Analysis of Packet Throughput and Delay in IEEE 802.11 WLANs with TCP Traffic

Riyadh Qashi
Faculty of Mathematics and
Computer Engineering, University of Leipzig
Johannisgasse 26, 04103 Leipzig, Germany.
Email: qashi@informatik.uni-leipzig.de

***Abstract*-The IEEE 802.11 standard is a successful wireless local area networks (WLAN) technology, because of its easy deployment. With WLAN, the ability of the IEEE802.11 standard to support multimedia applications with high quality of service (QoS) requirements has increased. This paper evaluates the capability of QoS support in Enhanced Distributed Channel Access (EDCA) mechanism of the IEEE 802.11e standard using TCP protocol. The EDCA is an enhancement for QoS support in 802.11. EDCA mechanisms allow prioritized medium access for applications with high QoS requirements by assigning different priorities to the access categories. The current work discusses the performance evaluation of 802.11 and 802.11e by simulations using TCP protocol. A comparative discussion between DCF und EDCA with TCP protocol is reported for different services, such as voice, video, best-effort and background traffic. Results and simulations show that the TCP protocol is usable for transferring audio and video data within special programs and applications. Moreover, it is shown that the UDP protocol with its higher performance is more suitable for this task**.

Keywords-component; TCP, EDCA, DCF, 802.11e, AC, WLAN, 802.11, QoS

I. INTRODUCTION

The IEEE 802.11 standard is a significant milestone in the provisioning of network connectivity for mobile users. However, due to the time-dependence characteristics of wireless links, interference from other devices and terminal mobility, 802.11-based wireless local area networks (WLAN's) suffer from performance drawbacks in relation to wired networks. In order to provide a proper wireless networking service for real-time applications, securing the quality-of-service (QoS), lower information (packet) loss and minimum latency should be featured. In order to provide a sufficient QoS for real time applications, the transfer service should be carried out via different priorities.

The architecture of IEEE 802.11 standard includes the definitions of Medium Access Control (MAC) layer and Physical Layer (PHY). Its MAC layer already provides two basic access methods: DCF (Distributed Coordination Function) and PCF (Point Coordination Function): a) DCF uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol, and it is best known for asynchronous data transmission. b) PCF uses a central-controlled polling method to support synchronous data transmission [1]. Up to now, only DCF is implemented in application devices [3], [14]. The IEEE802.11 wireless networks can be configured into two different modes: ad hoc and infrastructure modes. In ad hoc mode, all wireless stations within the communication range can communicate directly with each other, whereas in infrastructure mode, an access point is needed to connect all stations to a Distribution System, and each station can communicate with others through the access point [12].

The IEEE 802.11 DCF can only provide best-effort services without any QoS guarantee [1]. In DCF, every station statistically has the same probability to access the channel and transmit no matter what kinds of traffic they are sending. Obviously, this kind of channel access mechanism is challenged by time bounded services, such as VoWLAN, video conferencing, requiring guaranteed bandwidth, delay and jitter [2]. Without prioritized traffic, a station may have to wait an arbitrarily long time before it gets the chance to transmit so that these real-time applications may suffer [15]. In order to support application with QoS requirements, the IEEE 802.11 standard group has specified the IEEE 802.11e standard. The EDCF (IEEE 802.11e) protocol supports QoS and provides different services.

In this study, the capacity of the transfer is investigated, using the enhanced distributed channel access (EDCA) along with different access categories

DOI: 10.5176_2010-2283_1.4.110

(ACs: AC0, AC1, AC2 and AC3) [6]. The simulation is done using the INETMANET framework OmNET++ [4], [5]. Moreover, a comparison between DCF and EDCF is made. In section II and III, the DCF and EDCF are described respectively. The simulation and corresponding analysis of the capacity of EDCA with different ACs are explained in section IV. Finally our concluding remarks are given in section V.

