Dynamic Contention Window for Quality of Service in IEEE 802.11 Networks

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Abstract: *There is limited QoS support for multimedia applications in Wireless LANS (WLANs). In this paper the authors present a novel mechanism to allow prioritized medium access for applications with QoS requirements. The performance of the proposed mechanism is evaluated through simulations and the results are compared with EDCF scheme.*

1. INTRODUCTION

In Wireless networks, computers communicate with one another through wireless media i.e. air instead of wired media, using short range frequencies. IEEE standard 802.11 defines the overall architecture and communication mechanism for wireless LANs. With the passage of time and popularity of WLANs, the demand for new features supporting video, audio, Voice over IP and other multimedia applications has grown. For these applications, QoS is an important issue. IEEE 802.11 task group e is currently working on the provision of QoS by enhancing existing 802.11 medium access control (MAC) sublayer. This paper presents a mechanism called **Dynamic Contention Window** (DCW) to support QoS in 802.11operations. DCW is an improvement in EDCF scheme, which supports static allocation of contention windows to different applications. The paper explains the 802.11 standard and its mechanism followed by an explanation of 802.11e. Simulations in OPNET [1] and discussion of results conclude the paper.

2. IEEE 802.11

Data link layer in all the 802 protocols is split into two or more sublayers [2]. The Medium Access Control (**MAC**) sub layer in 802.11 determines how the channel is allocated, that is who will transmit next; while Logical Link Control (**LLC**) sublayer hides the differences between 802 variants for above layers.

There are two problems in a WLAN transmission. If a cell encircles a specific range; a problem called **Hidden Station Problem** occurs which states:

Two stations B and C lie in the same cell while A belongs to some other cell. C is transmitting to B. A wants to send message to B as well. Since A cannot hear the channel is busy, it sends to B resulting in a collision.

Another variant (inverse) of this problem is **Exposed Station Problem** stated as:

A, B and D constitutes a cell. A is transmitting to D. B senses the channel and finds it busy in an attempt to find possibility of sending message to C which is lying in some other cell. So B mistakenly thinks that transmission will fail.

As a result of these problems, 802.11 do not use **CSMA/CD** (Carrier Sense Multiple Access with Collision Detection) as Ethernet does.

3. IEEE 802.11 ACCESS MECHANISMS

To deal with the above problems, 802.11 have two access mechanisms: the DCF (Distributed Coordination Function) and PCF (Point Coordination Function). DCF does not have a central control (similar to Ethernet). DCF uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and is known for its asynchronous data transmission (best effort data transfer). PCF on the other hand uses centrally controlled polling method to support synchronous data transfer. The implementation of PCF is optional as stated in IEEE 802.11 specifications, but DCF is the basic medium access mechanism for 802.11. The channel contention procedure begins when a station senses the channel to find out whether or not another station is transmitting. The collision avoidance mechanism employs two techniques: interframe space insertion (IFS) and a backoff algorithm. The IFS is the period a station is required to wait after it senses an idle channel and enters the transmission process. If the channel is idle for a period of time equal to the DCF IFS (DIFS), the station can begin transmission. However if the channel is busy the transmission is deferred.

Two methods of operations are supported in CSMA/CA:

1. If a station wants to transmit, it senses the channel. There are two possibilities:

- The channel is idle. If so station starts transmitting and emit its entire frame. (Drawback: The frame may be destroyed due to interference at receiver).
- The channel is busy. If so, the station defers until it goes idle again and starts transmitting. If a collision occurs, the colliding stations wait a random time (**Binary Exponential Back off** algorithm is used to calculate it), and then try again later. This method is based on **Physical Channel Sensing**.

2. The second method is based on **MACAW** (Medium Access with Collision Avoidance for Wireless) and

based on **Virtual Channel Sensing**. The following scenario shows how this protocol works [2]:

Workstations A, B and C belong to a cell while D belongs to a cell of which B is also registered. A sends an **RTS** (Request to Send) frame to B. If B is willing to accept the message, it sends back a **CTS** (Clear to Send) frame. When A receives CTS frame, it starts an **ACK** (Acknowledgement) timer and starts transmitting. B sends an ACK frame on receipt of message. If A does not receive an ACK frame within in ACK timer, the same procedure is followed again as shown in Fig 1.

