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A Novel IEEE 802.11aa Intra-AC Prioritization Method for Video Transmissions

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***Abstract*—Ensuring QoS guarantees for real-time multimedia traffic in WLANs has recently attracted a lot of attention from standardization bodies and researchers. In order to increase the granularity of traffic prioritization and QoS support provided by EDCA, the intra-access category prioritization mechanism has been proposed in the recent IEEE 802.11aa amendment. In order to improve real time transmission over WLANs, two standard transmission selection algorithms can be used to prioritize traffic within the voice and video access categories of EDCA: the strict priority algorithm and the credit-based shaper algorithm (CBSA). This paper focuses on the improvement of video transmission over WLANs using two video transmission queues (primary and alternate) and the two traffic selection algorithms and compares the behavior of IEEE 802.11aa with legacy EDCA. Additionally, it comments on the possible ways of CBSA implementations. Finally, it proposes an adjustment of CBSA to wireless environment (WCBSA) which gives the most promising results.**

Keywords*—*IEEE 802.11aa, credit-based shaping, intra-AC prioritization, strict priority algorithm, video transmission

I. INTRODUCTION

The transmission of multimedia streams over IEEE 802.11 wireless local area networks (WLANs) has become popular and profoundly contributes to Internet traffic. Therefore, standardization bodies have tried to improve the effectiveness of such transmissions in recent years. The focus has been on bandwidth improvement and quality of service (QoS) support. The former has been the target of several 802.11 amendments (e.g., 802.11ac/ad). This paper concentrates on the latter issue.

The first QoS extension of the traditional distributed coordination function (DCF) was the enhanced distributed channel access (EDCA) function. Recently, the new 802.11aa amendment appeared [1]. It defines mechanisms to improve the delivery of audio-video streams over WLANs. In this paper, we focus on intra-AC prioritization of video streams (cf. Section II). Such differentiation may be required, e.g., when a real-time video conference competes with video streaming. The former has a lower tolerance to jitter and delay than the latter; therefore, it should have higher priority. To resolve this issue, 802.11aa provides two separate queues for the VI AC: primary and alternate. With the use of an appropriate transmission selection algorithm, video frames are scheduled between both queues before they are passed to EDCA functions to increase the delivery ratio of primary video frames.

In the literature, there have been several surveys [2]–[5] describing 802.11aa. Other papers concentrated on reliable multicast mechanisms [6]–[8] and mathematical modeling of intra-AC prioritization [9], [10]. Additionally, in our previous paper [11] we have presented the general concept of intra-ac prioritization.

In this paper we show that by an appropriate scheduling of video frames one video stream can be preferred over another, which can be valuable in real implementations (cf. Section VI). To achieve this goal, we have implemented intra-AC prioritization and different transmission selection algorithms (strict priority and credit-based shaper, described in Section II) in ns-3 [12]. To our best knowledge this is the first such implementation. We have also commented on the possible implementations of the credit-based shaper algorithm and proposed its adjustment to wireless environment (cf. Section III). We have shown that the proposed wireless credit-based shaper algorithm (WCBSA) is the most promising (cf. Section V). It provides the best fractional throughput division between queues within an AC. Finally, we have proposed a simple self-configuration mechanism for the $idleSlope$ parameter which relieves network administrator from complex management and increases the overall network throughput. We hope that this pioneer work on intra-AC prioritization of video streams will contribute to the understanding and successful deployment of 802.11aa in the future.

II. OVERVIEW OF IEEE 802.11AA AND TRANSMISSION SELECTION MECHANISMS

The recently released 802.11aa amendment extends the current 802.11 QoS provisioning mechanisms and allows efficient transmission of unicast/multicast multimedia streams. Among the most important mechanisms defined in 802.11aa are: Groupcast with Retries (GCR), the Stream Classification Service (SCS), Overlapping Basic Service Set (OBSS) management, interworking with the 802.1Q Stream Reservation Protocol (SRP), and intra-AC prioritization [2].

