QOS EVALUATION OF EDCF MEDIUM ACCESS SCHEME

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Abstract: The IEEE 802.11 family of standards represents the variety of WLAN technique designed for different data rates, spectrum bands and variation in access schemes. In this paper we present an evaluation of the QoS enhancements provided by EDCF medium access scheme, which is adopted in an upcoming IEEE 802.11e standard. Evaluation is made through comparison of EDCF access scheme with DCF medium access scheme defined by legacy IEEE 802.11 standard for WLANs. EDCF provides significant improvements over DCF especially for high priority traffic streams under high load conditions, however these improvements results in worse performances for lower priority traffic.

Keywords: WLAN, QoS, IEEE 802.11e, EDCF, simulation

1 Introduction

The advent of mobile devices and the need for round the clock network access has explosively expand the market for wireless communications in fields such as cellular telephony, satellite communications and wireless local area networks (WLANs). In the simplest of terms, WLANs do exactly the name implies: they provide all the features and benefits of traditional LAN technologies without limitations of wires or cables, so connectivity no longer implies physical attachment, local areas are measured not in meters but kilometres, and network infrastructure can move and change at the speed of the user's requirements. In other words, WLANs redefine the way we view LANs.

The most widely used WLAN technology today, which is viewed as the edge network of choice for the futuristic 4G cellular networks, is IEEE 802.11. IEEE 802.11 standard actually include a family of standards with specifications mostly for Physical Layer (PHY) and MAC sub-layer (MAC) of OSI reference model. The original IEEE 802.11 standard (IEEE std 802.11, 1999) supports data transmissions of up to 2Mbps in the 2.4 GHz ISM band. Revisions of the PHY specifications have produced 802.11b (IEEE std 802.11b, 1999) that extends the data rates up to 11Mbps at 2.4 GHz ISM band and 802.11a (IEEE std 802.11a, 1999) with rates up to 54Mbps at

5GHz UNI band. The most recent revision 802.11g can achieve data rates up to 54Mbps at 2.4 GHz ISM band by using advance modulation technique at PHY. Support of higher data rates and widespread use of multimedia applications push the demand of WLANs to support both traditional data and multimedia applications in the same infrastructure. However, legacy IEEE 802.11 MAC specification, which follows the best-effort paradigm, doesn't provide any traffic prioritisation to meet the QoS requirements imposed by multimedia applications such as real time voice, audio and video. Therefore, IEEE Task Group E is currently working on a new IEEE 802.11 MAC specification, named IEEE 802.11e (IEEE draft/D2.0 802.11e, 2001), which will enhance legacy MAC specification to support QoS sensitive multimedia applications. The legacy IEEE 802.11 MAC specification defines two access schemes: DCF (Distributed Coordination Function) and PCF (Point Coordination Function). DCF uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) algorithm and it is contention-based access scheme supporting asynchronous data transfer, while PCF uses a central-controlled polling method to support synchronous data transmission. The IEEE 802.11e standard introduces two additional access schemes: EDCF (Enhanced Distributed Coordination Function) and HCF (Hybrid Coordination Function). EDCF is an extension to the DCF contention-based access scheme which provides service differentiation via prioritisation of traffic supporting prioritised QoS, while HCF is a modification to the PCF for more efficient polling method supporting both prioritised and parameterised QoS.

Recently, several authors (Choi, 2003), (Garg, 2003), (Grilo, 2002), (Gu, 2003), (He, 2003) (Lindgren, 2003), (Mangold, 2002), (Truong, 2003) have shown interest in evaluation of QoS enhancements provided by new access schemes defined with IEEE 802.11e. Most of the evaluations are made through simulation using ns-2 (Garg, 2003), (He, 2003), (Lindgren, 2003) and OPNET (Gu, 2003) as simulating tools, which now have built-in support of both DCF/PCF and EDCF/HCF access schemes. This paper presents simulation-based evaluation of QoS enhancements provided by EDCF access scheme through performance comparison of EDCF and DCF. Simulation model based on Microsoft Visual Basic and SQL Server 2000 is utilized to investigate improvements provided by EDCF on several QoS parameters that we take into consideration. The paper is organized as follows: Section 2 and Section 3 give short descriptions of the legacy 802.11 MAC/DCF and 802.11e MAC/EDCF. Section 4 describes the simulation scenarios and results. Conclusions are outlined in Section 5.