II. DCF

The DCF of IEEE 802.11 is a fundamental MAC method and is based on the CSMA/CA protocol [6]. The DCF uses the CSMA/CA protocol and it is implemented for asynchronous transmission (best-effort). The DCF works with a single first-in-first-out (FIFO) transmission queue. The CSMA/CA comprises a distributed MAC based on a local assessment of the channel status, i.e. whether the channel is busy or idle. The initiation of delivery for any packet is preceded by the detection of the station's wireless medium. The medium should be idle for a minimum duration called DCF interframe space (DIFS). The station selects, randomly, the backoff timer interval from [0, CW_{min}] (CW: contention window); the backofftime = backoff-counter × SlotTime, where the SlotTime parameter depends on the underlying PHY, and then enters the backoff process [7]. Parallel to the count-down of the backoff timer, if the station detects the busy state of the medium, it stops decrementing the timer and does not reactivate the paused value until the channel is sensed idle again for more than a DIFS period. When a timer expires, the station is free to access the medium for a new packet transmission. When an acknowledgment frame is received, the transmission is considered successfully. The acknowledgment frame is transmitted after a short IFS (SIFS), which is shorter than the DIFS. As the SIFS is shorter than DIFS, the transmission of acknowledgment frame is protected from other station's contention. The CW is reset to minimum CW_{min} and the station stands-by for the next packet arrival. The transmission is considered failed if no acknowledgment is received within a specified timeout; the station repeats the backoff process with CW selection range doubled up to maximum contention window, CW_{max}. If the transmission has been re-tried for up to RetryLimit times, the packet will be discarded and the CW is reset to CW_{min} [8]. Note, the MAC parameters including SIFS, DIFS, Slot Time, CW_{min}, and CW_{max} are dependent on the underlying physical layer (PHY).

TABLE I: QoS-Parameters

ACs	Transport Protocol	CW_{min}	CW_{max}	$AIFS_N$	TXOP Limit
AC0	TCP	31	1023	7	0
AC1	TCP	31	1023	3	0
AC2	TCP	15	31	2	3 ms
AC3	TCP	7	15	2	1.5 ms

TCP: Transmission Control Protocol

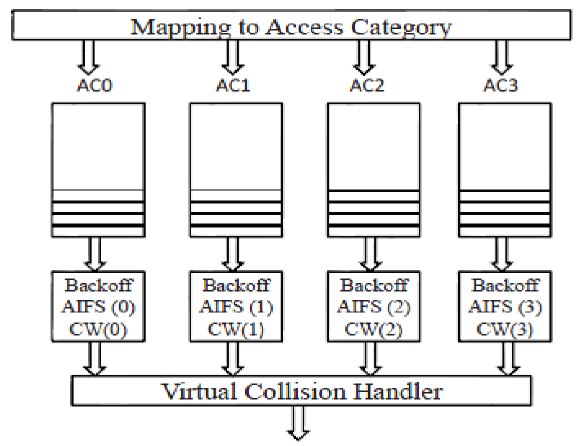

Fig. 1: Reference Implementation Model (Four ACs, each with its own queue, AIFS, CW and backoff timer). AC0: background, AC1:best-effort , AC2: video and AC3: voice

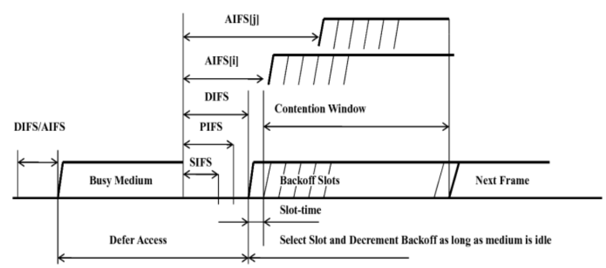

Fig. 2: Timing Relationship for EDCA

III. EDCF

The EDCF is an enhancement of DCF and provides prioritized QoS support among different types of traffic [9]. Each QoS-station defines eight user-priorities and maps the packets arriving at MAC layer into 4 different ACs (also known as EDCA), see Fig. 1. It assigns a set of backoff parameters, namely arbitration interframe space (AIFS), with the boundaries CW_{min}, and CW_{max} to each AC. Each AC uses its own backoff parameters to compete for the wireless medium by the same backoff rules as DCF stations described before, see Fig. 2.

The AIFS [AC], determined by

$$AIFS[AC] = AIFS_N[AC] \times SlotTime + SIFS. \quad (1)$$

It replaces the fixed DIFS in DCF (SIFS: short interframe space). The timing relationship of EDCA is shown in Fig. 2. Shorter AIFS[AC] in higher priority AC allow earlier timing for high priority traffic in order to unfreeze the paused timer after each busy wait period [3]. However, smaller CW sizes (statistically seen) provide shorter backoff stages to high priority traffic, see [8] for more details. An internal collision occurs when more than one AC finishes the backoff at the same time. In such a case, a virtual collision handler in every QoS-station allows only the highest-priority AC to transmit frames, and the others perform a backoff with increased CW values [10].

