

Developing a QoS 802.11e model in a Wireless environment

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Abstract

The need for mobile computing has launched a successful wireless access network market, with WLANs promising to replace most wired LAN infrastructures soon. WLANs allow users to move inside a building without interrupting their communication sessions and avoid the use of cables. Nowadays the prevailing WLAN products are based on the IEEE 802.11 standard. The use of multimedia networking applications has brought more requirements to the network, creating a need for end-to-end quality of service (QoS).

That requires QoS support mechanisms in the core IP network and in the access network. IEEE 802.11 standard has little QoS support, but a set of QoS enhancements to the Medium Access Control (MAC) form the main part of IEEE 802.11e, which is currently being specified. A new coordination function named Hybrid Coordination Function (HCF) can access the channel with or without contention. The contention channel access is ruled by the Enhanced Distributed Coordination Function (EDCF). On the other hand, contention-free access allows a Hybrid Coordinator (HC), located at the Access Point (AP), to start polling based contention-free access, referred as Controlled Access Phase (CAP), at any time during the contention period as needed to conform to the QoS parameterization. This paper describes the work carried out in "Enginyeria i Arquitectura La Salle" to model the IEEE 802.11e draft v4.0. The model is going to be used to analyze its behavior and to establish in which scenarios it can be helpful.

Results of this paper correspond with the first project's stage. This paper has a little overview of 802.11 and 802.11e technologies. Later there is an explanation of the modifications introduced in 802.11 OPNET's model to incorporate new 802.11e items. Finally a conclusion and further work in the implementation of the 802.11e model are commented.

Overview of 802.11 MAC

In 802.11 access layer there are two sub-layers: Logical Link Control (LLC) and Medium Access Control (MAC). IEEE 802.11 specifies the transmission schemes of PHY layer and the protocol that MAC layer follows. This paper focuses in the MAC sub-layer.

The 802.11 MAC protocol is built with the help of two coordination functions. The two coordination functions are the *Distributed Coordination Function* (DCF) for asynchronous services and the *Point Coordination Function* (PCF) for contention free services. This one can introduce some QoS support mechanism with the supplement 802.11e QoS, is offered with better guaranties.

Distributed Coordination Function

The distribution function DCF works in a listen-before-talk scheme, based on the Carrier Sense Multiple Access (CSMA). If the station detects a signal with power larger than a threshold, the radio channel is assumed to be busy and unavailable for transmission. Otherwise, the radio channel is assumed to be idle. The Network Allocation Vector (NAV) is an addition to the physical sensing of the radio channel. It is used as a virtual carrier. In fact the NAV has the function of reserving the channel for a determined time duration. As long as the NAV is set the radio channel is sensed as being busy and stations are not allowed to initiate transmissions.

The time between two MAC frames is called *Interframe Space* (IFS). IEEE 802.11 defines four different IFSs. Short Interframe Space (SIFS), Point Coordination Function Interframe Space (PIFS) and Distributed Coordination Function Interframe Space (DIFS) are used under normal conditions and represent three different priority levels for medium access. The shorter the IFS, the higher priority in medium access. The fourth IFS, called Extended Interframe Space (EIFS), is used when a station detects an on-going transmission as being interfered.

In the following, the durations used in 802.11 are listed in order, from shortest to longest.

- aSlotTime: The duration aSlotTime is used to calculate the IFSs. SIFS and aSlotTime are the basis of all other durations.
- SIFS: The SIFS is used to prioritize the immediate Acknowledgement (ACK) frame of a data frame, and different control frames.
- PIFS: The PIFS is used by stations operating under the PCF to obtain channel access with highest priority. PIFS is calculated as: $\text{PIFS} = \text{SIFS} + \text{aSlotTime}$.
- DIFS: The DIFS is used by stations operating under the DCF to obtain channel access to initiate frame exchanges. DIFS is calculated as: $\text{DIFS} = \text{SIFS} + 2 \cdot \text{aSlotTime}$.
- EIFS: The EIFS is used instead of DIFS by stations operating under the DCF whenever the PHY indicates that a frame transmission did not result in a correct sequence.

In wireless communications, a transmitter cannot detect a collision while transmitting. To account for this, 802.11 is based on Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA).

The 802.11 uses a CA mechanism to reduce the probability of collisions. A station performs a backoff procedure before starting a transmission. A station that wants to transmit has to keep sensing the channel for an additional random time duration after detecting the channel as being idle for the minimum duration DIFS. Only if the channel remains idle for this additional random time duration, the station is allowed to initiate its transmission. The duration of this random time is determined as a multiple of slot duration (aSlotTime). Each station maintains a Contention Window, which is used to determine the number of slot times a station has to wait before transmission. The contention window size increases when a transmission fails, i.e., when the transmitted data frame has not been acknowledged.