2 802.11 MAC

IEEE 802.11 networks are shared medium communication networks. They can be configured to work into two different modes: ad-hoc and infrastructure modes. In ad-hoc mode, all wireless stations with in communication range can communicate directly with each other, whereas in infrastructure mode an Access Point (AP) is required to connect all stations and each station can communicate with others through AP. IEEE 802.11 MAC specification defines two different access schemes, the mandatory DCF, and the optional PCF. DCF is distributed contention-based access scheme and can be used both in ad-hoc and infrastructure mode. PCF is central-controlled contention-free access scheme and can be used solely in infrastructure mode because the need of central authority (AP) which poll stations to give them opportunity to transmit. When PCF is enabled, the two access schemes are time multiplexed in a superframe, which is formed by a PCF contention-free period (CFP) followed by a DCF contention period (CP). The AP with broadcast of beacon frame announces the beginning of every superframe. (Fig. 1)

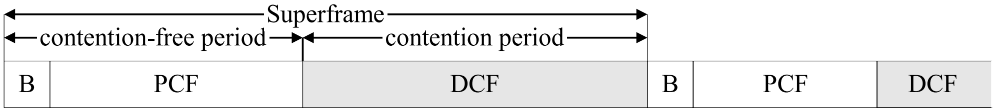

Fig. 1: 802.11 superframe

2.1 DCF

DCF is basically listen-before-talk access scheme. According to DCF, each station senses the medium before initiating a frame transmission. If the medium is found idle for a time interval longer than DCF InterFrame Space (DIFS), then the station can transmit frame immediately. If the medium is determined to be busy, the station shall defer until medium has been detected idle for at least DIFS interval. After deferral, the station will start backoff procedure setting its backoff timer at value between zero and current Contention Window (CW) size as follows:

$$BackoffTime = Rnd(0, CW) \times SlotTime \tag{1}$$

where $Rnd(0,CW)$ is a pseudorandom integer drawn from a uniform distribution over the interval $[0,CW]$ and *SlotTime* is constant which depends on the PHY layer type. For 802.11b PHY the value of *SlotTime* is 20μs. During backoff procedure, the station shall sense the medium to determine whether there is activity during each backoff slot. If the medium is free the station shall decrement its backoff timer by *SlotTime*. Otherwise, the backoff timer is paused and is resumed after the medium has been sensed idle for duration of at least DIFS interval. As soon as the backoff timer expires, the station is authorized to access the medium and transmit the pending frame.

Since in wireless environment collision detection is impossible, and due to significant difference between transmitted and received power levels, the DCF uses method of positive acknowledgment to notify the sending station that the transmitted frame has been successfully received. The transmission of the acknowledgment is initiated at a time interval equal to Short InterFrame Space (SIFS) after the end of the successful reception of frame. If the acknowledgment is not received, the sending station assumes that the transmitted frame was lost and starts the backoff procedure again. To reduce the probability of collisions, after each unsuccessful transmission attempt, the *CW* is doubled according to:

$$CW_k = 2^{k+p-1} - 1 \tag{2}$$

where k is the number of attempts to transmit the frame, and p is constant (which depends on PHY layer type) defining the minimum contention window for the first attempt, $CW_{min}=2^p-1$. For each unsuccessful transmission, contention window is doubled until a maximum value CW_{max} is reached. After successful transmission, the backoff procedure is also performing for the next frame but contention window is reset to a fixed minimal value CW_{min}. According this, the value of CW that should be used in setting backoff timer (1) depends on the current attempt to transmit the frame for which the backoff procedure is performed, and $CW_{min} \leq CW \leq CW_{max}$. The values CW_{min} and CW_{max} depend on PHY layer type. For 802.11b, values of CW_{min} and CW_{max} are 31 and 1023, respectively. The backoff procedure is shown in Fig. 2.