Transmission opportunity (TXOP) is defined in IEEE 802.11e as the interval of time when a particular QoS-Station has the right to initiate transmissions. The TXOP describes the sending interval, sending-start time and transfer period [13]. There are two modes of EDCA TXOP defined, the initiation of the EDCA TXOP and the multiple frame transmission within an EDCA TXOP [15]. An initiation of the TXOP occurs when the EDCA rules allow access to the medium. A multiple frame transmission within the TXOP occurs when an EDCAF retains the right to access the medium after the completion of a frame exchange sequence, e.g. on receipt of an acknowledgment frame. The TXOP limit duration values are announced by the QoS-Access Point in the EDCA Parameter Set Information Element in Beacon frames. During an EDCA TXOP, a station is permitted to transmit multiple MAC protocol data units (MPDUs) from the same AC with a SIFS time gap between an acknowledgment and the subsequent frame transmission. Hence, the throughput is raised. A TXOP limit value of 0 indicates that a single MPDU may be transmitted for each TXOP, see [7], [15] for more details.

IV. SIMULATION AND DISCUSSION

A. *Simulation Setup*

The network simulator Omnet++ and the available structures in the Inetmanet framework [5] are used to evaluate the performance of IEEE 802.11e EDCA mechanism and to compare this performance with the performance in DCF [11].

The simulation setup uses a single AP, a server and 4 stations (see Fig 3). The server contains the type TCPGenericSrvApp (*Generic server application for modelling TCP-based request-reply style protocols or applications*). Each station includes an AC. All stations contain the type TCPBasicClientApp (*Client for a generic request-response style protocol over TCP*). The types TCPGenericSrvAppn and TCPBasicClientApp are used together to send and receive TCP packets. All stations implement the TCP protocol to transmit their data. The simulation is performed for each EDCF and DCF in the simulation.

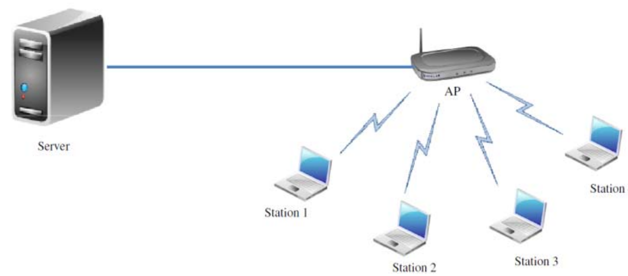

Fig. 3- Network topology used for simulations.

Consistent with specifications of the four Access Categories (ACs), background data (lowest priority), best-effort traffic, video traffic and voice traffic are carried under AC0, AC1, AC2 and AC3 (highest priority) respectively. In the simulation, the voice traffic started at second 5, video at secound 10, best-effort and background at second 15. The DCF mechanism uses the Best-Effort principal.

In all simulations, all PHY parameters are taken according to IEEE 802.11 standard: the maximum data rate is set at 11 Mbps and SlotTime = 20 ms. CW_{min} and CW_{max} are set at 31 and 1023 respectively while Short-IFS is 10 ms. The simulation parameters are shown in Table I for EDCA.

B. *SIMULATION RESULT*

The comparison of the mean throughputs of each traffic type, which started in different times, is plotted in Figs. 3 and 4. The figures show the effect of service differentiation on four concurrent TCP streams in DCF and EDCA; each set has a different Access Category. The figures show that the mean throughputs of voice, video, background and best-effort data are significantly different for the DCF rather than with the EDCA.

Figs. 4 and 5 show the simulation results of the mean throughput in EDCA and DCF. They show how EDCA behaves in the standard IEEE802.11e; the mean throughput of the voice traffic (AC3) in Fig. 4 is much higher than the best-effort (AC1) and background (AC0) with low priorities access category. This result suggests that the EDCA is able to provide service differentiation between different types of traffics over TCP. The mean throughput of voice in Fig. 5 for DCF reaches 0.32 ± 0.03 Mbps, while for EDCA it is 0.57 ± 0.05 Mbps. In Figs. 4 and 5, the throughput for video is higher in DCF than in EDCA. The mean throughput in DCF is low, because DCF is using the same CW-value for all ACs.

It can also be seen that the throughput of background and best-effort is low in EDCA as compared to it with DCF. This is due to DIFS, AIFS and contention window sizes dictated in this work. This high difference in throughput between voice in DCF and EDCA supports the usage of EDCA for streaming media and to use it for the transmission of VoWLAN.