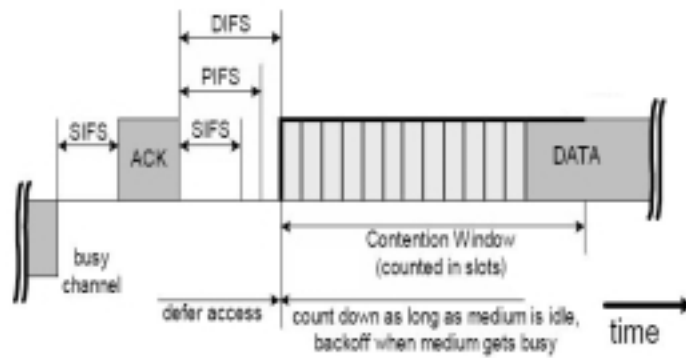


Figure 1: Interframe spaces and Backoff process with random CW

After an unsuccessful transmission, the next backoff is performed with a doubled size of the contention window. This reduces the collision probability in case there are multiple stations attempting to access the channel. The stations that deferred from channel access during the channel busy period do not select a new random backoff time. In this way, stations that deferred from medium access because their random backoff time was larger than the backoff time of other stations, are given a higher priority when they resume the transmission attempt. Beacon is a management frame used to synchronize stations within a BSS. Beacons are transmitted periodically and every station knows when the next beacon frame will arrive; this time is called Target Beacon Transmission Time (TBTT). The TBTT of each beacon is announced in the previous beacon. In order to give beacon transmissions highest priority of medium access, stations don't initiate frame exchanges upon reaching a TBTT. However, ongoing frame exchanges are completed. This may affect severely the QoS as introduces unpredictable time delays.

Point Coordination Function (PCF)

To support time-bounded services, the IEEE 802.11 standard defines the *Point Coordination Function* (PCF) to let stations have priority access to the radio channel,

coordinated by a station called Point Coordinator (PC). The PC typically resides in the AP.

The PCF has higher priority than the DCF, because the period during which the PCF is used is protected from the DCF access by the NAV. The time during which 802.11 stations operate is divided into repeated periods, called superframes. A superframe starts with a beacon. With an active PCF, a *Contention Free Period* (CFP) and a *Contention Period* (CP) alternate over time, where a CFP and the following CP form a superframe. During the CFP, the PCF is used for accessing the channel, while the DCF is used during the CP.

During CFP, there is no contention among stations; instead, stations are polled. See Figure 2 for a typical frame exchange sequence during CFP. The PC polls a station asking for a pending frame. Because the PC itself has pending data for this station, it uses a combined data and poll frame by piggybacking the CF-Poll frame into the data frame. Therefore, no idle period longer than PIFS occurs during CFP.

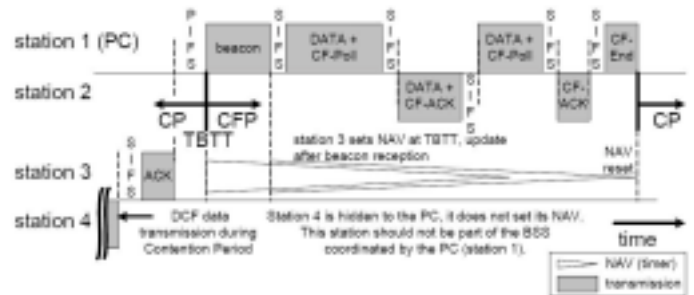


Figure 2: Contention Free Period Example

The PC continues polling other stations until the CFP expires. A CF-End control frame is transmitted by the PC as the last frame within the CFP to signal the end of the CFP.

There are problems with the PCF that motivated the current activities to enhance the protocol. Among others, the main problems are the unpredictable beacon delays and unknown transmission durations of the polled stations. The duration of the MSDU Delivery as a response to the CF-Poll frame is not under the control of the PC. This destroys any attempt to provide QoS to other stations that are polled during the rest of the CFP.