The intra-AC prioritization mechanism, which is investigated in this paper, extends the EDCA function by defining alternate MAC transmission queues for VO and VI ACs to obtain finer-grained prioritization between individual audio and video streams. As shown in Fig. 1, 802.11aa defines six queues: two VO (primary VO and alternate A_VO), two VI (primary VI and alternate A_VI), BE, and BK. These queues are derived from the 802.1D user priorities (UP) [13] and mapped to the four independent EDCA functions. A dedicated scheduler is used to determine which head-of-line frames from both primary and alternate queues should be passed to the appropriate EDCA function. The EDCA functions remain

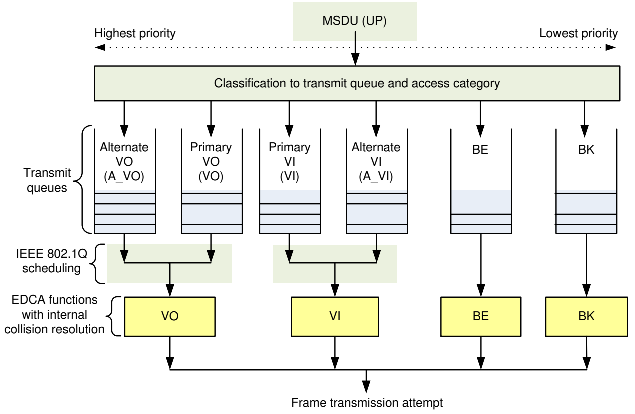

Fig. 1. Traffic prioritization in 802.11aa

unchanged and data transmission is organized using procedures defined in 802.11. Frames from two competing queues within an AC are selected using transmission selection algorithms defined in 802.1Q [14]: the strict priority algorithm (SPA) or the credit-based shaper algorithm (CBSA), using two queues. Importantly, these algorithms are configured so that frames belonging to the queue with higher UP are selected with a higher probability than from the queue with the lower UP. SPA is the default algorithm and gives absolute priority to the high priority queue, i.e., if there is at least one frame in the high priority queue it will be transmitted first. Therefore, the transmission of a frame from the low priority queue is possible only if the high priority queue is empty. CBSA is an optional algorithm. Due to its complexity, we give only a brief overview below, whereas a detailed description can be found in [14]. The permission for a frame transmission from a given queue is based on an internal *credit* parameter. A frame belonging to a given queue is selected for transmission only if (i) for the **high priority transmit queue** *credit* is non-positive and (ii) for the **low priority transmit queue** *credit* is either positive or when *credit* is equal to zero and there is no frame awaiting transmission in the high priority queue. The calculation of *credit* is based on the following two external parameters: *portTransmitRate* – the transmission rate, in bits per second, supported by the underlying MAC service, and *idleSlope* – the rate of change of *credit*, in bits per second, when the value of *credit* increases. The maximum portion of *portTransmitRate* available for the alternative traffic is given as: $idleSlope/portTransmitRate$. Another internal parameter, *sendSlope*, determines the rate of *credit* change, in bits per second, when the value of *credit* decreases:

$$sendSlope = idleSlope - portTransmitRate. \quad (1)$$

The value of *credit* is increased with a rate of *idleSlope* in two cases: (i) during the transmission of a frame from the high priority queue and (ii) when there is no transmission while *credit* is negative. Conversely, *credit* is decreased with a rate of $sendSlope$ during the transmission of a frame from the alternate queue. Additionally, if $credit$ is positive and there is no frame in the alternate queue then $credit$ is reset to zero.

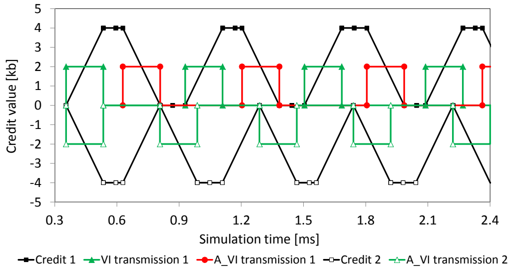

Fig. 2. Justification of the adjustment period requirement. Setting #1: frames transmitted from the primary and alternate VI queues (*VI transmission 1* and *A_VI transmission 1*). Setting #2: frames transmitted only from the alternate queue (*A_VI transmission 2*). WCBSA without the adjustment period is used.