In order to determine the state of medium (free/busy) every station should perform physical carrier sensing at PHY layer and virtual carrier sensing at MAC sub-layer. Virtual carrier sensing is performed using the duration field contained in the header of each frame, which indicates the amount of time needed for successful transmission of that frame. Each station uses this information to adjust its Network Allocation Vector (NAV), which indicates the amount of time that must elapse until the current transmission session is complete and medium becomes idle again. The medium is considered free when both physical and virtual sensing indicate free medium. Virtual carrier sense mechanism is shown in Fig. 3.

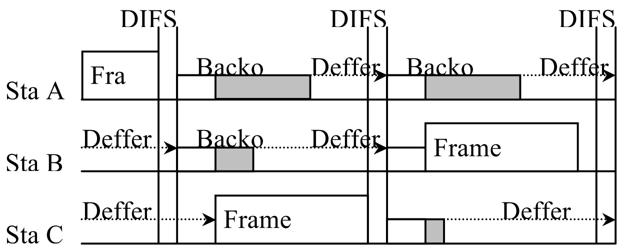

Fig. 2: Backoff mechanism

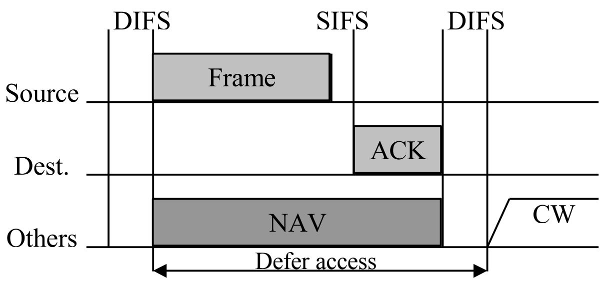

Fig. 3: Virtual carrier sense

3 802.11e MAC

The DCF access scheme doesn't include any differentiation or prioritisation mechanism. All stations and traffic classes have same priority to access the wireless medium, thus different QoS requirements of applications are not supported with the use of DCF. On the other hand, PCF provide some support for time-bounded applications (Gu, 2003), (Mangold, 2002) but without any traffic prioritisation and differentiation.

To support applications with QoS requirements over 802.11 WLANs, IEEE 802.11 TGe is currently developing extension, called IEEE 802.11e, which will enhance 802.11 MAC to support QoS. The upcoming IEEE 802.11e standard introduces two new medium access schemes: EDCF and HCF, which can concurrently exists with basic DCF/PCF for backward compatibility. EDCF is distributed contention-based access scheme, while HCF is central-controlled contention-free access scheme. According to IEEE 802.11e, both of them are mandatory and operate concurrently with in the superframe alternating over the time continuously. The EDCF is used in the CP only, but unlike PCF, HCF can be used in both phases by interrupting CP and inserting contention-free Controlled Access Periods (CAPs) at any time during a CP. The structure of the IEEE 802.11e superframe is shown on Fig. 4.

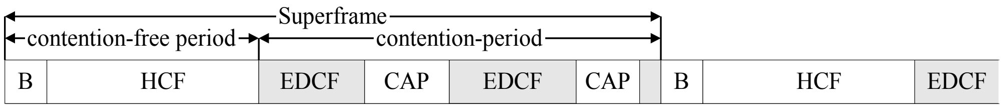

Fig. 4: 802.11e superframe

3.1 EDCF

EDCF is simply enhancement of DCF access scheme with possibility of traffic prioritisation, thus in this section we will pay attention on main difference between DCF and EDCF. As it can be seen from DCF access scheme described above, at least two contention parameters can be used to provide medium access prioritisation: DIFS and CW used in calculation of backoff timer. Generally, lower DIFS and CW values will give higher priority for medium access. Following this idea, EDCF allows traffic to be classified into 8 (minimum 4) different Traffic Categories (TC) with different values of the above contention parameters.