What happens at C: C receives a RTS frame. From the information provided by RTS, C calculates the transmission time (ACK + DATA + CTS + RTS) and asserts a virtual channel busy state indicated by **NAV** (Network Allocation Vector), for itself.

What happens at D: D does not receive RTS, but receives CTS sent by B, so its NAV is also calculated to refrain it from transmitting.

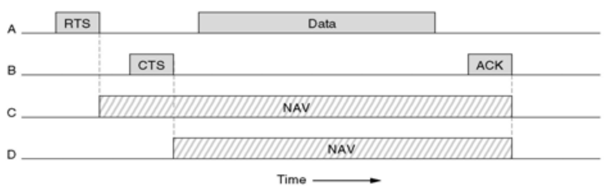

Fig. 1 The use of Virtual Channel Sensing using CSMA/CA [2]

Wireless networks are unreliable and noisy. To deal with this problem, 802.11 allows frames to be fragmented into smaller pieces. The fragments are individually numbered and acknowledged with **stop-and-wait protocol** (Fragment is not transmitted until the acknowledgement of the previous frame is received). Once a station acquires the channel, multiple fragments can be sent in a sequence called a **Fragment Burst** as shown in Fig 2**.** Fragment Burst is possible in PCF mode.

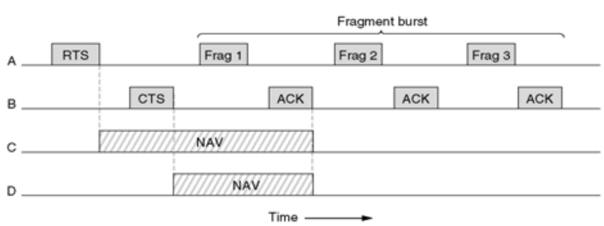

Fig. 2 ragment Burst [2]

PCF (Point Coordination Function) mode is optional in 802.11, and emphasize on synchronous data transfer. It is actually a polling medium access method with the point coordinator (PC) performing the role of the polling master. The PC resides in the AP. Once AP gains access to wireless medium, it polls the associated stations on a polling list. During contention free period a station may transmit only if it gets polled. With PCF, a contention free period (CFP) and contention period (CP) alternate over the time. PCF is used for medium access during CFP while the DCF is used during the CP. Once a station is signed up for polling service at a certain rate, it is effectively guaranteed a certain fraction of the bandwidth, thus making it possible to give QoS guarantees with some limitations.

DCF and PCF can coexist in a cell. This is managed by defining inter frame time interval. After a frame has been sent, a certain amount of dead time is required before any station can send a frame. Four different intervals are defined for specific purposes [2]:

i. **SIFS (Short Interframe Spacing)** is the shortest interval. It is used to allow parties in a single dialog to go first. Examples can be:

   - Receiver sending CTS in response of RTS.
   - Receiver sending an ACK for a frame.
   - Sender of fragment burst transmitting the next fragment without having to send RTS again.

ii. **PIFS (PCF Interframe Spacing)** is the time interval designated to base station activities. When SIFS passes without any activity and PIFS time is elapsed, the BS may transmit a beacon frame. So in this case, BS always grabs the channel when previous sender is done without having to compete with eager users.

iii. **DIFS (DCF Interframe Spacing)** is used for distributed mode. If BS has nothing to say, and a time DIFS elapses, any station may attempt to acquire the channel. The usual contention rules apply, and Binary Exponential Back off may be needed if a collision occurs.

iv. **EIFS (Extended Interframe Spacing)** is used only by a station that has just received a bad or unknown frame to report the bad frame. The idea of giving this event the lowest priority is the fact that the receiver may have no idea of what is going on. It should wait a substantial time to avoid interfering with an ongoing dialog between two stations.

