Impact of the IEEE 802.11aa Intra-AC Prioritization on QoE for H.264 Compression

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Abstract: Recently, a new 802.11aa amendment has been released. Its main goal is to increase quality of service support for audio-video traffic streams. Among others, it defines the intra-access category prioritization mechanism coupled with appropriate traffic selection procedures, in order to increase the granularity of traffic prioritization in comparison to the currently used EDCA. This paper presents the preliminary study of the possible impact of the new feature on quality of experience (QoE) in case of H.264 video streams. The obtained results show that IEEE 802.11aa and 802.1Q parameters should be tuned to efficiently use the available bandwidth.

1 INTRODUCTION

The transmission of audio-video traffic streams over IEEE 802.11 networks has recently become very popular. As a result, standardization bodies try to improve the effectiveness and Quality of Service (QoS) support in the IEEE 802.11 standard (IEEE 802.11, 2012) by adding new QoS features and increasing theoretical network throughput in the form of new amendments. The first QoS successor to the original distributed coordination function (DCF) is the enhanced distributed channel access (EDCA), which maps traffic streams to four independent access categories (ACs): voice (VO), video (VI), best effort (BE), and background (BK). The granularity of traffic prioritization defined by EDCA is rather limited because differentiation of traffic streams within a single AC is not supported. The second QoS successor of DCF is the recently proposed 802.11aa amendment (IEEE 802.11aa, 2012), which defines a number of mechanisms to improve audio-video streaming over wireless local area networks (WLANs) in comparison to EDCA (Kosek-Szott et al., 2012) and introduces the intra-ac prioritization.

Since the appearance of EDCA a number of papers addressed the problem of the possibility of mapping of different priority video frames to different ACs for the H.264 compression (Choudhry and Kim, 2005), (Koo et al., 2006), (Ksentini et al., 2006), (Pliakas et al., 2007), (Birlik et al., 2007), (Milani et al., 2008), (Chen et al., 2008), (MacKenzie et al., 2009), (Birlik et al., 2009), (Politis et al., 2011), (Debnath, 2012), (Yoon et al., 2012), (Wang and Liu, 2012), (Yao et al., 2013). This proves the importance of the described research area. However, only several of them concentrate both on video transmission and Quality of Experience (QoE) (Debnath, 2012) (Wang and Liu, 2012), which is an important subjective measure of a customer's satisfaction with a service (e.g., video streaming). There is also one paper in which the authors propose an intra-access category traffic prioritization (Sutinen and Huusko, 2011) coupled with the adaption of H.264 streams in the MAC layer. However, in the literature there are no papers describing 802.11aa in the context of QoE.

In this position paper, we focus on the 802.11aa intra-AC prioritization of H.264 video frames using two transmission queues: primary VI and alternate VI coupled with a credit-based transmission selection algorithm (cf. Section 2). We illustrate how the increased granularity of traffic prioritization may impact the QoE in WLANs (cf. Section 3 and 3.1).

2 INTRA-AC PRIORITIZATION AND CREDIT-BASED SHAPING

The intra-AC prioritization mechanism extends the operation of legacy EDCA by defining alternate MAC transmission queues for the VO and VI ACs to obtain a finer-grained prioritization between individual audio and video traffic streams. As a result, 802.11aa defines six transmission queues: two VO (primary VO

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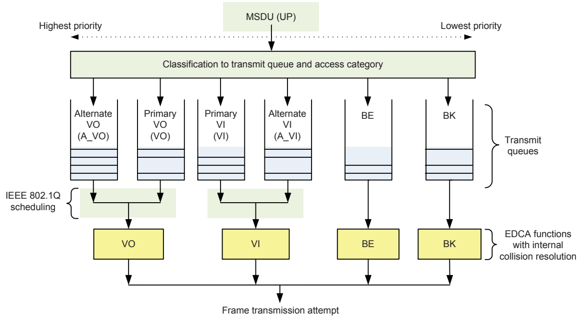

Figure 1: Traffic prioritization in 802.11aa.

and alternate A_VO), two VI (primary VI and alternate A_VI), BE, and BK (Fig. 1). The six queues are derived from the 802.1D user priorities (UPs) (IEEE 802.1d, 2004). Frames belonging to competing queues within an AC are selected using an appropriate transmission selection algorithm defined by the 802.1Q standard (IEEE 802.1q, 2011): strict priority algorithm (SPA) or credit-based shaper algorithm (CBSA)[1]. Importantly, the transmission selection algorithm must be configured so that frames belonging to the queue with the higher UP are selected with a higher probability than from the lower priority queue. Having been scheduled, frames are mapped to four independent EDCA functions and the actual frame transmission is organized using the standard 802.11 transmission procedures.