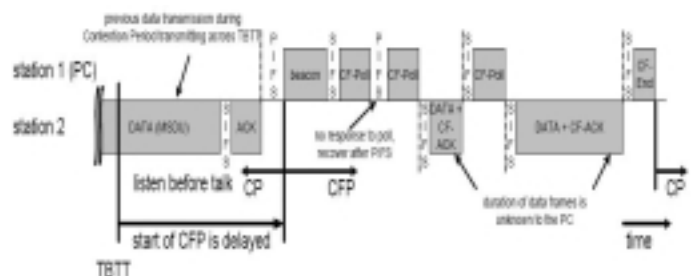


Figure 3: PCF QoS providing problems

Overview of 802.11 MAC

The MAC enhancements of 802.11e enable the support of QoS for a wide variety of applications. 802.11e MAC has a new important attribute, the *Transmission Opportunity* (TXOP). This attribute makes that a station which has obtained channel access must not allocate radio resources for durations longer than a specified limit. A TXOP is an interval of time during which a station has the right to initiate transmissions. TXOP can be obtained via the contention-based channel access, known as EDCF-TXOPs, and can be obtained by the HC via the controlled channel access, known as *Controlled Access Phase* (CAP). The duration of an EDCF-TXOP is limited by a QBSS-wide parameter called *TXOPlimit*. This *TXOPlimit* is distributed regularly by the HC in an information field of the beacon. However, legacy stations can transmit for longer durations than allowed by the *TXOPlimit*, because they don't understand new fields defined in 802.11e. Another modification is that in 802.11e any station is not allowed to transmit across the TBTT. Frame exchanges only can be initiated if they can be completed before the next TBTT. This reduces the expected beacon delay, which gives the HC a better control over the channel, especially if the optional CFP is used after the beacon.

EDCF

The EDCF is the basis of the contention-based channel access of the HCF. EDCF is used to support differentiated services with priorities. The controlled channel access of the HCF is based on the EDCF and is used for time-bounded services with strict QoS guarantees. The QoS support in EDCF is carried out with the introduction of *Access Categories* (ACs) and parallel backoff entities within one 802.11e station. Each backoff entity is parameterized with AC-specific parameters, the EDCF parameter sets. There are four different ACs, thus, four backoff entities exist in every 802.11e station, with four priorities AC 0 ... 3.

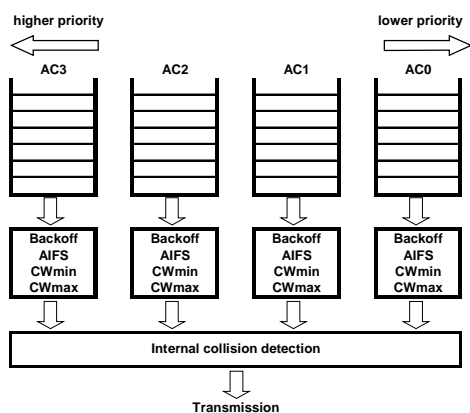


Figure 4: 802.11e station backoff entities

The EDCF parameter sets define the priorities in channel access by modifying the backoff process with individual interframe spaces, contention windows and many more parameters per AC.

Each backoff entity within the stations contends for a TXOP independently. It starts down-counting the backoff-counter after detecting the channel being idle for an *Arbitration Interframe Space Duration* (AIFSD[AC]). The AIFSD [AC] is at least PIFS, and can be enlarged per AC with the help of the parameter *Arbitration Interframe Space* (AIFS[AC]). The AIFS[AC] defines the duration of AIFSD[AC] according to

$$\text{AIFSD [AC]} = \text{SIFS} + \text{AIFS[AC]} \cdot \text{aSlotTime}, \text{ where } 1 \leq \text{AIFS [AC]} \leq 10$$

The smaller AIFS [AC], the higher the channel access priority.

Another EDCF parameter is the minimum size of the contention window, CWmin [AC] , and is dependent on the AC. The initial value for the backoff counter is a random number taken from an interval defined by the *Contention Window* (CW), similar to legacy DCF. The contention window may be the initial minimum size CWmin [AC] , or higher values. In case packet transmission failures occurred, entity selects its counter as random number drawn from the interval $[1, \text{CW} + 1]$

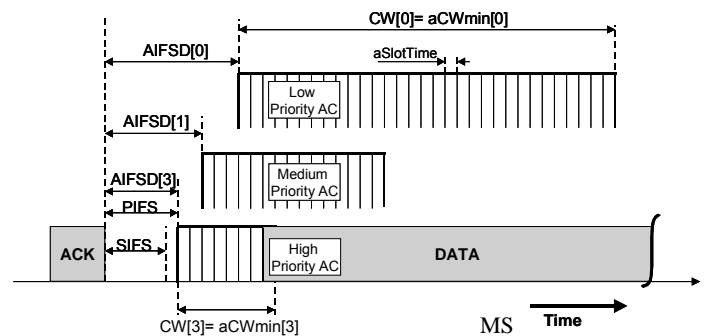


Figure 5: EDCF Contention between backoff entities

When packet transmission failures occur, the contention window increases but never exceeds the value of CWmax[AC] , which is the maximum possible value. This parameter is defined per AC as part of the EDCF parameter set. The smaller the CWmax[AC] , the higher the channel access priority. However, a small CWmax[AC] may increase the collision probability.