Instead of waiting a DIFS interval before trying to access the medium, or continuing to decrement backoff timer after it was paused as in DCF, an interframe space called Arbitration InterFrame Space (AIFS) is used for each TC. The AIFS interval for TC *i* is set according to the following formula:

$$AIFS(TC_i) = DIFS + \Delta TC_i \times SlotTime \qquad (3)$$

where ΔTC_i is integer and $\Delta TC_i \geq 0$. This means that TC using large ΔTC_i (large AIFS) will have lower priority than TC using small ΔTC_i (small AIFS), since it will wait longer before trying to access the medium or continuing to decrement backoff timer after it was paused.

To be able to further differentiate between TCs, the contention window from which the backoff timer is calculated is different for each TC. The backoff timer for TC *i* is calculated as follows:

$$BackoffTime(TC_i) = Rnd(1, CW(TC_i) + 1) \times SlotTime \qquad (4)$$

where $Rnd(1,CW(TC_i)+1)$ is a pseudorandom integer drawn from a uniform distribution over the interval $[1,CW(TC_i)+1]$. $CW(TC_i)$ is current contention window size for TC *i*, $CW_{min}(TC_i) \leq CW(TC_i) \leq CW_{max}(TC_i)$, where $CW_{min}(TC_i)$ and $CW_{max}(TC_i)$ is minimal and maximal value of the contention window for TC *i*. Choosing a smaller CW_{min}/CW_{max} for a given TC will cause generating shorter backoff intervals for that TC, thus gaining priority over a TC with larger CW_{min}/CW_{max} which generates longer backoff intervals. Unlike in DCF where after any unsuccessful transmission attempt backoff timer is calculted using doubled CW, EDCF calculates new CW with the help of the Persistence Factor (PF) which can be different for each TC. New CW for TC *i* is calculated as follows:

$$newCW(TC_i) \geq \left[(oldCW(TC_i) + 1) \times PF(TC_i)\right] - 1 \qquad (5)$$

where $PF(TC_i)$ is PF for TC *i*, and $newCW(TC_i)$ is a value of CW that should be used in calculating backoff timer for the next attempt to transmit the frame from TC *i*. Of course, $newCW(TC_i)$ never exceeds the parameter $CW_{max}(TC_i)$ which is the maximum possible value for CW of TC *i*.

Since a station can transmit traffic flows which belong to different TCs, each station, that supports IEEE 802.11e, should have up to 8 (minimum 4) independent transmission queues (MAC buffers). These queues behave as virtual stations which are contending for transmission opportunity with in the station. If the backoff timers of two or more parallel TCs in a single station reach zero at the same time, a scheduler inside the station treats this as virtual collision and transmit the frame which belong to TC with higher priority. Therefore, there exist two levels of medium access contention: internal contention among traffic of different priorities inside the same station and external contention among traffic from different stations. Collisions may happen at both levels and are resolved similarly such that higher prioritised traffic (by means of: $AIFS(TC_i)$, $CW(TC_i)$ and $PF(TC_i)$) will obtain the channel first and lower priority traffic will have to defer.

4 Evaluation

In order to evaluate QoS performances of EDCF access scheme, an event-driven simulator with support of both DCF and EDCF access schemes has been implemented. The simulator was built by using Microsoft Visual Basic and SQL Server 2000. Simulation model assume ideal PHY channel with negligible propagation delay and no transmission errors, so eventually frame retransmission is a result of collision. We only consider an infrastructure-type WLAN where all traffic flows generated from wireless stations are directed to the AP. All PHY dependent MAC parameters were set assuming 802.11b DSSS PHY layer, i.e. DIFS=50μs, SIFS=10μs, SlotTime=20μs, and for DCF the CW_{min} and CW_{max} are set to 31 and 1023, respectively.

To evaluate the QoS enhancements of EDCF we simulate two WLAN scenarios: with 11Mbps and 2Mbps data transmission rate. For both scenarios and each station we measure achieved throughput, delay of transferred frames and number of buffered frames as functions of time. These simulations are made for both DCF and EDCF access scheme.