In CBSA, frame selection is based on an internal *credit* parameter. A frame belonging to a given queue is selected only if (i) for the primary transmit queue *credit* is non-positive or (ii) for the alternate transmit queue *credit* is either positive or when *credit* is equal to zero and the primary queue is empty. The value of *credit* is calculated based on 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 latter determines the maximum portion of *portTransmitRate* available for the transmission of frames stored in the alternate queue. Additionally, *sendSlope*, an internal parameter, determines the rate of *credit* change, in bits per second, when the value of *credit* decreases:

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

The operation of CBSA is illustrated in Fig. 2. The increase of *credit* occurs with a rate of *idleSlope* (i) during the transmission of a frame from the primary 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 the alternate queue is empty then *credit* is reset to zero.

Apart from the main parameters of the CBSA algorithm the following auxiliary values are defined in 802.1Q: *loCredit*—the minimum value that can be accumulated in the *credit* parameter:

$$loCredit = maxFrameSize \times \frac{sendSlope}{portTransmitRate} \quad (2)$$

and *hiCredit*—the maximum value that can be accumulated in the *credit* parameter:

$$hiCredit = maxInterferenceSize \times \frac{idleSlope}{portTransmitRate}, \quad (3)$$

where *maxFrameSize* is the maximum size of a frame that can be transmitted and *maxInterferenceSize* is the maximum size of a burst of traffic that can delay a frame transmission.

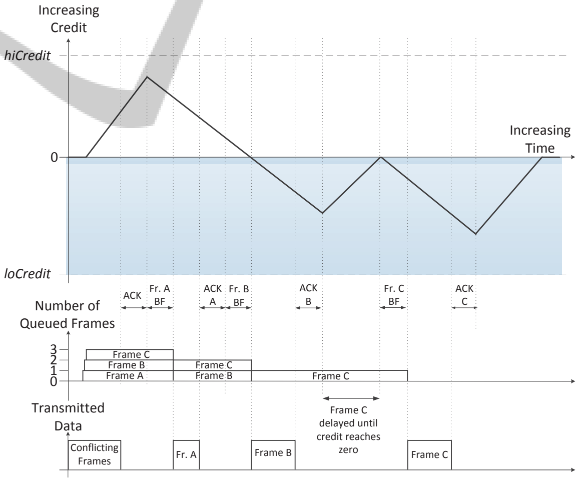

Figure 2: CBSA operation for three frames (A, B, and C) accumulated in the alternate queue during the transmission of conflicting traffic. Backoff time was named BF in the figure.

3 EXPERIMENT SETTINGS

In order to analyze the impact of mapping of H.264 frames to different 802.11aa VI queues on QoE we performed subjective tests. The tests were performed over one week in June 2013 at the Department of Telecommunications at AGH University of Science and Technology in Poland. We selected eight source sequences with different number of details and

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[1] SPA is the default transmission selection algorithm which gives absolute priority to the higher priority queue. CBSA is an optional algorithm which allows flexible bandwidth allocation. We selected CBSA in our tests, as more powerful.

with different movement dynamics (media.xiph.org, 2014): (1) for the birds, (2) crowd run, (3) moss forest, (4) ducks take off, (5) speed bag, (6) park joy, (7) controlled burn, and (8) old town cross. Each sequence was 10 seconds long. All video sequences were encoded using ffmpeg converter integrated with libx264 encoder. In predominant number of cases, the native resolution of the original video traces (media.xiph.org, 2014) was 1920x1080 (full HD), however all video sequences were resized during the encoding process to 1280x720 (HD), which is better supported by slower mobile devices. The frame rate was equal to 50 fps. Each sequence was encoded three times: to obtain fixed quality scale (VBR), 9 Mbps CBR, and 12 Mbps CBR. Two-pass encoding option was set to efficiently use the assumed bitrates. The maximum size of GOP was set to 18 and it determined the maximum distance between I-frames. Every P frame was separated by two B frames with hierarchical coding: B-frame (reference frame) and b-frame (non-reference frame). Therefore, the maximum GOP structure was IbBPbBPbBPbBPbBPbP.