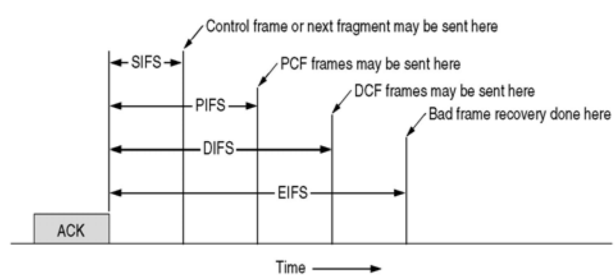

Fig. 3 Inter-frame spacing in IEEE 802.11 [2]

IEEE 802.11 wireless network can be configured to two different modes:

- In **Ad hoc mode**, all stations within the communication range can communicate directly with each other.
- And in **Infrastructure mode**, an Access Point (**AP**) is needed to connect all stations to a Distributed System (**DS**), and each station can communicate with others through AP.

4. 802.11e: QoS ENHANCEMENTS IN 802.11

802.11e standard adds a new function called a Hybrid Coordination Function (**HCF**) that includes both controlled contention free and contention based channel access methods in a single channel access protocol to ensure QoS. The HCF uses a contention based channel access method called Enhanced DCF (**EDCF**) that operates concurrently with a controlled channel access mechanism based on a central polling mechanism [3]. HCF supports both prioritized and parameterized medium access.

Back off Interval in DCF

If the medium is busy, the station selects a random number called a back off time, in the range of 0 to **CW** (Contention Window). The back off timer decrements the BI (Back off Interval) each time the medium is sensed to be idle for an interval of one time slot. As soon as the BI becomes zero, the station can begin to transmit. If the transmission is not successful, a collision is considered to have occurred. In this case, the CW is doubled, a new back off procedure starts. This process is called exponential backoff. The process will continue until the transmission is successful or discarded. The back off time is computed as:

$$\text{Back off Time} = \text{Random()} * \text{Slot Time} \quad (1)$$

Where Random() is an integer drawn from a uniform distribution over the interval [0, CW]. CW is an integer within the range of values of the physical characteristics of the medium i.e. CW_{min} and CW_{max} ($CW_{min} \leq CW \leq CW_{max}$). Slot Time is also based on PHY characteristics.

CW initial values would be CW_{min}. The CW will take the next value in the series after each unsuccessful transmission, until CW reach the value of CW_{max}. Once it reaches the CW_{max}, it remains there until it is reset. This improves the stability of the system under high load conditions. The CW should be reset to CW_{min} after each successful transmission. The set of CW values shall be sequentially ascending integer powers of 2 minus 1, beginning at CW_{min} and continuing up to CW_{max}.

The effect of this back off procedure is that multiple stations defer and go into random back off and a station with the smallest back off time will win the contention. The DCF does not differentiate the data traffic and stations. All stations and traffic classes have the same priority. The different delay and bandwidth requirements of the applications are not supported by the use of DCF.

EDCF and HCF

EDCF introduces four traffic categories (TCs) which are called access categories (ACs) [3]. There are eight priorities for stations from 0 to 7. These are called user priorities (UPs). AC's range from 0 – best effort, 1- video probe, 2 – video and 3 – voice. Each station may have up to four ACs to support eight UPs. One or more UPs are assigned to one AC. A station accesses the medium based on the AC of the frame to be transmitted.

There are two basic priority based mechanisms [3]

1. An AC with higher priority is assigned a shorter CW in order to ensure that in most cases the high priority AC would be able to transmit before low priority AC. This is done by setting the CW limits CW_{min}[AC] and CW_{max}[AC] from which CW[AC] is computed for different values of ACs.
2. Different Inter-frame space time (IFS) is introduced according to ACs. Instead of DIFS arbitration IFS (AIFS) is used. The AIFS is at least DIFS and can be enlarged individually for each AC.

If the medium is sensed to be idle in the EDCF, transmission can begin immediately otherwise station defers until the end of current transmission. After deferral, the station waits for a period of AIFS [AC] to start a back off procedure. The back off interval is now a random number drawn from the interval [1, CW[AC] + 1]. Each AC within a single station behaves like a virtual station; it contends for access to the wireless medium (WM) and independently starts its back off time after sensing the medium is idle for at least AIFS. Collisions between ACs within a single station are resolved, such that the data frames from the higher valued ACs received the TXOP (transmission opportunity). TXOP is a time interval when a particular station has the right to transmit onto the WM.