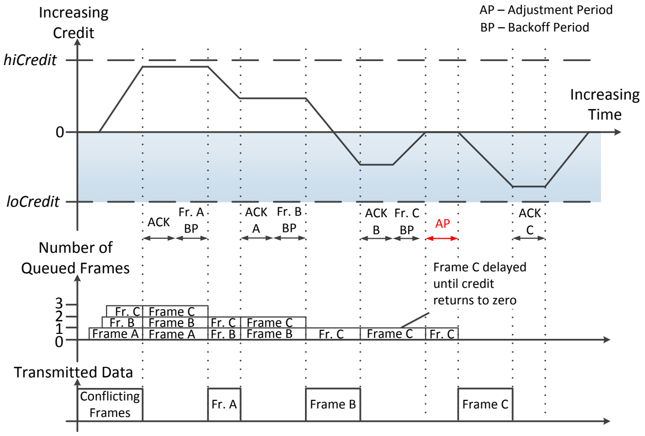

Fig. 3. WCBSA operation for three frames (A, B, and C) queued in the alternate queue during the transmission of conflicting traffic.

III. INTERPRETATION OF CBSA

The understanding of CBSA is rather complex, mostly because the definition of CBSA in 802.1Q is very general (i.e., it is only fairly straightforward for wired networks) and, therefore, its final shape for wireless environment is left open for CBSA developers. Therefore, four straightforward interpretations of the CBSA were considered in this paper (named CBSA 1–CBSA 4, Table I). They are differentiated by the definition of the *transmission period*, viewed from the perspective of a single queue (either primary or alternate), which is used by CBSA to accumulate the *credit* value. CBSA 1 is based on the duration of a frame transmission performed by the PHY layer (which is similar to CBSA operation in wired networks). CBSA 2 extends this period with the time required to perform the acknowledgment procedure. In CBSA 3, all possible retransmissions are treated as part of a frame transmission. In CBSA 4, the medium access request for a frame transmission is treated as the beginning of the transmission period. As a result, the backoff time and waiting for a free medium are part of the frame transmission period.

Another approach, which is proposed in this paper to provide the best fractional throughput division between primary and alternate queues within an AC, is to change the *credit* value only during the actual frame transmission in the wireless medium and keep the counter stopped during certain periods (characteristic to the contention-based channel access), during which transmission of frames from either queue (primary or alternate) is not possible (cf. WCBSA in Table I). From the perspective of a given wireless station these periods are the following: busy medium and backoff countdown while medium

TABLE I. POSSIBLE INFLUENCE OF TRANSMISSION-RELATED EVENTS ON THE SLOPE OF *credit* CHANGE IN CBSA IMPLEMENTATIONS

		Credit value														
		NON-POSITIVE		POSITIVE				NON-NEGATIVE		NEGATIVE				ZERO		
	Event	Medium access request for a high priority frame	High priority frame transmission start	Frame transmission end	ACK reception end	ACK awaiting end	Frame transmission failure (no more retransmissions possible)	Medium access request for a low priority frame	Low priority frame transmission start	Frame transmission end	ACK reception end	ACK awaiting end	Frame transmission failure (no more retransmissions possible)	*Credit* reaches 0 while no frame is transmitted	*Credit* was reset from a positive value	Added adjustment period
CBSA Type	CBSA1	–	↗	↘*	–	–	–	–	↘	↗	–	–	–	STOP	STOP	–
	CBSA2	–	↗	–	↘*	↘*	–	–	↘	–	↗	↗	–	STOP	STOP	–
	CBSA3	–	↗	–	↘*	–	↘*	–	↘	–	↗	–	↗	STOP	STOP	–
	CBSA4	↗	–	–	↘*	–	↘*	↘	–	–	↗	–	↗	STOP	STOP	–
	WCBSA	STOP	↗	STOP	↘**	–	↘**	STOP	↘	STOP	↗**	–	↗**	STOP	STOP	STOP