The analyzed test sequences were evaluated by 24 testers who varied in age (there were eight testers in each group: $18-26$ years, $27-38$ years, and $39-50$ years) and sex (there were 14 females and 10 males). The chosen test sequences were displayed in the center of a 15.6 LCD monitor with a resolution of 1600x900 pixels. Prior to the QoE tests, the testers' sight was evaluated using a visual acuity and a color blindness tests. The sequences were played out in the VLC-2.0.7 multimedia player[2] (VLC, 2014) in a random order. The testers scored each sequence using the MOS scale. Each experiment started with three training sequences in order to familiarize the tester with the specificity of the test.

3.1 Test Sequences

The ns-3.17 simulator (www.nsnam.org, 2014) was selected to prepare the tested video sequences with appropriate mapping of different video frames. We have implemented the complete 802.11aa intra-AC prioritization feature together with the CBSA traffic selection procedure in the the simulator. Moreover the EvalVid module adopted for ns-3.17 was added (on the basis of Evalvid module for ns-3.13 developed by GERCOM (gercom.ufpa.br, 2014)).

A Video Quality Evaluation Tool-set 2.7 was used for the purposes of damaging video files in accordance to simulation results and obtaining transmission statistics like frame losses (Klaue et al., 2003), (EvalVid, 2014). In order to simulate transport with RTP, at the first step the hint track for the input video files was added with the use of the MP4Box - an application being a part of GPAC multimedia framework (gpac.wp.mines-telecom.fr, 2014). This preparation was done for the transmission with MTU size set to 1500 bytes. Next, the mp4trace application from the EvalVid was used to obtain input trace files for the EvalVid module implemented in ns-3. However, because mp4trace in EvalVid-2.7 was unable to recognize B frames treating them like P frames, a slight modification was added. The result was that mp4trace was able to recognize three kinds of frames: 1) intra-coded frames (I frames), 2) not-intra-coded frames being reference frames (P and B frames) and 3) non-reference b frames. In consequence our frame categorization was performed basing not only on their prediction category but also on the frames' joint dependence.

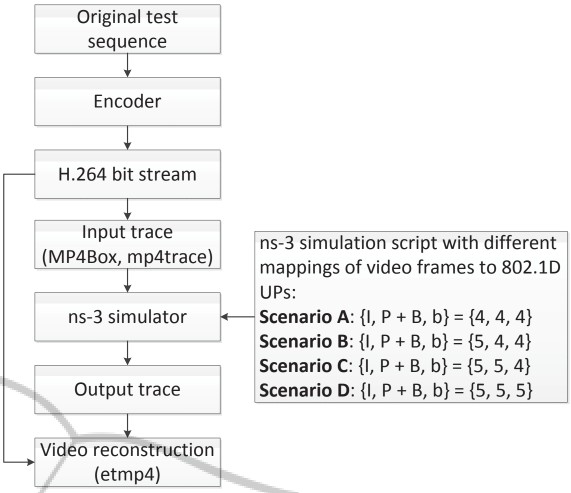

Figure 3: Preparation of video sequences for QoE tests.

During the simulations the ns-3 EvalVid module produced output trace files which were then passed to etmp4 application calculating evaluation results. In this manner we obatained not only statistical information about frame losses but also output video files with damages which were then used for QoE examination. Importantly, etmp4 did not perform slice reconstruction and, in consequence, a whole video frame was treated as lost in case of any of its data loss.

The whole process of video sequences preparation is shown in Fig.3. Its main steps are the following: encoding, trace file preparation, simulation of different scenarios and, finally, video reconstruction according to the simulation output trace file.

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[2] We selected VLC as one of the most commonly used free multimedia players.

Table 1: FLRs of sequences 1-8 for scenarios A-D and for variable rates (CBR 9 Mpbs, CBR 12 Mbps, and VBR).

