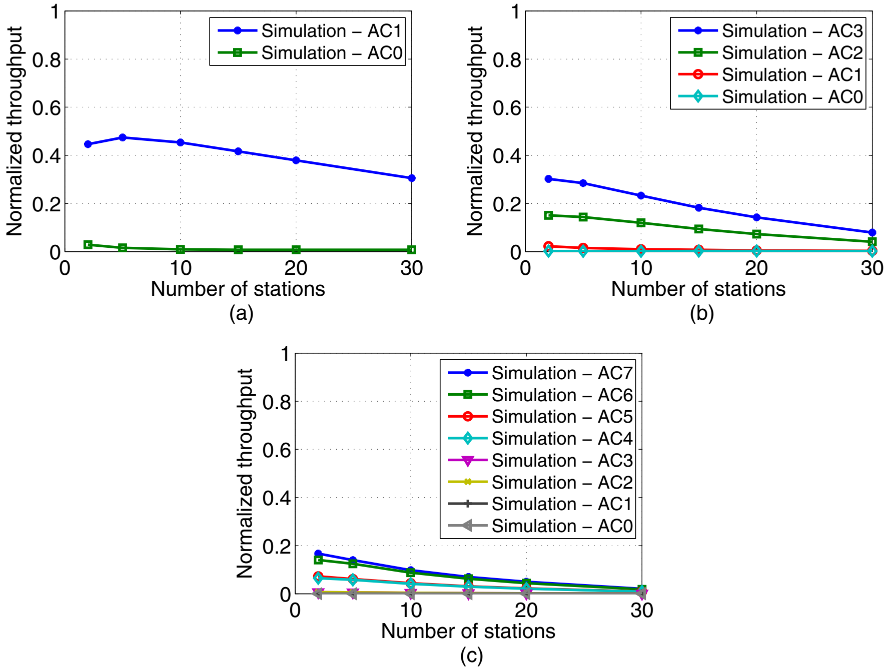

Fig. 3. Normalized throughput for networks with 2 ACs (a), 4 ACs (b) and 8 ACs (c) as a function of the number of stations

For Scenario 5 it is assumed that the saturated network uses the EDCA scheme with 4 ACs as it is defined in the 802.11e standard. Each station transmits only one of the four traffic types. Normalized throughputs for each traffic type in comparison to throughput of the DCF scheme are shown in Fig. 4.

Hence, we can see that under the saturation condition the throughput for the EDCA scheme in the presence of only one of the four traffic types is lower than the throughput for the DCF scheme. The highest throughput difference is observed when only voice traffic is transmitted in the network. In the case of 30 stations the throughput for the EDCA scheme is one half of the throughput for the DCF scheme. It is because under the saturation condition frames collide more frequently, and at the same time for the higher-priority frames the CWmax is half or equal to the CWmin of the lower-priority frames. Thus, after applying the collision avoidance mechanism, a probability of two or more stations to generate equal backoff and the probability for higher-priority frames to collide again increases. Because CWmin equals to CWmax for the background and best effort traffics, the only reason for the throughput difference is to apply the AIFS-differentiation. Hence, an increase in the number of AIFS from 70 to 150 μs decreases the throughput by about 0.05. For the saturated wireless network, when stations always have ready-to-be-sent frames, the EDCA priority-access scheme in general is less efficient (provides a lower total throughput) than the DCF scheme that doesn't provide priority access. Using of the EDCA with 2 ACs

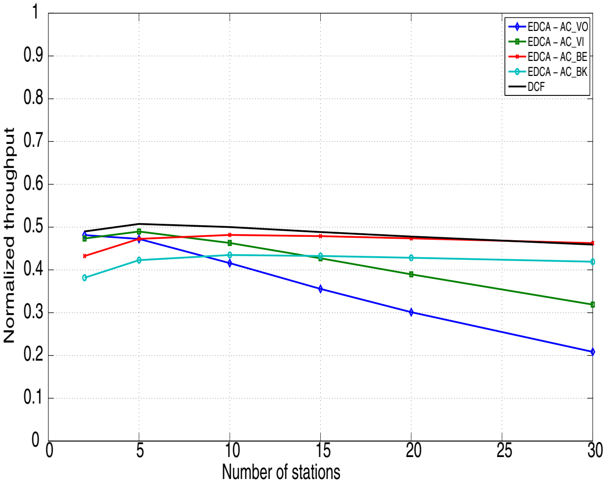

Fig. 4. Normalized throughput for each type of traffic as a function of the number of stations

allows to provide a good prioritized access for the higher-priority traffic. And the total throughput for the EDCA with 2 ACs is lower than the throughput for the DCF by just about 0.05–0.1.