Beginning of: ↗ positive *credit* slope (*idleSlope*) ↘ negative *credit* slope (*sendSlope*) – *credit* slope does not change
↘* negative *credit* slope (non-empty alternate queue) or *credit* is reset (empty alternate queue) STOP *credit* counter is stopped
↗** positive *credit* slope if no new frame is selected for transmission ↘** *credit* is reset if the alternate queue is empty

access is requested, acknowledgment reception, and frame retransmission. Additionally, the *credit* counter stops when a frame is selected for transmission. Furthermore, during the actual frame transmission the *credit* value changes according to the traditional CBSA rules. Finally, to provide linear limitation of throughput available for the low priority queue, when the high priority queue is empty, each low priority frame selected for transmission is additionally delayed after the *credit* counter returns to zero. This *adjustment period*, given by Eq. (2), is introduced to compensate backoff and acknowledgment procedures, which were encountered by high priority frames, prior to the selection of a low priority frame for transmission by the CBSA algorithm.

$$T_{\text{adjustment}} = \left(\frac{100\%}{idleSlope[\%]} - 1\right) \times T_1 + T_2 \tag{2}$$

where:

$$T_1 = 2 \times \text{SIFS} + \left(\text{AIFSN[AC]} + \frac{CW_{min}\text{[AC]}}{2}\right) \times T_{\text{SlotTime}} + T_{\text{ACK\_duration}} \tag{3}$$

and

$$\begin{aligned} T_2 &= \text{SIFS} + \big(AIFSN\text{[AC]} + \text{rand}\left(0, CW\text{[AC]}\right)\big) \times \\ &\times T_{\text{SlotTime}}. \end{aligned} \tag{4}$$

Fig. 3 presents the overall operation of the proposed *Wireless Credit-Based Shaper Algorithm* (WCBSA) for three frames queued in the alternate queue.

The graphical justification of the compensation requirement is illustrated in Fig. 2. It compares two cases of the *credit* value changes for WCBSA without the adjustment period and *idleSlope* set to 50%. The former (*credit* 1) is connected with the transmissions performed by both queues (primary and alternate) under saturation. The latter (*credit* 2) shows the operation of the algorithm in case when only the alternate queue is saturated and the primary one is empty. In this second case alternate frames are delayed only until the *credit* counter returns to zero. After the *credit* reaches zero the alternate frame transmissions take place immediately. However, when both queues are loaded, the *credit* changes only during the actual frame transmissions. Additionally, after each transmission an acknowledgment and backoff procedures take place. As a result, without the adjustment period, the alternate queue obtains higher throughput because of the lack of primary frame transmissions (this counterbalances the duration of the acknowledgment and backoff procedures). The application of the adjustment period enables more precise throughput control.

In order to select the best candidate we implemented all five algorithms in ns-3 and performed extensive simulations. The most interesting results are presented in Section V.

IV. SIMULATION SETTINGS

Simulations were performed using the ns-3.17 simulator in which the complete 802.11aa intra-AC prioritization feature was implemented with six transmit queues and different traffic selection procedures: SPA and five versions of CBSA. To our best knowledge this is the first such implementation. The simulation parameters are presented in Table II. The 802.11a physical layer (PHY) was chosen[1] and the contention windows (CW_{min}, CW_{max}) were set according to the standard definition of the EDCA VI access category. Because we considered only AC VI, internal collisions did not occur[2]. Additionally, constant bit rate (CBR) traffic was generated by the stations and UDP was used at the transport layer. Furthermore, the wireless channel introduced no errors. Finally, in our simulations, the *idleSlope* parameter was given in % (and not Mbps), i.e., it represented the fraction of *portTransmitRate* available for the alternate queue and was calculated as

$$idleSlope[\%] = \frac{idleSlope\ \text{[Mbps]}}{portTransmitRate\ \text{[Mbps]}} \times 100\%. \tag{5}$$

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[1] 802.11a was used to easier obtain saturation conditions. However, the general conclusions hold also for other standards, e.g., 802.11n/ac.