Scen.	**Rate**	**Seq. No.**	**FLR [%]**				**Scen.**	**Rate**	**Seq. No.**	**FLR [%]**			
			I	**P + B**	**b**	**All**				**I**	**P + B**	**b**	**All**
A	9 Mbps	1	0	7.87	1.82	5.41	C	9 Mbps	1	0	0	0	0
		2	0	8.82	10.24	8.8			2	0	0	0	0
		3	0	12.34	1.2	7.95			3	42.86	0.32	0	2.58
		4	0	2.61	5.42	3.4			4	0	0	0	0
		5	0	8.5	10.24	8.6			5	20.69	0	0	1.2
		6	0	6.86	9.04	7.2			6	0	0	0	0
		7	0	9.48	16.48	11.21			7	39.29	0	0	2.2
		8	0	5.99	11.93	7.47			8	0	0	0	0
	12 Mbps	1	0	16.82	2.84	11.21		12 Mbps	1	0	0	0	0
		2	0	11.11	16.87	12.4			2	21.43	0	0	1.2
		3	0	14.61	5.99	10.93			3	13.16	0	0	0.91
		4	0	16.99	39.76	23.6			4	42.86	10.06	1.2	8.95
		5	0	18.86	19.89	17.85			5	0	1.2	0	0.73
		6	0	8.82	19.28	11.8			6	0	0	0	0
		7	5.26	13.73	5.11	10.38			7	12.5	2.75	0	2.43
		8	0	9.15	16.87	11.2			8	0	0	0	0
	VBR	1	0	8.5	0	5.2		VBR	1	7.14	0	0	0.4
		2	0	0	0	0			2	0	0	0	0
		3	0	0	0	0			3	14.29	6.86	0	5
		4	0	38.56	58.43	43			4	0	0	0	0
		5	0	8.44	7.78	7.75			5	34.48	0	0	2
		6	0	17.32	63.25	31.6			6	0	0.65	0	0.4
		7	0	7.87	0.61	5.01			7	39.29	0	0	2.2
		8	0	39.87	74.1	49			8	0	0	0	0
B	9 Mbps	1	0	0	0	0	D	9 Mbps	1	0	0.32	0	0.2
		2	42.86	1.3	0	3.18			2	0	0	0	0
		3	0	3.67	9.66	5.42			3	0	0	0	0
		4	0	0	0	0			4	0	0	0	0
		5	24.14	0.66	0.61	2			5	0	0	0	0
		6	28.57	0	0	1.6			6	0	0	0	0
		7	0	0.6	2.27	1.09			7	0	0	0	0
		8	0	0	0	0			8	0	0	0	0
	12 Mbps	1	6.25	10.7	2.84	7.85		12 Mbps	1	0	10.39	3.59	7.55
		2	0	7.78	13.07	8.93			2	0	0	0	0
		3	0	8.82	24.1	13.4			3	0	0	0	0
		4	0	0	1.2	0.4			4	0	0	0	0
		5	0	0.33	2.41	1			5	0	0	0	0
		6	0	0	1.81	0.6			6	0	0	0	0
		7	13.16	2.99	3.41	3.83			7	0	0	0	0
		8	50	12.66	10.18	13.92			8	0	0	0	0
	VBR	1	0	8.5	49.4	21.6		VBR	1	0	0	0	0
		2	17.86	0	0	1			2	0	0	0	0
		3	0	0	0	0			3	0	0	0	0
		4	37.93	0	0	2.2			4	0	0	0	0
		5	0	33.33	57.83	39.6			5	0	0	0	0
		6	0	0	0	0			6	0	0.33	0.6	0.4
		7	0	0	0	0			7	0	0	0	0
		8	14.29	30.72	63.86	40.8			8	0	0	0	0

3.2 Parameters and Scenarios

The simulation parameters are presented in Table 2. 802.11a was used at the PHY layer. The wireless channel introduced no errors. The standard EDCA parameters were used at the MAC layer. The *idle-Slope* of CBSA was set to 25%. Analyzed scenarios are presented in Fig. 3. Frame loss ratios (FLRs) of different video frame types in all test sequences are presented in Table 1.

Table 2: Simulation settings.

Parameter	Value	Parameter	Value
PHY layer	802.11a	CW_{min}	7
Data rate	54 Mbps	CW_{max}	15
Basic rate	6 Mbps	AIFSN	2
RTS/CTS	Turned off	Queue size	400 frames
Mode	Ad-hoc	MSDU Lifetime	100 ms
SIFS	16 μs	Slot time	9 μs
Preamble	16 μs	PLCP header	4 μs
MTU	1500 B	No. of stations	1
IdleSlope	25%	No. of streams	1

4 SUBJECTIVE TEST RESULTS

We performed a post-experiment inspection of the subjective results. The rejection criteria (correlation coefficient $R^2 < 0.75$) verified the level of correlation of the scores of one tester according to the mean score of all the testers over the entire experiment. It ap-