In addition to the backoff parameters, the TXOPlimit [AC] is defined per AC as part of the EDCF parameter set. The larger TXOPlimit[AC] , the larger the share of capacity for this AC.

Construction of the 802.11 model

This section deal with modifications introduced in 802.11 OPNET's in order to make 802.11e model with EDCF MAC procedures.

First of all we chose the node model to be modified between the wlan_workstation_adv and wlan_station_adv. The chosen model was wlan_station_adv because it is easier to modify than a workstation model due to it has not protocol stack. On the other hand, a workstation model provides more flexibility, so when the station model will be finalized, we can migrate the station model to a workstation model.

Once the node model was chosen, we add three traffic_bursty_source modules as shown in figure 6. This type of source module allows configuring several attributes like packet length and generation frequency. The new source modules are connected by a packet stream to the wlan_mac_intf module. Each traffic source module represents a different AC and can be configured on the project editor. In order to simulate different kinds of traffic, three traffic profiles have been defined in wlan_station_adv. These profiles try to emulate the default traffic distribution that OPNET gives in GSM voice transmissions, light video conferencing, and heavy FTP transfers. These profiles can be chosen through the project editor.

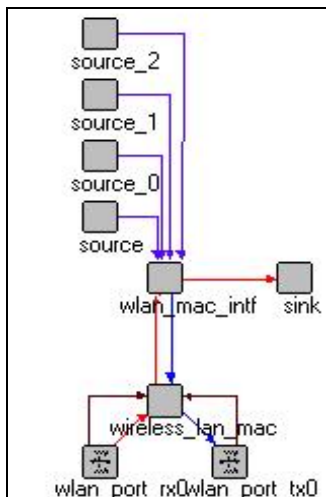


Figure 6: wlan_edcf_station_adv node model

Next, the wlan_mac_intf module was modified to deal with the new packet streams added and to determine which type of service corresponds with each packet stream. This module also decides the destination address for every packet. All this information is passed to the next module (wireless_lan_mac) through an Information Control Interface (ICI) associated with the packet.

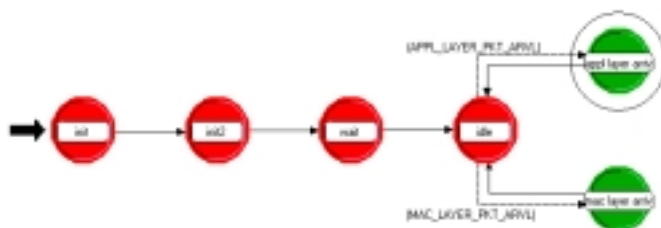


Figure 7: wlan_mac_intf process model.

Next window shows a piece of the application_layer_arrival enter exec code.

```
if (intrpt_strm==0) type_of_service=0; //type of service depends on traffic stream
if (intrpt_strm==2) type_of_service=1;
if (intrpt_strm==3) type_of_service=2;
if (intrpt_strm==4) type_of_service=3;
op_ici_attr_set (wlan_mac_req_iciptr, "type_of_service", type_of_service);
/* Install the control information and send it to the MAC layer. */
op_ici_install (wlan_mac_req_iciptr);
```

When a packet arrives to wireless_lan_mac module from wlan_mac_intf with its associated ICI, it is queued in one of the four queues added, one for each Access Category. The destination queue is chosen using the type_of_service parameter passed through the ICI. A new function queues the packets coming from higher layer when we are using the HCF. This new function is referred as wlan_hlpk_enqueue_hcf (Packet * hld_pkptr, int dest_addr, int type_of_service) and a piece of code is shown in the following window.

```
wlan_higher_layer_data_arrival (void)
...
/* Read ICI parameters at the stream interrupt. */
ici_ptr = op_intrpt_ici ();
op_ici_attr_get (ici_ptr, "type_of_service", &type_of_service);
...
wlan_hlpk_enqueue_hcf (hld_pkptr, dest_addr, type_of_service);

wlan_hlpk_enqueue_hcf (Packet* hld_pkptr, int dest_addr, int type_of_service)
...
hld_ptr->type_of_service = type_of_service;
/*Insert the packet in the correct list*/
switch (type_of_service){
case 0:
op_prg_list_insert (hcf_0_list_ptr, hld_ptr, OPC_LISTPOS_TAIL);
wlan_flags->AC_0 = OPC_TRUE;
// get statistics
....
break;
...}
wlan_flags->data_frame_to_send = OPC_TRUE;
```

