

Fairness and Transmission Opportunity Limit in IEEE802.11e Enhanced Distributed Channel Access

by Anni Matinlauri

Instructor: Jouni Karvo

Supervisor: Professor Raimo Kantola

Agenda

- Background
- Research Question
- Research Method
- Results
- Conclusions
- Further Research

IEEE802.11 Family

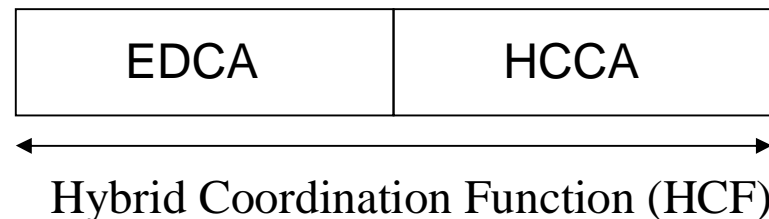
- IEEE 802.11 standards body was created in May 1989 motivated by regulations which allowed unlicensed transmissions in 83 MHz band in the 2.4 GHz range.
- 1997 the first standard was ratified, which is now called legacy 802.11 standard.
- Legacy 802.11 forms the basis of all later standards and it offered 1 and 2 Mbit/s data rates.
- Data rates were considered too slow so the work continued with two paths: one group focused on 2.4 GHz range while the other on 5 GHz range. From this work came 802.11b and 802.11a standards.
- After these several amendments have been approved focusing on different aspects.

IEEE802.11 Family

1997	1999	2001	2003	2004	2005	2007 (Predicted)	2008 (Predicted)	2009 (Predicted)
Legacy 802.11 2.4 GHz band Typ 1 Mbit/s Max 2 Mbit/s	802.11a 5.0 GHz band Typ 25 Mbit/s Max 54 Mbit/s Approx. 50m range 802.11b 2.4 GHz band Typ 6.5 Mbit/s Max 11 Mbit/s Approx. 100m range	802.11d Roaming between regulatory domains	802.11g 2.4 GHz band Typ 25 Mbit/s Max 54 Mbit/s Approx. 100m range 802.11h Spectrum management extension for 5GHz for Europe	802.11i MAC Security amendments 802.11j Extensions for Japan	802.11e MAC level QoS enhancements	802.11k Radio resource management	802.11n 2.4 or 5.0 GHz Typ 200 Mbit/s Max 540 Mbit/s Approx. 50m range 802.11r Fast Roaming 802.11w Protected management frames 802.11y 3650-3700 MHz operation in USA	802.11p Wireless access for the vehicular environment 802.11u Interworking with external networks 802.11s ESS mesh networking 802.11v Wireless network management

IEEE802.11e

- 802.11e amendment focusing on the media access control (MAC) layer.
- It introduces features ment to provide 802.11 networks with quality of service features (QoS)
- It is not dependent on the physical layer used. 802.11a, 802.11b or later can be used.
- It is divided into two parts: Enhanced distributed channel access (EDCA) and hybrid coordination function controlled channel access (HCCA). These two together form the hybrid coordination function (HCF).
- EDCA period is a contention period and HCCA period is a contention free period.



Legacy IEEE802.11 MAC

- Legacy 802.11 MAC also has two mechanisms: Distributed coordination function (DCF) and point coordination function (PCF).
- DCF is used during contention period and PCF during contention free period.
- DCF uses carrier sense multiple access with collision avoidance (CSMA/CA).
- DCF does not result in a mechanism to differentiate between stations or their traffic.
- PCF was meant to provide some QoS support. When using PCF the system alternates between contention and contention free periods. During contention free periods the point coordinator (PC) allocates transmission opportunities via polling.
- However, PCF has not been implemented in many actual devices. The central polling scheme has issues that make it inefficient.

IEEE802.11e MAC

- Eight traffic categories (TC) that are mapped to four access categories (AC)
- Each AC has its own transmission queue
- During EDCA, an EDCA parameter set determines the channel access
- In HCCA the hybrid coordinator (HC) allocated transmission opportunities via polling.
- HCCA has also not been implemented in many devices.