Table 1 and Table 2 describe simulated scenarios. Tables show characteristics of traffic flows generated by the stations, categorization in TC along with the corresponding EDCF parameters assigned to each TC, which we used in simulations. Three different types of traffic are considered: voice, video and data. Voice and video traffic is assumed to have constant inter-arrival time of frames (CBR traffic), whereas inter-arrival time of data frames is exponentially distributed with mean value given in parenthesis. Inter-arrival times for video and data traffic are set different for each scenario. Each station generates only a single type of traffic, and hence, we refer to a station according the traffic type that it generates, i.e., the station that generates data traffic we refer as data station. In 11Mb scenario we simulate one video station and three data stations, whereas in 2Mb scenario we simulate one voice, one video and three data stations. Furthermore, because each station generates only a single type of traffic, stations are modelled with a single transmission queue (MAC buffer) of **infinitive** size.

Note that in 11Mb scenario we set up EDCF parameters in a such way that traffic flows generated by each station are categorized in different TC with different priority. However, in 2Mb scenario EDCF parameters (ΔTC_i, $CW_{min/max}$) are set according draft recommendation (Choi, 2003) for voice, video and data traffic. As a result, the traffic flows generated by voice and video stations belong to different TC with different priority, but all traffic flows generated by data stations belong to same TC and hence have same priority.

Station	Traffic type	Inter-arrival frame time	Frame Size (bytes)	Data Rate (Mbps)	Prior-ity	TC	EDCF parameters			
							ΔTCi	CWmin	CWmax	PF
Video Station	Video	Constant (0.0016s)	1000	5	4	TC4	0	7	15	1
Data Station 1	Data	Exponential (0.008s)	1500	1.5	3	TC3	1	15	31	1.25
Data Station 2	Data	Exponential (0.008s)	1500	1.5	2	TC2	2	31	63	1.5
Data Station 3	Data	Exponential (0.008s)	1500	1.5	1	TC1	3	63	1023	1.75

Table 1: 11Mb scenario

Sta-tion	Traffic type	Inter-arrival frame time	Frame Size (bytes)	Data Rate (kbps)	Priority	TC	EDCF parameters			
							ΔTCi	CWmin	CWmax	PF
Voice Station	Voice	Constant (0.025s)	200	64	4	TC_4	0	7	15	1
Video Station	Video	Constant (0.0156s)	1000	512	3	TC_3	0	15	31	1.25
Data Station 1-3	Data	Exponential (0.027s)	1500	448	1	TC_1	1	31	1023	1.75

Table 2: 2Mb scenario

The following section presents results from performed simulations and their analysis.

4.1 Simulation results

Fig. 5 and Fig. 5(a) show time dependence of throughput achieved by stations (i.e. the amount of traffic successfully transmitted in every second during simulation time) in a case of DCF and EDCF, respectively, for 11Mbp scenario. Fig.6 and Fig. 6(a) show the same but for 2Mb scenario. By observing throughput for video flows in a case of DCF, we can notice remarkable degradation in performances. For example, in 11 Mb scenario after activations of all data flows, achieved throughput of video station is decreased for about 23%. Even low demand voice flow, in 2Mb scenario, is not able to achieve its required constant throughput. In both scenarios we can also notice variation in throughput for voice and video flows although they are CBR traffic. By comparing results for DCF and EDCF we observe that there are significant improvements in achieved throughput for prioritised traffic flows in a case of EDCF. We can notice that voice and video flows achieve almost constant throughput with value almost equal with its data rate. However, in both scenarios there is degradation in throughput for data traffic flows in a case of EDCF (this is easily noticeable for data flow 3 in 11Mb scenario), which means that improvements for prioritised traffic flows are on the cost of traffic flows categorized as low priority.