[2] The intra-AC prioritization with presence of internal collisions was studied in our previous paper [11].

TABLE II. SIMULATION SETTINGS

Parameter	Value	Parameter	Value
PHY layer	OFDM (802.11a)	CW_{min}	7
Data rate	54 Mbps	CW_{max}	15
Basic rate	6 Mbps	AIFSN	2
RTS/CTS, TXOPLimit	Turned off	Queue size	400 frames
Operation mode	Ad-hoc	MSDU Lifetime	100 ms
SIFS	16 μs	Slot time	9 μs
Preamble length	16 μs	PLCP header length	4 μs
DATA payload	1000 B	No. of stations	Variable
Traffic type	CBR	Transport protocol	UDP

Different scenarios were considered in order to: **select the best CBSA candidate** (cf. Section V), **illustrate the operation** of different traffic selection algorithms, compare the results with legacy EDCA, and **present examples of the usefulness** of the intra-AC prioritization in real (non-academic) scenarios (cf. Section VI).

Due to the space limitation only the following metrics are presented: throughput and frame loss ratio (FLR) calculated as

$$FLR = 100\% - \frac{\text{no. of received frames}}{\text{no. of generated frames}} \times 100\%. \qquad (6)$$

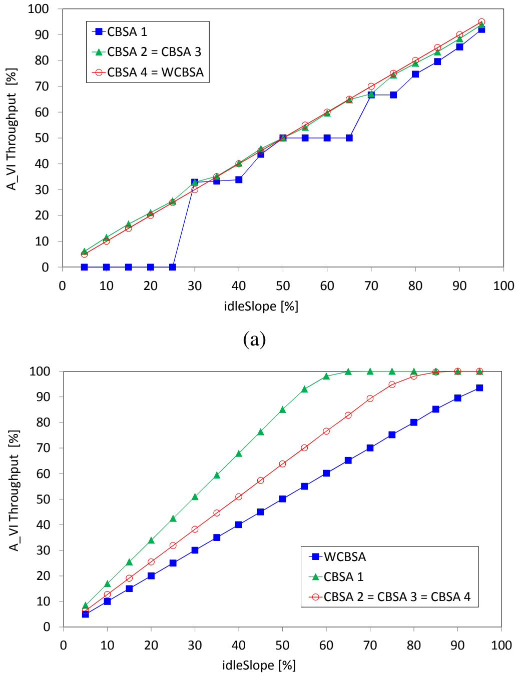
Additionally, in all figures the error of each simulation point for a 95% confidence interval did not exceed ±2%.

V. RESULTS: SELECTION OF THE CBSA IMPLEMENTATION

The comparison of different implementations of CBSA are presented in Fig. 4. They were gathered for a network in which an access point (AP) was a source of either one or two video streams. Throughput illustrated in Fig. 4 is the fraction of the overall network throughput under saturation calculated as:

$$\begin{aligned} &\textit{A\_VI Throughput}\ [\%] = \\ &= \frac{\textit{A\_VI throughput}\ [\text{Mbps}] \times 100\%}{\textit{Network throughput under saturation}\ [\text{Mbps}]}. \end{aligned} \qquad (7)$$