EDCA Parameter Set

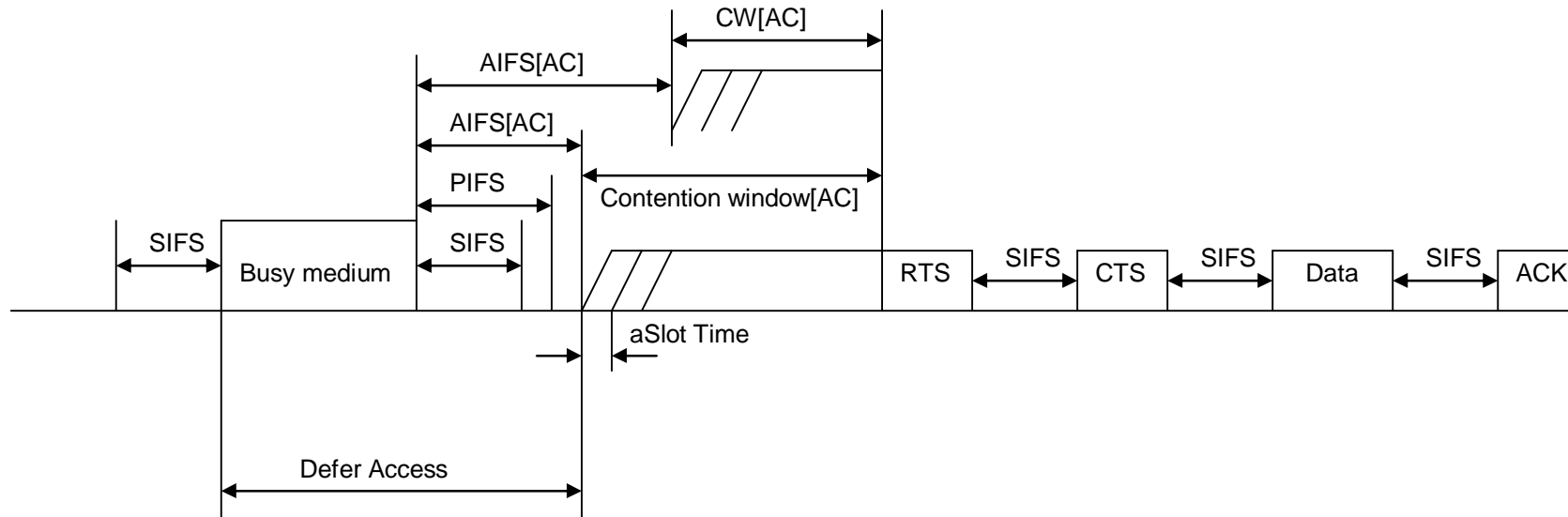
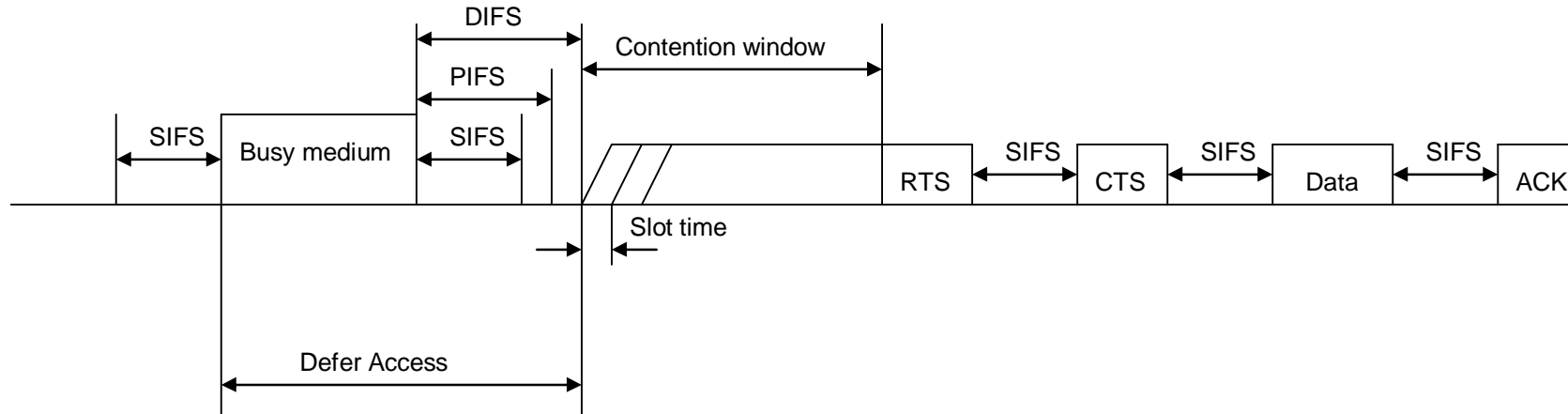
- The EDCA parameter set creates the differentiation between access categories.
- It has four parameters: Contention window (CW) minimum and maximum, arbitrary interframe space (AIFS) and transmission opportunity limit (TXOP).
- The transmission opportunity limit is the duration during which the station is allowed to transmit.
- TXOP limit zero means that the station is allowed to send one frame
- If the TXOP is long enough for multiple packets to be sent, the QSTA calculates how many it can send so that the ACK packet is also received. Any time left over the QSTA will release.
- TXOP limit is a multiple of 32 μs from zero up to the maximum of 8160 μs .

Standard EDCA Parameter Set

- All stations use the same parameter set, which is broadcasted by the QAP in beacon frames.