Because IEEE 802.11e introduces new fields in header structure we also have modified the support wireless OPNET's files to add those header structures. All new fields defined in the standard were added, but only the fields needed for an EDCF access are used. The remaining fields are going to be used in future revisions of the model. A new primitive called wlan_prepare_qos_frame_to_send prepares all fields of QoS data packet header.

In 802.11e there are four backoff entities that are ruled by EDCF parameters set. So when the FSM of the process

wireless_lan_mac is in DEFER state it schedules a self interrupt for every AC that has traffic to transmit. Four interrupts codes (like WlanC_Deference_Off_[AC]) indicates which AIFSD has elapsed. A new transition between the states BACKOFF and BKOFF_NEEDED is needed in order to schedule self interrupts with WlanC_Backoff_Elapsed_[AC] when the AIFSD has been completed. This new transition is shown in the figure 8.

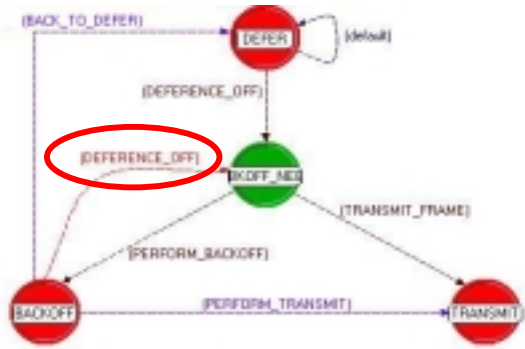


Figure 8: New transition added between BACKOFF and BKOFF_NEEDED

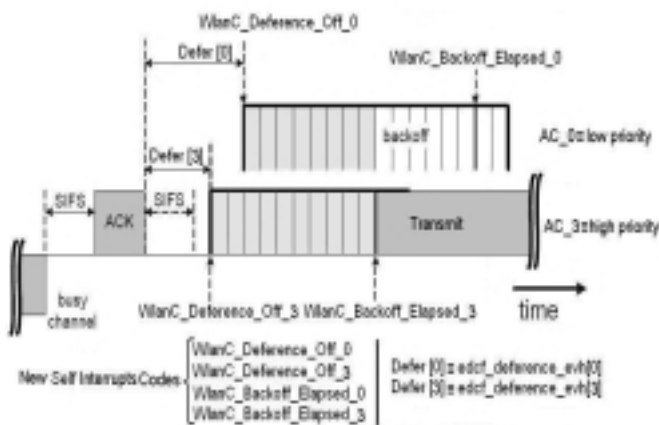


Figure 9: Interrupts scheduled in backoff process

Each backoff entity does the backoff process when detects that the radio channel has been busy and defer time has ended. In order to calculate the time of backoff a value is chosen within the contention window. The contention window is defined according to the parameters CW_min [AC] and CW_max[AC]. Normally its value will be CWmin[AC], but in the case of having collisions this value will be increased by each attempt of transmission until arriving at the CW_max[AC] value. In the header block, four codes (WlanC_Backoff_Elapsed_0...) for interruptions of type "self" have been added; each one of these new codes indicates a backoff process end for each AC.

Simulated scenarios and results

The first scenario was designed to show AC traffic differentiation using the same traffic distribution for each AC. It has three stations, one transmitter and two receivers. The transmitter station sends a 0.4Mbps constant rate for each AC. All stations are in IBSS mode

and use 2Mbps environment. The added generated traffic results in a 1.6Mbps, so there isn't congestion and traffic for each AC is send correctly. But simulations show that traffic generated in AC 3 (high priority) has less delay than the other AC (figure 10 left).

When the generated traffic is doubled, that is 0.8 Mbps generated for each AC, there is congestion. The added generated traffic is 3.2Mbps with a 2Mbps channel. Here is easily shown the traffic differentiation. With lower priority ACs, delays go to infinity, while with higher priority ACs, delay remains like there wasn't congestion (figure 10 right).