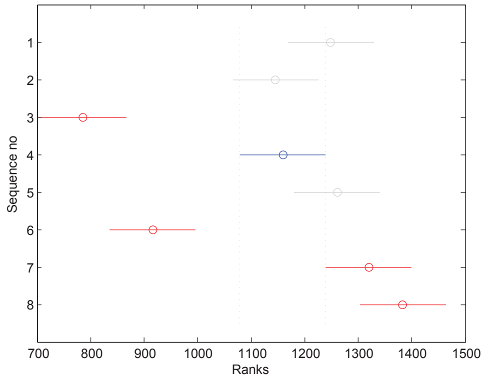
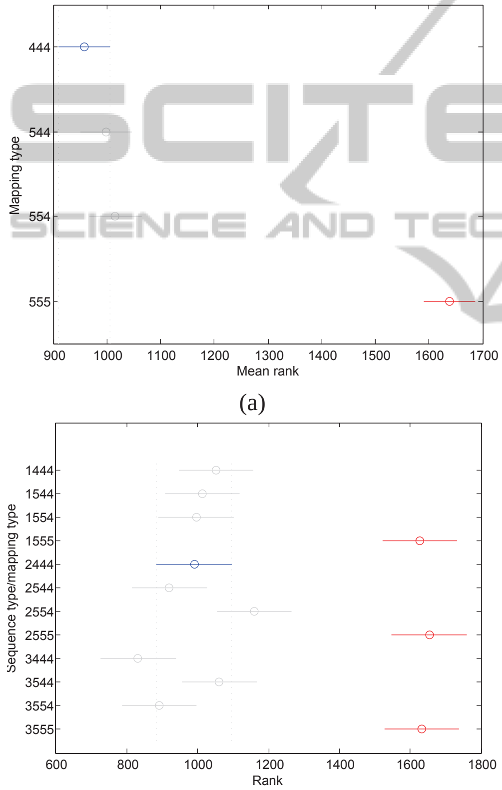


Figure 4: Verification of test sequences.



(a)

(b)

Figure 5: Subjective test results: mean ranks for different mapping types (a), mean ranks for different mapping types for different bit rates (1 – CBR, 12 Mbps, 2 – CBR, 9 Mbps, 3 – VBR) and mapping types (the last three positions in the Y axis) (b).

peared that all testers appropriately ranked the viewed sentences. Fig. 4 additionally shows mean ranks depending on the source sequence number. It proves that the test sentences were appropriately varied.

Fig. 5(a) shows mean ranks for different mapping types. As can be seen only the mapping proposed in Scenario D ({I, P + B, b}={5, 5, 5}) is considerably better from the three others. This means that static assignment of different priority H.264 video frames into both primary and alternate transmission queues is not satisfactory and worsens the overall QoE. Additionally, Fig. 5(b) shows mean ranks of different mapping types for different bit rates (1 – CBR, 12 Mbps, 2 – CBR, 9 Mbps, 3 – VBR). The results are in line with Fig. 5(a).

5 CONCLUSION

In this work-in-progress paper we show that the static setting of the CBSA parameters is not appropriate to improve the QoE in WLANs. This is because the main objective of the CBSA algorithm is to reserve some part of throughput for the alternative traffic and to simultaneously limit the same traffic to the specified level. With our default settings, the 25% of throughput was reserved for the alternative queue and thus the primary one has guaranteed 75% of throughput. At the same time, the analyzed static mapping was producing two streams of various bitrates dependent on the selected scenario and the examined video sequence.

In case of the CBR sequences, the prioritized I-frames were huge and could generate traffic overcoming guaranteed throughput. At the same time alternative traffic was smaller than the reserved 25% and thus all of it was protected. In fact, the analyzed mechanism gives reverse results to the original intentions - small frames were transmitted successfully while the most important I-frames were damaged because they were not able to use the whole throughput when the alternative queue was not empty. On the other hand, in some other cases the amount of the limited throughput could not be satisfactory and some frames were dropped even if the traffic in the prioritized queue did not consume all of its guaranteed throughput.

The conclusion is that the CBSA settings should be modified dynamically to adapt to current demands, for example the *idleSlope* parameter should be increased when the traffic in the primary queue is small enough. Another solution is to design a more intelligent prioritization scheme. For example it could resign from assigning the whole frame to the queue with the limited bandwidth if there is no possibility to transmit all of its data in time lower than the MSDU Lifetime Limit. Therefore, as future work we envision designing self-configuration mechanisms which will allow appropriate setting of the parameters characteristic to the CBSA algorithm in order to improve the QoE in future WLANs and relieve network administrators from complicated management.

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