Access Category	AIFS	CW_{min}	CW_{max}	TXOP limit 802.11a PHY	TXOP limit 802.11b PHY
Priority 0 AC_VO	2	$(aCW_{min}+1)/4 - 1$ (7)	$(aCW_{min}+1)/2 - 1$ (15)	1.504 ms	3.264 ms
Priority 1 AC_VI	2	$(aCW_{min}+1)/2 - 1$ (15)	aCW_{min} (31)	3.008 ms	6.016 ms
Priority 2 AC_BE	3	aCW_{min} (31)	aCW_{max} (1023)	0	0
Priority 3 AC_BK	7	aCW_{min} (31)	aCW_{max} (1023)	0	0

DCF vs. EDCA



Motivation Behind the Research

- Although 802.11e is a great improvement in QoS provisioning in wireless networks, there is still room for development.
- At first, research focused on comparing 802.11e and 802.11 and it was found that especially EDCA is an efficient traffic differentiation method compared to the 802.11. For example Del Prado et al. found that EDCA offers a 5-20% throughput improvement compared to DCF.[1]
- Early on the idea of fine tuning EDCA parameters to improve the efficiency further was mentioned in the literature.
- In addition, the simple scheduler for the HCCA introduced in the 802.11e amendment was found inefficient.
- Improving EDCA or HCCA have both received research attention.

[1] Del PradoPavon, J. Shankar, S. Impact of frame size, number of stations and mobility on the throughput performance of IEEE802.11e. Wireless communications and networking conference. March 2004.

Research Question

- It was noted by several researchers such as Xi et al.[2] that in EDCA higher priority traffic acquires the channel very effectively which quickly leads lower priority traffic starvation. This means that the network fairness is not high. Even though we want to prioritize the high category traffic it is not optimal if the lower category flows are completely starved.
- In the area of fine tuning the EDCA parameter set CW has received the most attention from researchers.
- The effect of the TXOP limit has not been investigated thoroughly.

I investigate the effect TXOP limit has in the network, especially in relation to fairness. I want to find out if modifying the TXOP limit improves fairness in the network and if so how the TXOP limit should be changed for best results.

Fairness

- Generally fairness in computer networks is a good thing. However in QoS systems the differentiation wanted must be maintained.
- In this case, absolute fairness is not a useful measure.
- Instead, one should focus on relative fairness. When users make unequal demands for resources, the fairness in relation to their respective demands is a better way to measure fairness.
- In computer networks fairness could be measured in fairness of time allocation, which is called temporal fairness, or it could be measured as throughput fairness, access probability fairness, delay fairness etc.
- I have focused on relative throughput fairness.

Jain's Fairness Index

- In my fairness calculations I have used Jain's fairness index, which was introduced by Jain et al [3]. It is a well known index of fairness and suitable for many situations.
- If the amount of contending users is n and the i th user receives an allocation x_i , then Jain's fairness index $f(x)$ is

$$f(x) = \frac{\left[\sum_{i=1}^n x_i \right]^2}{n \sum_{i=1}^n x_i^2} \quad x_i = \begin{cases} \frac{a_i}{d_i} & \text{if } a_i < d_i \\ 1 & \text{Otherwise} \end{cases} \quad (\text{This is to measure relative fairness})$$

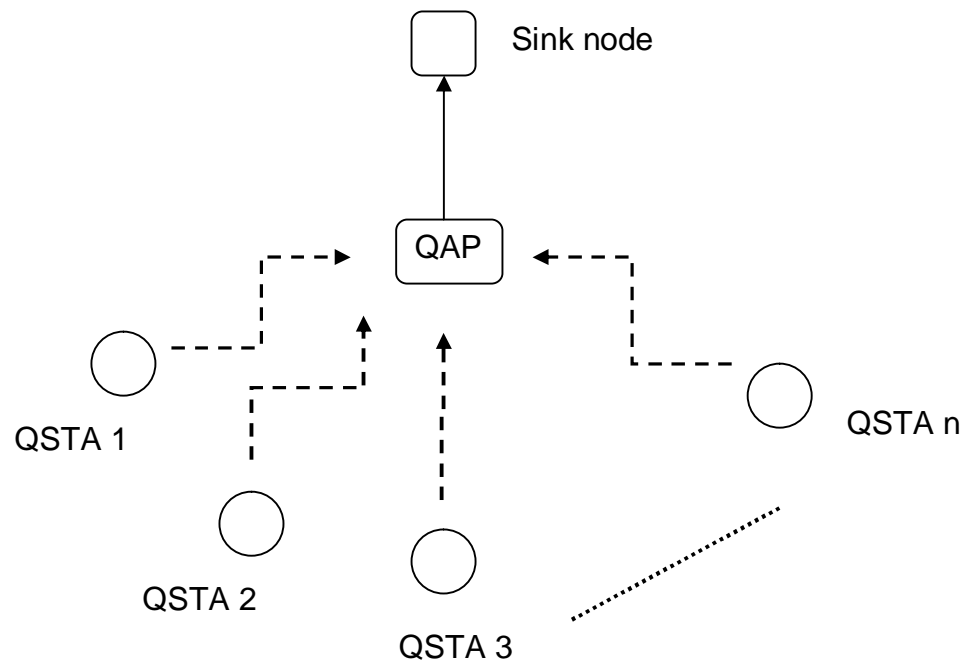
The index gets values between zero and one. With value 1 the system is 100% fair.