Fig. 4(a) presents the percentage of traffic transmitted from the low priority queue versus the *idleSlope* value when both alternate and primary VI queues are saturated. As can be observed, CBSA 1 performs far from expectations. This is because fair throughput division is impossible when the acknowledgment procedure is employed. In CBSA 1, the *credit* value accumulated during the frame transmission is reduced during the ACK procedure. If the counter reaches zero before the ACK reception is finished, the alternative queue is blocked. This situation can be observed for $idleSlope \leq 25\%$. CBSA 2 and CBSA 3 perform identically because of the lack of retransmissions, however, the results are not ideal, i.e., at some points both algorithms allow up to 3% more throughput for the A_VI queue. At other points the alternate queue obtains up to 3% poorer results than expected. Both CBSA 4 and WCBSA implementations ensure correct throughput division. Fig. 4(b) shows the percentage of available throughput obtained by the saturated alternate VI queue for the changing $idleSlope$ value, when the primary queue is empty. Only WCBSA performs perfectly. Other implementations do not provide fair throughput division (the error is up to 20%). This emphasizes the need of correcting the CBSA behavior in case of the absence of prioritized traffic. From the conducted study we select WCBSA as the best credit-based shaper. It was used for further 802.11aa investigations presented in the next section.



(a)

(b)

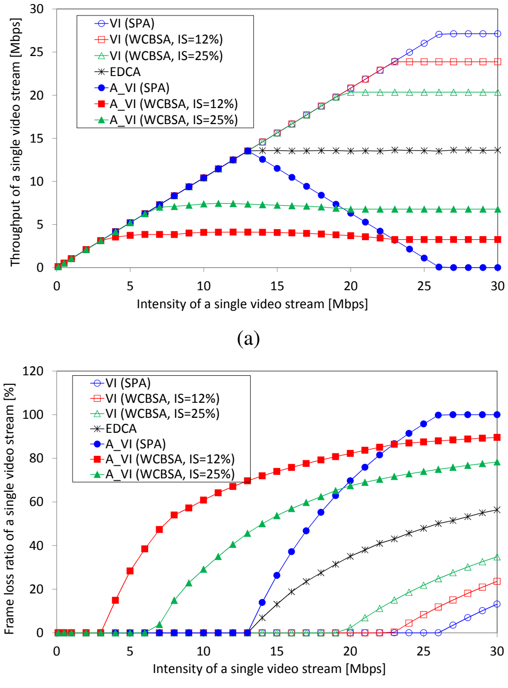
Fig. 4. Comparison of CBSA implementations: (a) A_VI throughput [%] vs. the *idleSlope* for saturated alternate and primary VI queues, (b) A_VI throughput [%] vs. the changing $idleSlope$ value for an empty primary queue.

VI. RESULTS: USEFULNESS OF THE INTRA-AC PRIORITIZATION

In this section, due to space limitation, we show only one (the most representative) scenario in which WCBSA and SPA implementation is validated and discussed. Apart from that, we analyze only realistic (non-academic) scenarios to highlight the usefulness of the intra-ac prioritization in future WLANs.

Scenario A: Network composed of an AP which is a source of two (high and low priority) VI streams. Intensity of each stream increases from 0 to 30 Mbps. Four configurations are considered: EDCA AC VI is used to transmit both VI streams, SPA is used to prioritize within AC VI, two settings of WCBSA are used ($idleSlope = 12\%$ and 25%) to prioritize within AC VI. **Goal**: Comparison of prioritization mechanisms for an AP. Validation of SPA and WCBSA implementations.

Fig. 5 shows that WCBSA allows granting a fraction of throughput to the alternate VI stream. The primary VI stream can use this throughput only when the alternate queue is empty. Additionally, the alternate stream cannot exceed the allocated throughput and frames may be lost even if transmission is possible. However, in contrast to SPA, the alternate VI stream cannot be blocked by the primary one. In comparison to EDCA, the primary VI stream can obtain much higher throughput. For EDCA the maximum throughput is about 14 Mbps, for SPA about 28 Mbps, for WCBSA with $idleSlope = 12\%$ about 24 Mbps, and for WCBSA with $idleSlope = 25\%$ about 20 Mbps. For these throughput



(a)

(b)

Fig. 5. Scenario A: (a) throughput, (b) frame loss ratio vs. intensity of a single video stream.

values the standard recommendation for maximum delay and maximum jitter (100 ms) for the primary VI are not exceeded and FLR is also acceptably low (Fig. 5). Therefore, with 802.11aa it is possible to support higher intensity video streams than it was possible with EDCA thanks to sacrificing the quality of a lower priority video stream (e.g., video streaming). As a result, the more desired transmission (e.g., a video conference) can be served with high quality.