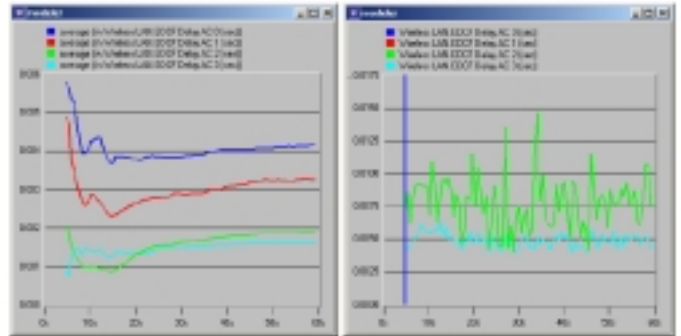


Figure 10: Delay without and with congestion

Second scenario compares DCF vs. EDCF. In this scenario there were 4 voice stations, 2 video stations and 4 data stations. Traffic profile used for voice, video and data is shown in the next table. Second table shows the EDCF parameter set configuration for each AC. Simulation results are shown in Figure 11. With DCF, video traffic has a 1.5 average delay and voice traffic has 500ms peaks. On the other hand with EDCF, delays for voice and video traffic are practically unappreciated (4ms for voice and 10ms for video).

Profile	AC	Interarrival Time (seconds)	Packet Size (bytes)	Segmentation Size (bytes)	Bps
Voice	3	Constant (0.02)	Constant (96)	1500	38.4 Kbps
Video	2	Constant (0.1)	Constant (17280)	1500	1.38 Mbps
Data	0	Exponential (0.05)	Constant (12500)	1500	2 Mbps

Table 1: Traffic profiles

Access Category	CW min	CW max	AIFS (slots)	Retry Limit	Buffer Size (bits)
AC 0	31	1023	15	7	Infinity
AC 2	7	15	7	7	1024000
AC 3	7	15	1	7	20000

Table 2: EDCF parameter set

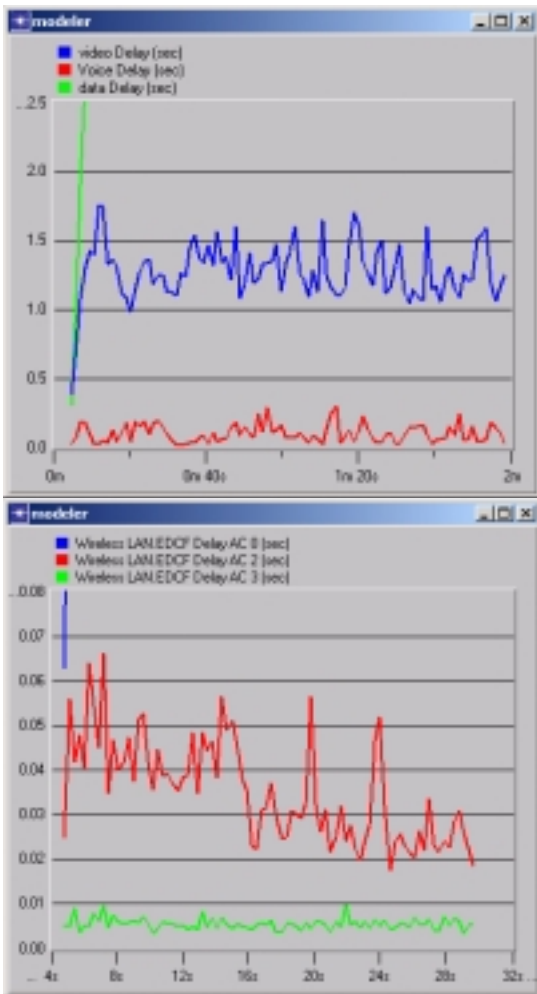


Figure 11: DCF delay vs. EDCF delay

[3] Stefan Mangold, "Analysis of IEEE 802.11e and Application of Game Models for Support of Quality-of-Service in Coexisting Wireless Networks", Junio 2003.

[4] Sunghyun Choi, Javier del Prado, Sai Shankar N, Stefan Mangold, "IEEE 802.11e Contention-Based Channel Access (EDCF) Performance Evaluation", 2003.

Conclusions

This paper gives an overview of wireless technologies 802.11 and 802.11e. Also gives a guideline of how to implement the EDCF backoff procedure to perform traffic differentiation. This project is still under development and the next stages will be:

- Add new fields to beacon's header
- Adapt EDCF parameter set with beacon header's information
- TBTT protection
- TXOPlimit control

Bibliography

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[2] 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.