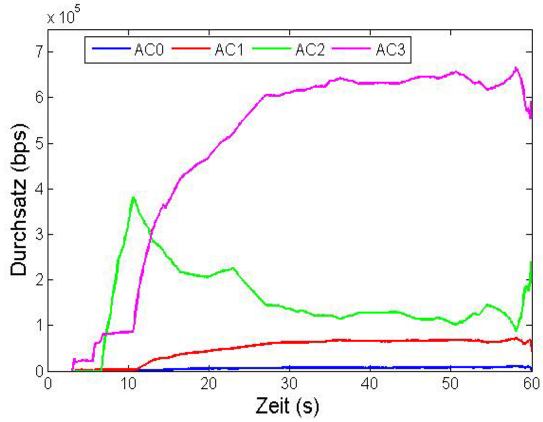

Fig.4- Mean throughput in different access categories in EDCA for scenario 1

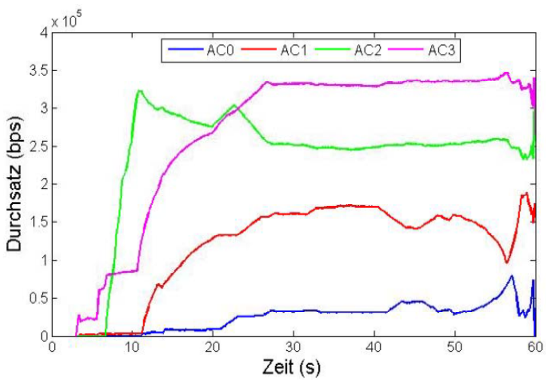

Fig.5- Mean throughput in different access categories in DCF for scenario1

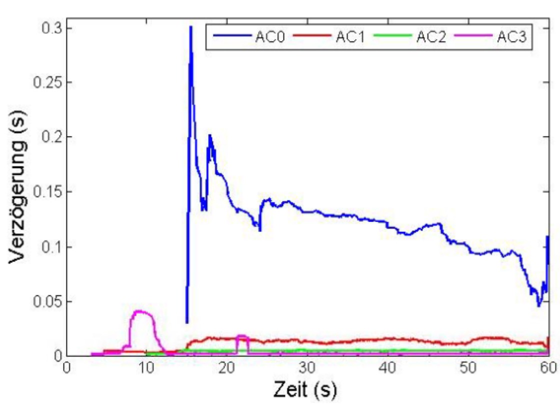

Fig.6- Mean delay in different access categories in EDCA for scenario 1

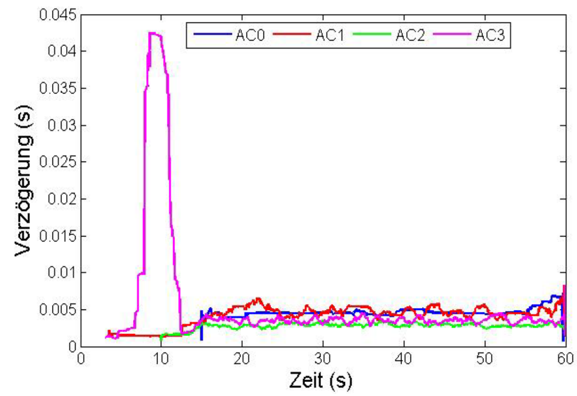

Fig.7- Mean delay in different access categories in DCF for scenario 1

Figs. 6 and 7 show the mean delay in EDCA and DCF. It can be seen that the mean delay for DCF (3 ± 1 ms) is lower than the delay in EDCA (38 ± 8 ms). Furthermore, the delay of voice in EDCA (2 ms) is lower than in the low priorities access category. The delay for background and best-effort traffic (119 ± 11ms, 12 ± 3 ms) is also high in the EDCA in comparison to DCF (4 ± 0.51 ms , 4 ± 1ms). The mean delay for video traffic in DCF (2 ms) is lower than the mean delay in EDCA (3 ms).

These results illustrate that the real time services with stringent quality of service (QoS) requirements have problems with DCF over TCP, which has no service differentiation between the different types of traffic. These applications need transmission via EDCA, which provides differentiated channel access for different traffic types. The results support that EDCA can provide and equip multimedia applications with a reasonable quality of service.

The TCP protocol can be used as a transfer protocol for special applications environments. In order to use the TCP protocol for data transfer, certain network features and properties are required. Among these features are the network stability and the bandwidth-sharing. However, under these conditions the transfer of audio and video data is achievable at low (limited) performance. This applies especially when WLAN is used. From the above reported results and simulations, it is shown that the TCP protocol is usable for transferring audio and video data within special programs and applications. However, the UDP protocol with its higher performance is more suitable for this task.