The typical values of CW limits and AIFS for different ACs are shown in Table 1:

AC	**CW_{min}**	**CW_{max}**	**AIFS**
0	CW_{min}	CW_{max}	2
1	CW_{min}	CW_{max}	1
2	$(CW_{min} + 1)/2 - 1$	CW_{min}	1
3	$(CW_{min} + 1)/4 - 1$	$(CW_{min} + 1)/2 - 1$	1

Table 1 Access Categories (802.11e) [3]

The working of contention free mechanism in 802.11 and 802.11e is same.

5. DYNAMIC CONTENTION WINDOW (DCW)

Dynamic Contention Window (DCW) dynamically reassigns and reshapes the contention window of different ACs when any of the queues have no frame to transmit. In this scheme the contention window (CW) of the head-off frame of the queue under consideration is changed in such a way that the time elapsed during contention in the original queue is adjusted after shifting the CW to the new queue having the higher priority.

There are four priority classes based on the AC defined in 802.11e. If there is no frame in the higher priority queue, then the traffic of the next ACs is shifted to the higher priority queue. The procedure is as follows;

- First the remaining time (*Remaining time (new)*) of Backoff Interval (BI) is calculated for the head off frame in the low priority queue so that its elapsed time can be adjusted in high priority queue proportionally.
- Now its contention window is recalculated according to high priority class.

If α and β are the minimum and maximum contention windows for the ACs defined in 802.11e. *i* and *j* are the two queues under consideration.

*Remaining Time (new) = (Current Remaining Time / (β (j) - α(j))) * ((β (i) - α(i)))* (2)

Where *Current Remaining Time* is the time, frames still have to wait before transmission. *Remaining time (new)* is the time calculated on the basis of *Current Remaining Time* of the frame in the original AC that is (Current Remaining Time) to be adjusted in the new AC. The new CW_{min} is calculated as:

$CW_{min} = \alpha(i) + \text{Remaining time (new)}$
While CW_{max} remains the same.

The pseudo-code of Dynamic Contention Window's is:

do if AC [i] is empty

then do for each remaining ACs [j]

Do if remaining AC[j+1] is not empty

then Reschedule(i,j,Rem_time(j))

*/*Reschedule is the procedure which recalculates the contention window based in remaining time*/*
Reschedule (i,j,Rem_time(j))
New_Rem_time= (Rem_time(j)/(β(j)-α(j)((β(i)-α(i))*
$CW_{min} = \alpha(i)+New\_Rem\_time$
$CW_{max}=\beta(i)$
*/*Where Rem_Time=Current Remaining time and New_Rem_Time=Remaining time(new)*/*

6. SIMULATION EVALUATION

A simulation model was developed using OPNET [1]. Fig 4 shows four WLAN workstations configured in ad hoc mode, each representing an AC. Station 4 has the lowest priority and station 1 has the highest priority (Table 2). OPNET 802.11b PHY module was used as a standard with maximum data rate up to 11Mb/s. 802.11b frequency hopping was used in which CW_{min}=15, CW_{max}=1023, and slot time was 50µs. The packet size is 1024.

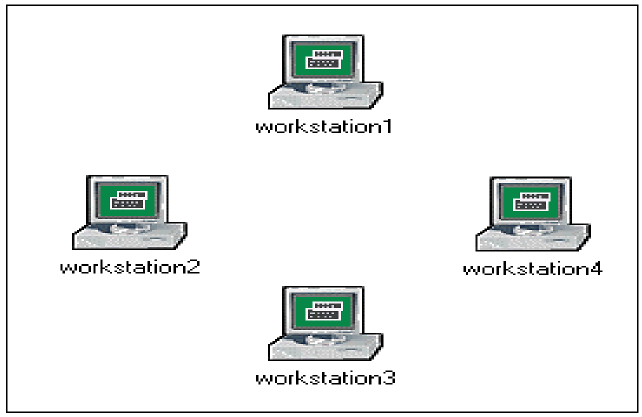

Fig 4. The Simulation Scenario

Figures 5 (a), (b), (c) and (d) show the media access delays for DCW, EDCF and 802.11. DCW has the lowest Media Access Delay for all the workstations. Table 2 shows the type of traffic for all workstations.