Scenario B: Network composed of an AP which is the source of two VI streams: constant intensity VI and variable intensity VI. The former has an intensity of 3.2 Mbps while the intensity of the latter is increased from 0 to 30 Mbps. Three configurations are considered: EDCA AC VI is used for transmission of both VI streams and two settings of WCBSA are used by the network administrator (*idleSlope* = 12% and 25%) to reserve throughput for the constant VI stream. For WCBSA the constant VI stream is transmitted using the A_VI queue while the variable one is transmitted using the VI queue. **Goal**: Verification of the possibility of reserving a specific amount of throughput within an AC by the network administrator.

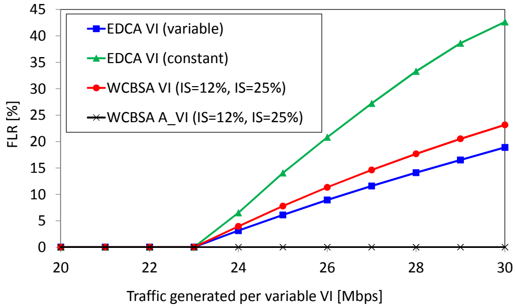
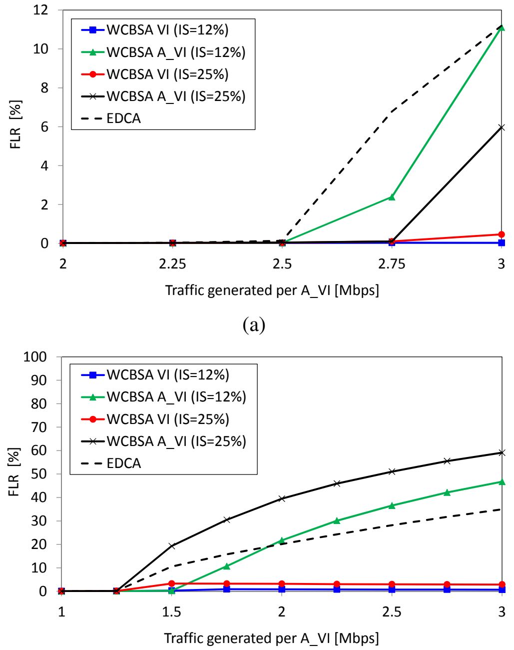


Fig. 6. Scenario B: frame loss ratio vs. intensity of the variable video stream.



(a)

(b)

Fig. 7. Scenario C: frame loss ratio vs. traffic generated per A_VI for a network composed of (a) 4 and (b) 5 stations.

Because with the chosen PHY layer (802.11a) the maximal achievable throughput is about 27 Mbps, the *idleSlope* = 12% gives protection for about 3.24 Mbps and the *idleSlope* = 25% reserves about 6.75 Mbps. Additionally, the protected A_VI queue serves only a single VI stream (3.2 Mbps) and, therefore, the operation of WCBSA for both settings of *idleSlope* gives the same results (unused alternate throughput is utilized by the primary queue). When the traffic load of the primary queue increases, WCBSA protects the reserved throughput for the alternate queue, i.e, all QoS metrics of A_VI are satisfactory, and in particular its FLR remains equal to zero, even despite the fact that the primary queue gets overloaded (Fig. 6). This feature is unavailable with the use of the legacy EDCA because all VI streams share the same transmit queue and, as a result, they have the same probability of dropping a frame when overload conditions occur.

Scenario C: Two networks are analyzed (four and five stations). Each station generates two VI streams: primary and alternate. The former has an intensity of 3.2 Mbps while the intensity of the latter is tuned by a network administrator in order to find the best available throughput with minimal FLR. Three configurations are considered: EDCA and two WCBSA settings (*idleSlope* = 12% and *idleSlope* = 25%). **Goal**: Verification if a network administrator can use traffic differentiation with throughput protection (enabled by WCBSA) in order to serve users with better quality than it was possible with EDCA.