MAC delays, measured as a time interval between the moment when the frame enters the MAC buffer and the moment when ACK is received for that frame, are shown on Fig. 7 and Fig. 7(a) for 11 Mb, and on Fig. 8 and Fig. 8(a) for 2 Mb scenario. Under DCF, it is noticeable that video flows suffer from very high delays, which is result of high load environment and the assumption of infinite station's output buffer. Delay characteristic of voice flow, in 2 Mb scenario under DCF, has also poor performances since it has big variations and peaks above 50ms, which is unacceptable for voice traffic. As we expect, EDCF introduce significant improvements in delay characteristics of high priority traffic. By comparing improvements in throughput and delay, we can conclude that EDCF has more positive impact on delay than on throughput for prioritised traffic flows. Under EDCF, maximal delays for video frames are reduced on 3ms, in 11Mb scenario, and on 30ms, for 2Mb scenario. Also, delays for voice frames are under 12ms which means that under EDCF voice transfer can be fully supported. Delay characteristics show that EDCF also reduce variations in frame delays (jitter), which is very important QoS characteristic for both voice and video traffic. Again the improvements in delay characteristics of prioritised traffic flows, are on the cost of traffic flows categorized as low priority, thus delay of data frames are much higher under EDCF, than under DCF.

Finally, Fig. 9, Fig. 9(a) and Fig. 10, Fig. 10(a) show the length of station's MAC output buffers as a number of buffered frames at the end of each second during simulation. Comparing with DCF, EDCF significantly reduce the number of buffered frames for prioritised video flows. This means that in realty with limited buffer size, EDCF will also reduce dropped frames because of buffers overflow. For low priority data flows, situation is reverse comparing with high priority video flows; they have more buffered frames under EDCF, then under DCF. This implies that under EDCF more frames which belong to lower priority flows can be lost due to the buffer overflow.

Analysing EDCF results in a portion of time when all data flows are not activated, (overall network load is low) we can conclude that there aren't any significant improvements over DCF in all analysed QoS parameter for prioritised traffic flows. This means that prioritising effects of EDCF is much clearer when the network load is higher. However, besides low QoS improvements for prioritised traffic flows in lightly loaded network conditions, EDCF keeps negative impact on flows categorized as low priority, which depend much on EDCF parameters. For example, in 11Mb scenario when network load is low (between 0 and 15s), mean frame delay for prioritised video flow is reduced for about 7%, but mean frame delay for data flow 3 is increased for about 52%.

Comparing EDCF throughput for video flows in 2Mb and 11Mb scenario, we can notice same variations in throughput characteristic of video flow in 2Mb scenario. This implies that recommended EDCF prioritising parameters do not necessarily provide best performances for prioritised traffic flows. In 11Mb scenario we set up such values for EDCF prioritising parameters to clearly make differentiation among traffic flows. This differentiation is also obvious from obtained results which show that achieved QoS performances are inversely proportional to the assigned values of ΔTC, CW_{min}/CW_{max} and PF. For example, note that data flow 3 which has highest assign values for EDCF parameters also has worst performances in all analysed QoS parameters. Consequently, EDCF parameters have very strong impact on effects produced by EDCF.

5 Conclusion

This paper presents an evaluation of QoS support provided by new EDCF medium access scheme, adopted in an upcoming 802.11e standard. Using simulation we compare EDCF with legacy 802.11 DCF medium access scheme. Results from simulations show that EDCF can provide prioritised channel access, which result in significant improvements over DCF in QoS performances for traffic flows categorized as high priority by means of EDCF prioritising parameters. These improvements are much clearer especially under high load conditions, and result in worse performances for traffic flows categorized as low priority. Also EDCF has different impact on QoS performances. Simulations show that EDCF has stronger effect on delay characteristic than on throughput of traffic flows. Furthermore, in lightly loaded network conditions EDCF doesn't significant improve performances of high priority traffic flows, but keep the negative impact on low priority flows which depend on chosen EDCF parameters. This implies that in setting of EDCF prioritising parameters should be considered overall traffic conditions in WLAN. We believe that dynamically tuning of EDCF parameters according traffic conditions will result in better overall performances for both high and low priority traffic flows. However, generally speaking, EDCF introduces QoS in WLANs in simple and efficient way because of its decentralized manner of prioritisation of traffic flows which should be the basis for eventually further improvements of EDCF medium access scheme.