V. CONCLUSION

This paper studies the performance of the TCP protocol for voice application in EDCA and DCF and investigates which is suitable with a propoer QoS for different data transmissions over WLANs. The simulations have used the types TCPGenericSrvApp and TCPBasicClientApp to send and to receive TCP packets. The results show that, high priority traffic using EDCA can reduce MAC delay up to 2 ms in voice traffic, which maintain a throughput of over 0.57 Mbps. From the reported results and simulations, it is shown that the TCP protocol is usable for transferring audio and video data within special programs and applications. However, the UDP protocol with its higher performance is more suitable for this task.

The analysis of the TCP application in EDCA differentiation mechanisms demonstrates that, contention window sizes have a pronounced effect on the traffics, which is the same in DCF for all ACs, as for EDCA (as given in Table I). The higher priority traffic streams are better served than lower priority traffic streams. This paper recommends the use of EDCA for streaming of VoWLAN using TCP protocol, which emphasizes more advantages than DCF. Using the TCP protocol, video and audio transmissions can be managed.

ACKNOWLEDGEMENT

The author would like to thank Prof. Dr. K. Hänßgen for his valuable comments on the manuscript and for supporting this publication.

REFERENCES

[1] IEEE Std. 802.11-1999, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Reference number ISO/IEC 8802- 11:1999(E), IEEE Std. 802.11, 1999 edition, 1999.

[2] P. Počta, P. Kortiš, and M. Vaculík, “Impact of background traffic on speech quality inVoWLAN,” Adv. MultiMedia, vol. 2007, no. 1, pp. 1–9, 2007.

[3] R. Qashi, M. Bogdan, and K. Hänssgen, “Performance analysis of WLANs for the IEEE 802.11 EDCF in real-time applications,” in International Academic Conference of Young Scientists ”Computer Science and Engineering 2010, 2010.

[4] OpenSim-Ltd, “Omnet++ integrated development environment. Vers 4.1b2.” http://www.omnetpp.org.

[5] OMNeT-Community, “Inet framework for omnest/omnet++ 4.0 inetmanet. vers. 2010,” http://inet.omnetpp.org.

[6] Shao-Cheng Wang and A. Helmy. “Performance Limits and Analysis of Contention-based IEEE 802.11 MAC”. Local Computer Networks, Annual IEEE Conference on. Vol. 0, pp. 418-425. 2006. USA.

[7] M.-S. Kim, J.-P. Ryu, T. Byun, and K.-J. Han, “Throughput analysis of ieee 802.11e edca protocol,” in High Speed Networks and Multimedia Communications, vol. 3079. Springer Berlin Heidelberg, 2004, pp. 579–588.

[8] S.-C. Wang and A. Helmy, “Performance limits and analysis of contention-based ieee 802.11 mac,” Local Computer Networks, Annual IEEE Conference on, vol. 0, pp. 418–425, 2006.

[9] I. Inan, F. Keceli, and E. Ayanoglu, “Analysis of the 802.11e enhanced distributed channel access function,” CoRR, vol. abs/0704.1833, 2007.

[10] S. Choi, “On the performance characteristics of wlans: revisited,” in in Proc. ACM SIGMETRICS05, 2005, pp. 97–108.

[11] L. Hluze. OMNET, 802.11 patch for INETMANET 20080920 vers.2.0, http://www.hluze.net.

[12] H. L. Vu and T. Sakurai, “Accurate delay distribution for IEEE 802.11 DCF”, IEEE Comms. Letters, vol. 10, no. 4, pp. 317-319, Apr. 2006.

[13] J. Sengupta and G. S. Grewal, “Performance evaluation of ieee 802.11 mac layer in supporting delay sensitive services,” International Journal of Wireless and Mobile Networks, no. 1, 2010.

[14] T. Nadeem and A. Agrawala, “IEEE 802.11 DCF enhancements for noisy environments”, in Proceedings of the15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2004), vol. 1, pp. 93–97, Sept. 2004.

[15] S. Sehrawat, R. P. Bora, and D. Harihar, “Performance analysis of QoS supported by enhanched distributed channel access (edca) mechanism in IEEE 802.11e,” in IMECS, 2006, pp. 943–948.

[16] R. Qashi, M. Bogdan, K. Hänßgen “Analysis of Packet Throughput and Delay in IEEE 802.11 WLANs with UDP Traffic” International Journal on Computing (JoC) Vol. 1 No. 3, 2011.