3.4 EDCA Performance under Nonsaturation Network Condition

The saturation network condition allows to study a limiting behaviour of the 802.11 standard and to obtain a bound value for the network throughput and delay. However, realistic networks are not fully saturated due to bursty data traffic. Therefore, in this section we study network throughput in a full load range from a nonsaturated to a saturated input traffic.

Simulations for the variable-offered load have been done taking into account the network size. The network consisting of 5 stations corresponds to a small network, 15 stations – a midsized network, 30 stations – a large network. Different network size allows to analyse its influence on the network characteristics.

The total normalized throughput as a function of the offered load is shown in Fig. 5.

The total normalized throughput dependence increases for both the simulator and the analytical model for the offered load between 0 and 0.5. Then it saturates. The network transmits almost all offered load that is lower than 0.4 for all scenarios. Only in the case of the large network (Fig. 5c) for Scenarios 3 and 4 the total normalized throughput becomes saturated for the offered load higher than 0.3. At the same time, the total throughput saturates faster for more stations and more ACs in the network.

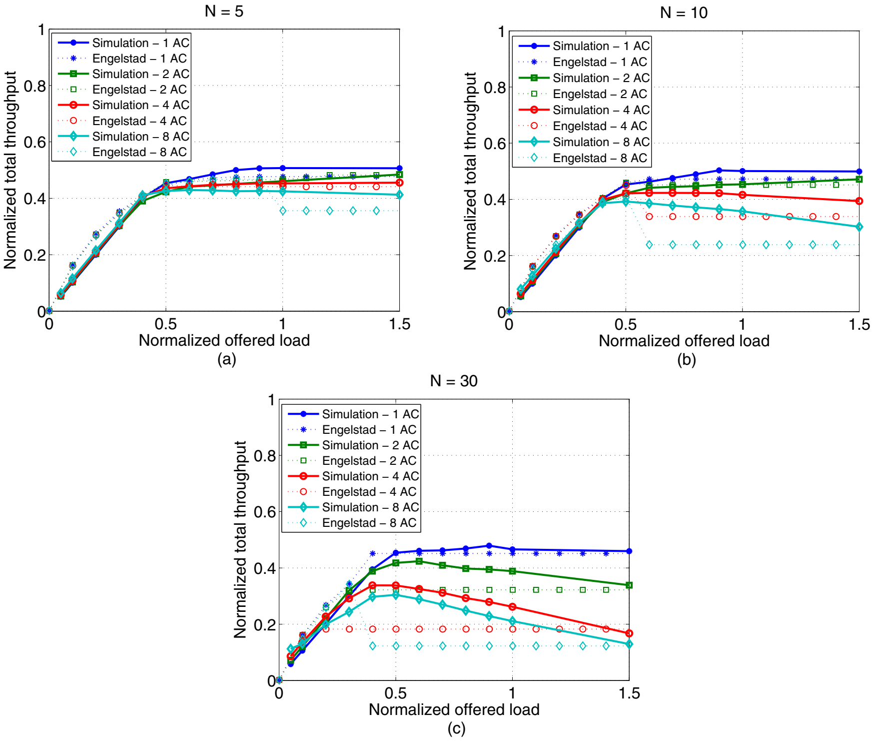

Fig. 5. Normalized total throughput for small (a), midsized (b) and large (c) networks as a function of the offered load

For the offered load in the range 0.1–0.4 the total normalized throughput obtained by the analytical model is higher than the offered load by about 0.07. It means that the station transmits more traffic than it generates. These discrepancies have also been noted in [4]. There it has been suggested that probably the AIFS-differentiation is done rough. For the higher offered load than 0.4–0.5 there are also noticeable discrepancies between the results of the analytical model and the simulator due to numerical errors.