In case of four stations (Fig. 7(a)), if the intensity of each alternate VI stream is below 2.5 Mbps, all of them can be served by EDCA with FLR = 0.13 % and by WCBSA with FLR = 0.03 % (for both *idleSlope* settings). Moreover, for *idleSlope* = 25 %, there is a possibility to serve alternate VI

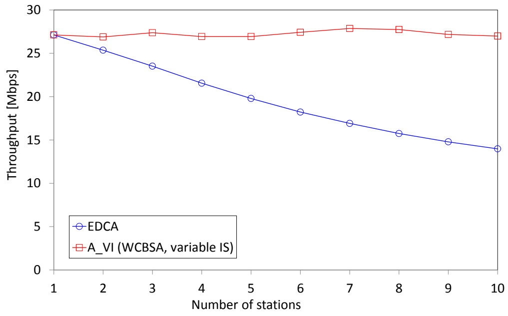


Fig. 8. Scenario D: overall network throughput vs. number of stations.

streams with higher quality (2.75 Mbps and FLR = 0.1 %). At the same time, the setting of *idleSlope* = 12 % results in FLR = 2.4 %, which is unacceptable for most codecs. This emphasizes the need for a careful configuration of WCBSA. In case of five stations (Fig. 7(b)), WCBSA with *idleSlope* = 12 % gives better results than with *idleSlope* = 25 %. It allows serving alternate VI streams of 1.5 Mbps with FLR = 0.26%. At the same time, legacy EDCA and WCBSA with *idleSlope* = 25% can only serve alternate VI streams of 1.25 Mbps with a desired quality. This shows that improperly configured WCBSA performs similarly to legacy EDCA.

Scenario D: Network composed of one to ten stations. Each station generates one alternate VI stream of 30 Mbps. WCBSA is employed to fairly limit the available alternate VI stream throughput for each station. The *idleSlope* is changed automatically according to the network size (i.e., it is equal to (1 ÷ number of stations)) in order to relieve the network administrator from complex management. **Goal**: Illustration of the *idleSlope* parameter self-configuration, which is used to increase the overall network throughput.

The proposed simple self-configuration mechanism reduces the number of physical collisions because each station, immediately after its transmission, waits for the *credit* value to return to zero. During this time all other stations can attempt to transmit their data. Additionally, since all A_VI queues are saturated and stations transmit right after WCBSA allows them to, VI transmissions become synchronized and the number of collisions is reduced to minimum. Fig. 8 compares the operation of WCBSA with self-configuration turned on with the operation of the legacy EDCA. WCBSA outperforms EDCA and provides the optimal network performance. The proposed self-configuration of the *idleSlope* parameter can be used to reduce the number of collisions not only when all transmissions are limited by WCBSA but also when primary VI traffic is present in the network.

VII. CONCLUSION

The intra-AC prioritization feature of 802.11aa provides a method for finer grained prioritization of multimedia traffic than was possible with the use of EDCA. In this paper, we have presented the first implementation of intra-AC prioritization and studied its performance for video streams. Additionally, we have commented on the possible implementations of the CBSA algorithm and selected the most promising one, adjusted to wireless environment. The proposed WCBSA assures adequate fractional throughput division between queues within an AC. Furthermore, we have shown the differences in network operation for two selection transmission procedures (SPA and WCBSA) and compared their behavior with legacy EDCA. With the use of SPA it was possible to protect the primary VI stream and sacrifice the alternate one when network resources were insufficient. WCBSA added the possibility of controlling throughput for the two VI transmit queues, which can be helpful in the reduction of frame losses and the improvement of multimedia transmission in WLANs. We have also analyzed three non-academic scenarios in order to show the usefulness of the intra-AC prioritization in real environment. Finally, we have proposed a simple self-configuration mechanism for the $idleSlope$ parameter in order to relieve network administrators from complex management and increase the overall network throughput.

ACKNOWLEDGMENTS

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