Simulations

- As a method to investigate the research question I have used simulations with Network Simulator 2 (ns-2) compiled with an EDCA extension module developed by Wiethölter et al. [4]
- In addition I have modified the ns-2 source code so that I am able to change the TXOP limit.
- During simulations I have only modified the TXOP limit, as other parameters I have used the standard EDCA parameter set
- Each station transmits two kinds of traffic, voice and data. Voice traffic is modelled according to ITU-T G.729 standard and data traffic generated with a bounded pareto distribution.
- Simulation duration is 2000 seconds and each simulation is repeated 20 times.

Simulation Topology

- The nodes are evenly distributed in a circle around the access point. They do not move and can always hear each other. The radio links are free from errors.

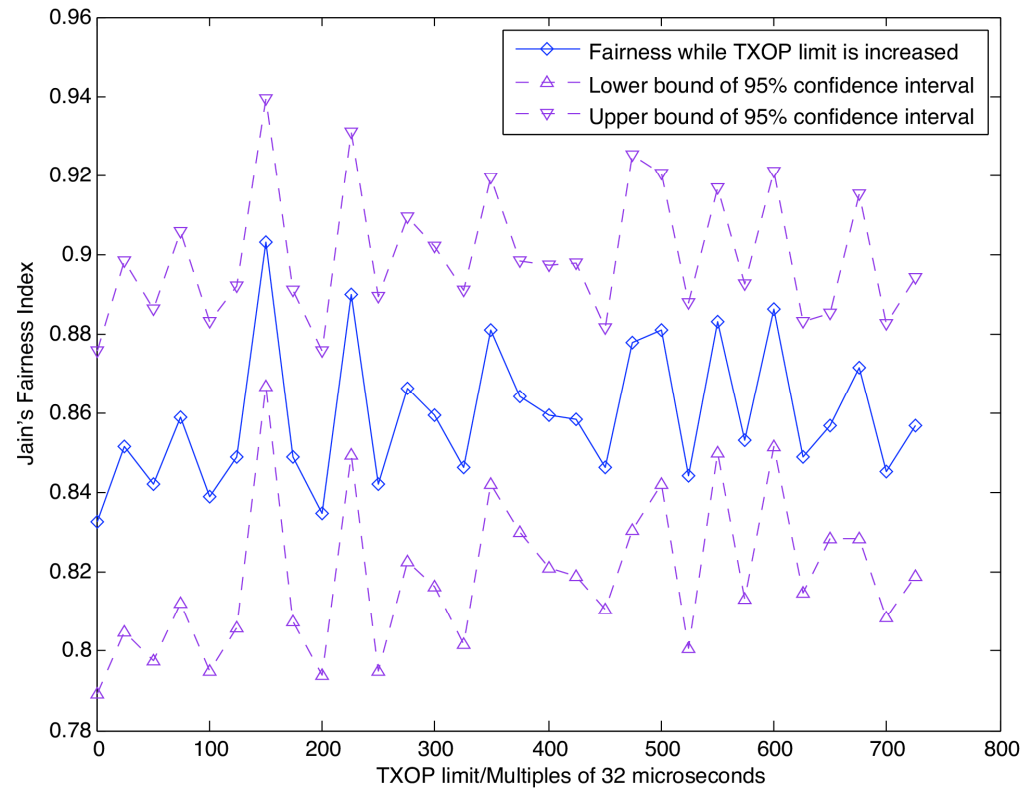


Simulation Details

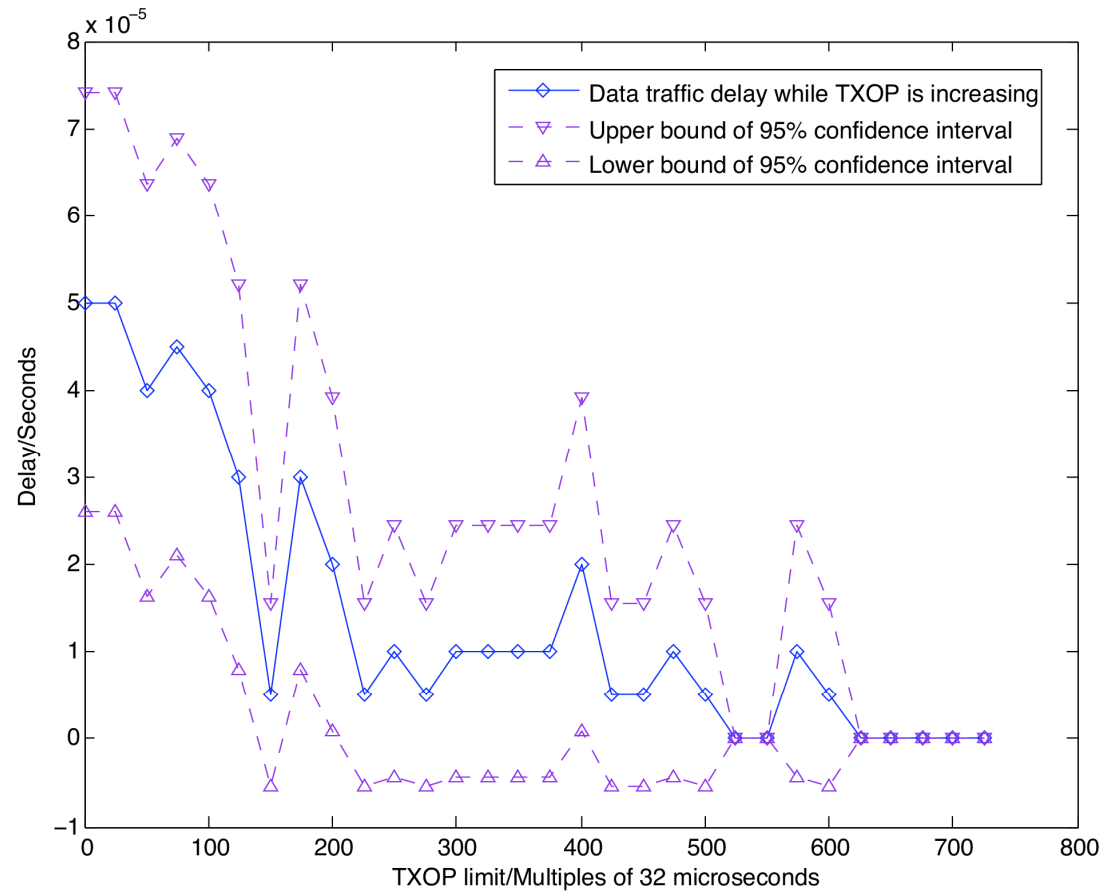
- I have used three simulation scenarios. The first is the reference scenario with the standard EDCA parameter set and no change to the TXOP limit.
- The second uses a non-zero fixed TXOP value for data traffic.
- The third changes the TXOP limit dynamically so that each time TXOP limit is set to such a value that all waiting packet could be sent. This is the maximum useful TXOP limit value.
- In these scenarios fairness minimum is 0.5 instead of 1 because only two values, one from data traffic and one from voice traffic are used.
- I have used awk scripts and Matlab to produce figures from the ns-2 output data.

Fairness

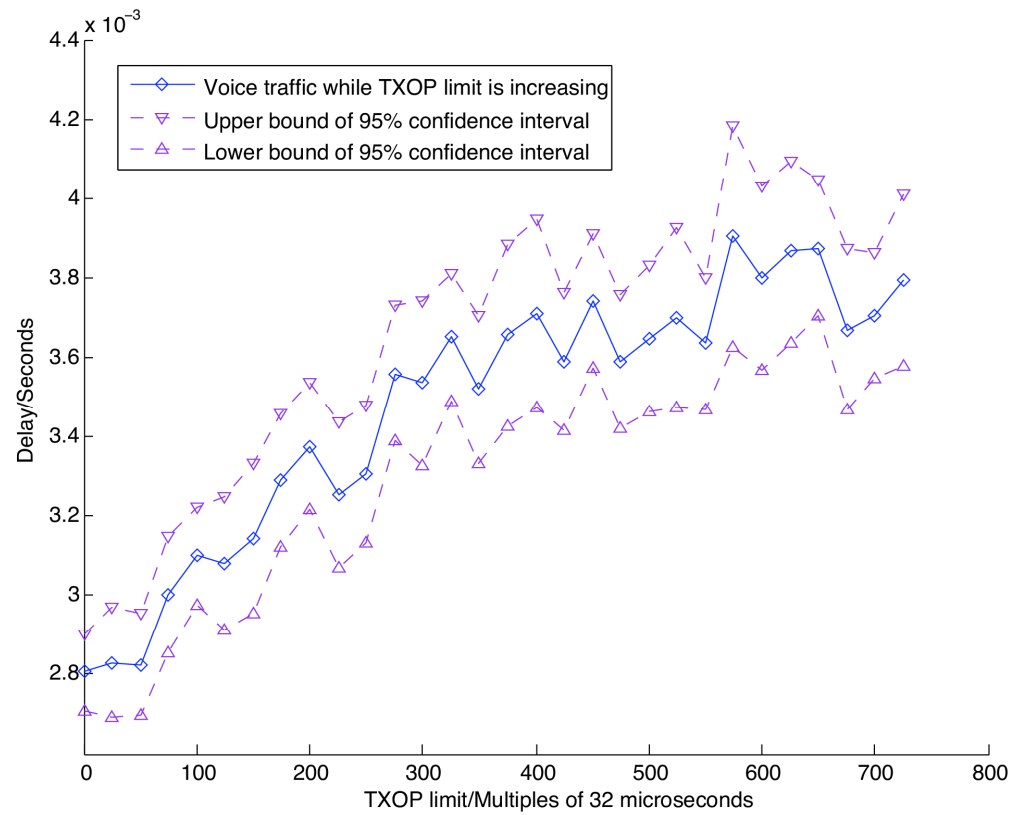
- 7 stations transmitting, from one simulation set to another the TXOP limit is increased by $25 \times 32 \mu\text{s}$