	Type of Traffic
Workstation 1	Interactive Voice
Workstation 2	Interactive Multimedia
Workstation 3	Streaming Multimedia
Workstation 4	Best Effort

Table 2. Types of Traffic

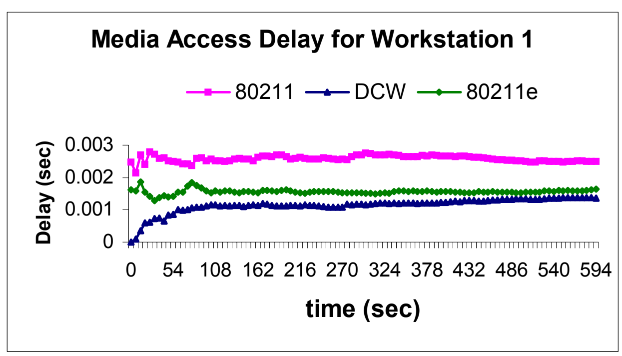

Fig 5 (a) Media Access Delay for Work Station 1

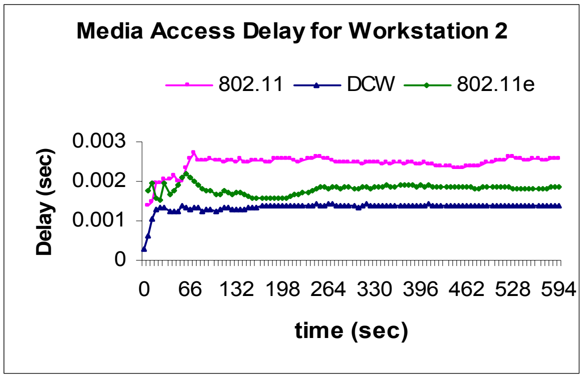

Fig 5 (b) Media Access Delay for Work Station 2

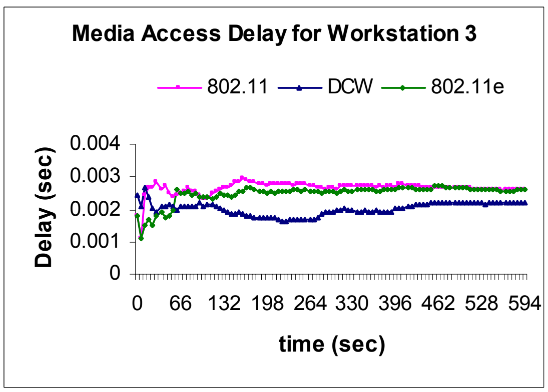

Fig 5 (c) Media Access Delay for Work Station 3

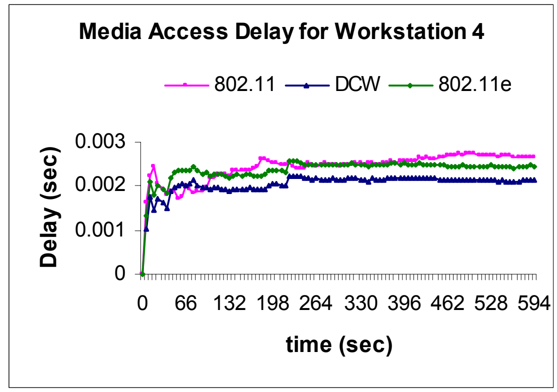

Fig 5 (d) Media Access Delay for Work Station 4

7. CONCLUSIONS

A detailed overview of IEEE 802.11 and 802.11e (EDCF) is presented. The simulation results show that the ***Dynamic Contention Window*** has improved the QoS for different priority classes (ACs) as compared to 802.11e standard.

The simulation results show that Media Access delay has decreased for all workstations using DCW.

REFERENCES

[1] MIL3. www.opnet.com

[2] Andrew S. Tannenbaum, *Computer Networks*, 4th Edition., Prentice Hall, 2003, pp.292, 297-299.

[3] D. Gu and J. Zhang, "QoS Enhancement in IEEE802.11 Wireless Local Area Networks", *IEEE Communication Magazine*., vol 41, issue 6. pp. 120-124, June 2003.