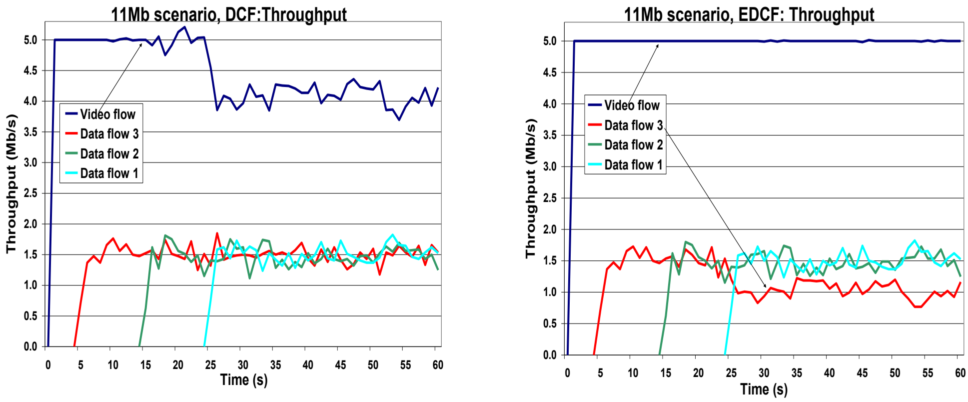

Fig. 5: 11Mb scenario: throughput

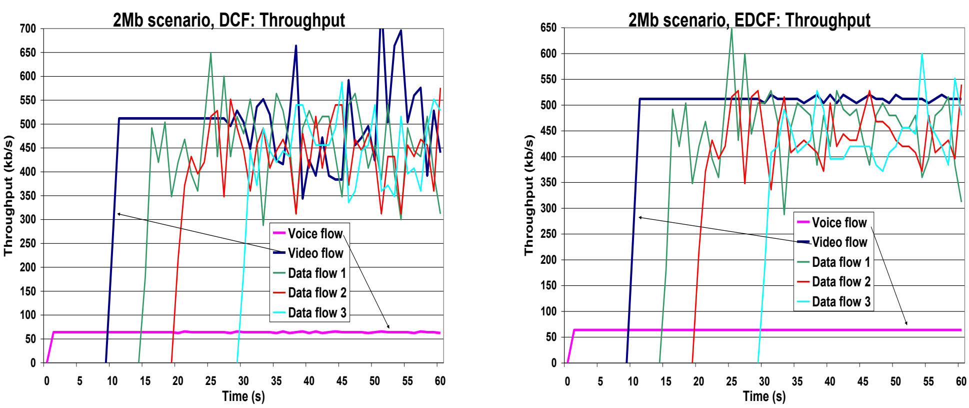

Fig. 6: 2Mb scenario: throughput

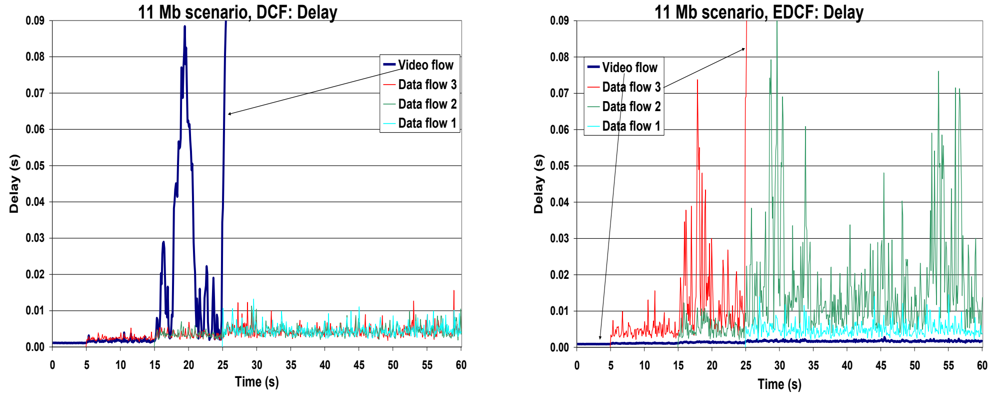

Fig. 7: 11Mb scenario: MAC delay

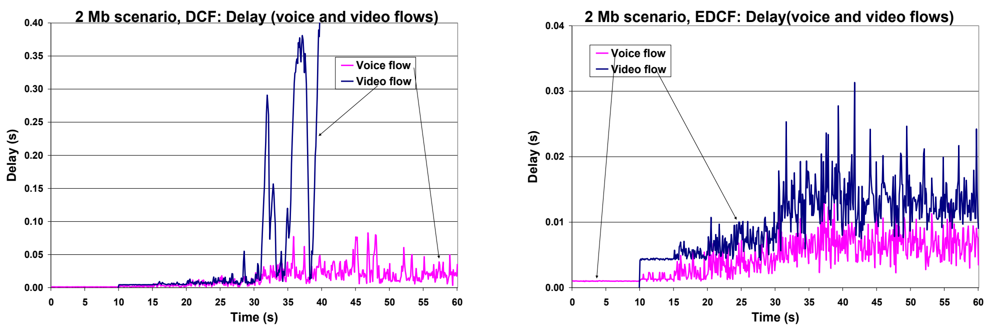