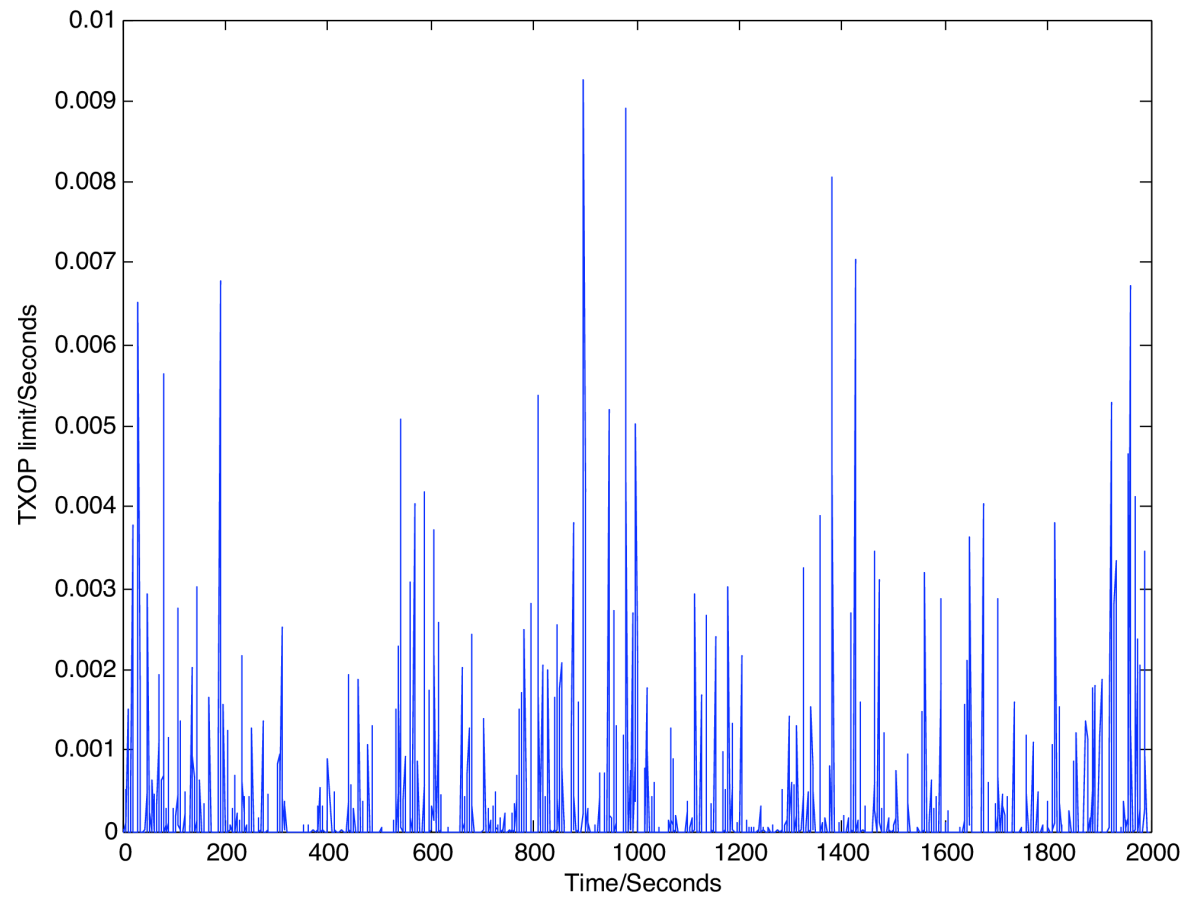
Data Traffic Delay



Voice Traffic Delay

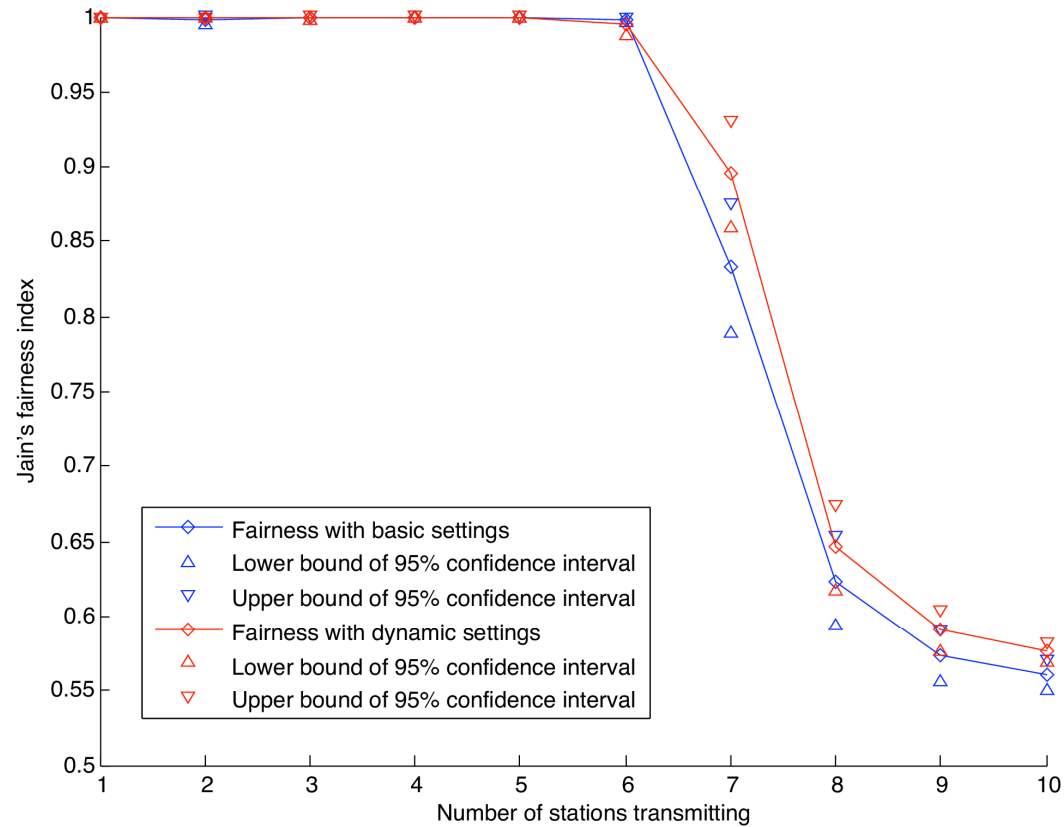


Example of TXOP Changes During A Dynamic Scenario

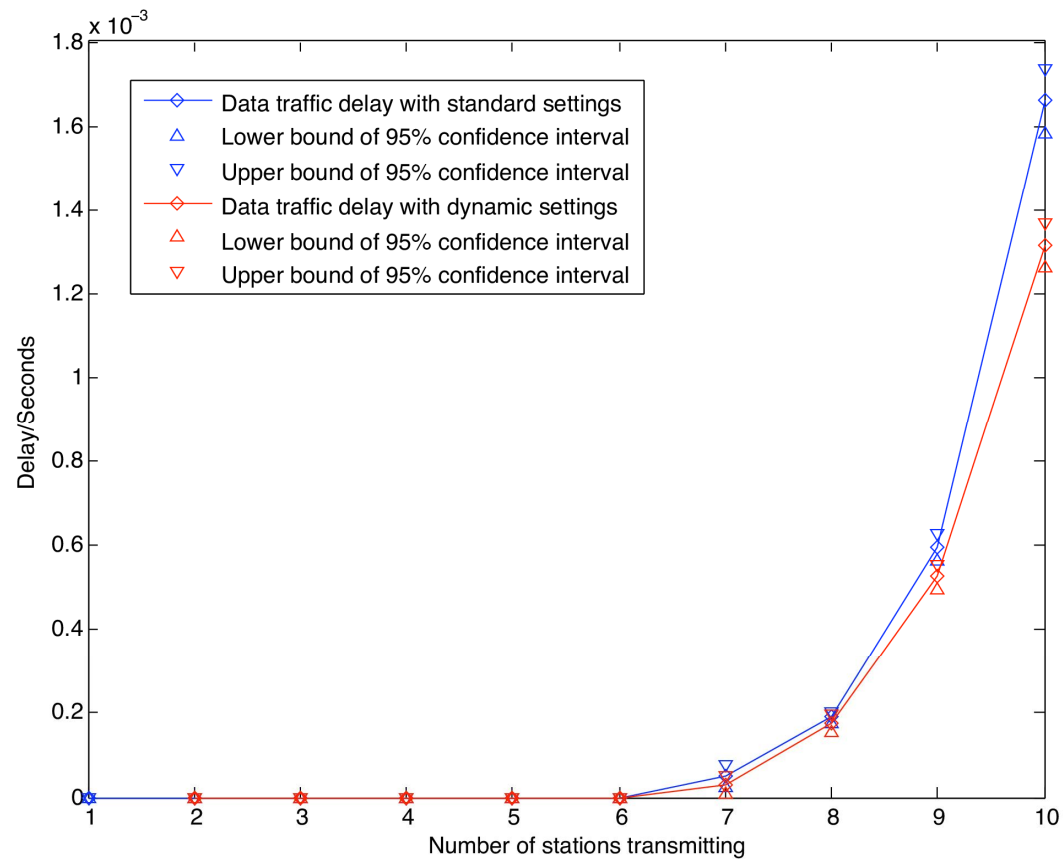


Fairness

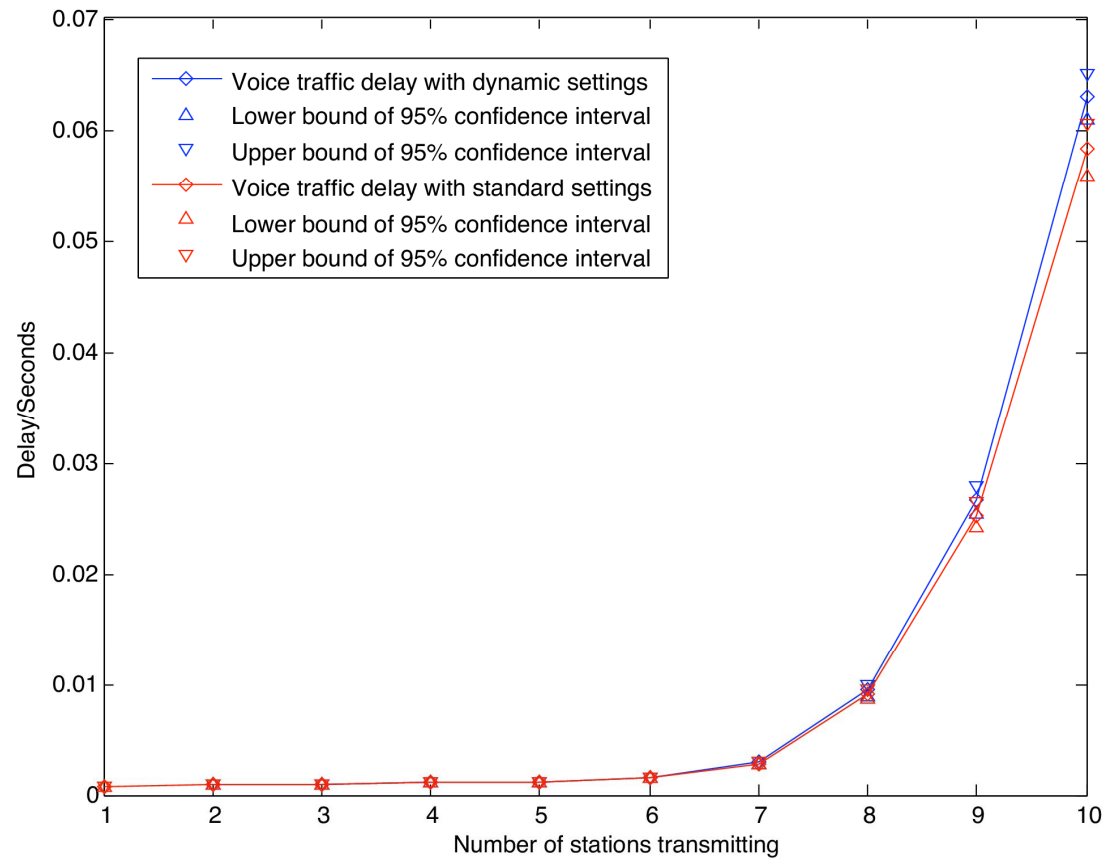
- Scenarios 1 and 3 compared. From each simulation set to another number of stations transmitting is increased by one.



Data Traffic Delay



Voice Traffic Delay



Conclusions

- No optimal static TXOP value can be found.
- If lower access category TXOP limit value is changed from zero, the delay of lower category traffic becomes smaller. At the same time voice traffic delay increases, but does not yet seem to be too large.
- If lower access category TXOP limit is set to non-zero value, the fairness in the system increases when the network starts to saturate. This means that more lower category traffic is getting through.

Further Research

- Simulations with real traffic traces
- Development of a more complex dynamic model to adjust TXOP limit
- Maximum delay voice traffic can handle at each given moment as a way of setting the data traffic TXOP limit
- Investigating TXOP limit interaction with other EDCA parameters
- Developing an overall dynamic algorithm to adjust the parameters
- Using network measurements to adjust parameters