The efficiency of the EDCA prioritized scheme in the full load range can be estimated by analysing the throughput for each AC. Fig. 6 shows a normalized throughput for each AC of the midsized network that has 2, 4 or 8 ACs as a function of the offered load. As it is shown analysing the total throughput the offered load lower than 0.4 is almost all transmitted through the network. As the offered load increases, the higher-priority traffics achieve higher throughput than the lower-priority traffics. Even for a highly loaded network the EDCA provides a prioritized access for the higher-priority frames. With an increase of the number of ACs the effectiveness of the differentiated service decreases.

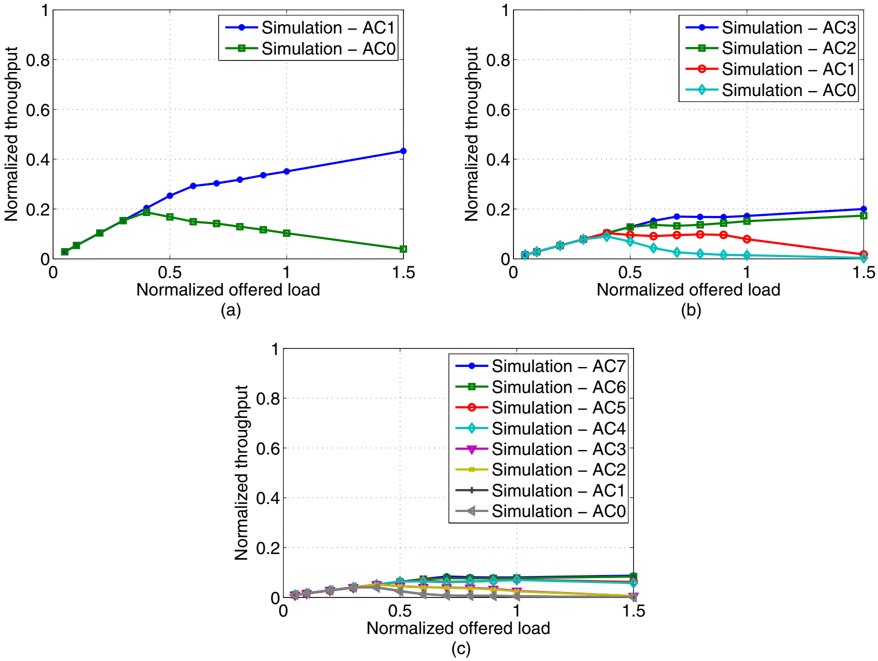

Fig. 6. Normalized total throughput for midsized networks with 2 ACs (a), 4 ACs (b) or 8 ACs (c) as a function of the offered load

Also, it can be observed that for the traffic AC1 in case of network with 4 ACs (Fig. 6b) the normalized throughput in the range 0.4–1 is about one half of the throughputs of the traffics AC2 and AC3. This is revealed by means of an increase of the offered load that leads to more collisions between higher-priority frames, and gives the opportunity to be transmitted for the traffic AC1.

We conclude that the EDCA efficiency strongly depends on the offered load, the number of stations and on the number of ACs. The higher these parameters are the less efficient EDCA is.

4 Conclusions

We presented a simulation and analytical analysis of the EDCA efficiency for the network with a different number of the ACs. The prioritized channel access provided by the 802.11 standard is sensitive to the size of the network, the network load, and the number of ACs. The higher these parameters are the less efficient EDCA is. It is shown that decreasing of the number of ACs can improve the total throughput, even under highly load network condition. Use of the EDCA with 2 ACs provides a good prioritized access for the higher-priority traffic in the full load range (from nonsaturation to saturation). Although the EDCA provides the prioritized access, for larger networks EDCA is inefficient in contrast to the DCF, especially when only higher-priority traffic is present in the network. The possibility of an adaptive adjusting of the number of ACs for increasing the total performance of a wireless network may be studied in the future works.

References

1. IEEE Std 802.11™-2007, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. IEEE Std. (2007)
2. Xiao, Y., Rosdahl, J.: Performance analysis and enhancement for the current and future IEEE 802.11 MAC protocols. ACM SIGMOBILE Mobile Computing and Communications Review (MC2R), Special Issue on Wireless Home Networks 7, 6–19 (2003)
3. Leontyeva, O., Obelovska, K.: Modeling of the multiple access method to physical environment of wireless networks. The Technical News 1(25)-2(26), 78–81 (2007)
4. Engelstad, P., Østerbø, O.: Analysis of QoS in WLAN. Telektronikk 1, 132–147 (2005)