Fig. 8: 2Mb scenario: MAC delay

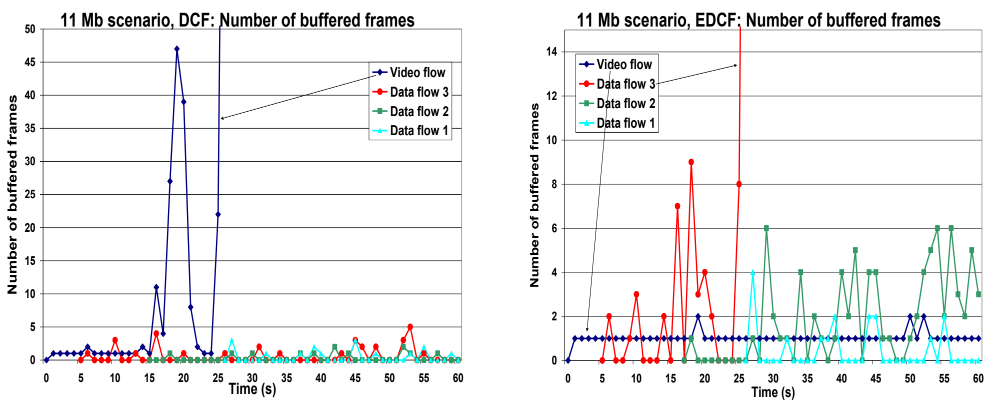

Fig. 9: 11Mb scenario: Length of MAC buffers

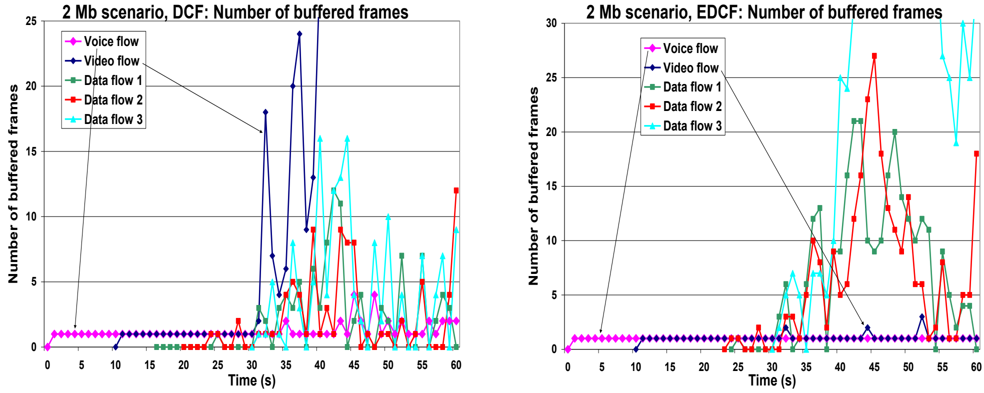

Fig. 10: 2Mb scenario: Length of MAC buffers

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