QUALITY OF SERVICE: MAC PROTOCOL IN IEEE802.11 WLAN

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Abstract - *The most popular and widely used Wireless LAN standard all over the world today is IEEE 802.11. It is likely to play a major role in the next generation wireless communication networks. IEEE 802.11 WLANs has two basic co-ordination functions at MAC layer: DCF (Distributed Coordination function) and PCF (Point Coordination Function). DCF is the basic access function for asynchronous data services and is based on carrier sense multiple access with collision avoidance (CSMA/CA) with a binary slotted exponential contention (back off) algorithm .PCF uses a centralized polling method requiring a node to play the role of a point coordinator (PC) developed for time bounded services. Providing QoS support in IEEE 802.11 is challenging task, as QoS solutions for wired networks cannot be applied out-of-the-box for wireless mobile ad hoc networks, due to specifics of radio networking and mobility. QoS problem has two major perspectives: (1)network perspective (2) application/user perspective. Networks receive from the applications implicitly or explicitly their QoS parameters and need to respond to these requests by supplying QoS services. In this paper we first analyze the QoS limitations of legacy DCF and PCF IEEE 802.11 wireless MAC. Then, we present the upcoming IEEE 802.11e standard introduced as a proposal defining the mechanisms for WLANs aiming to provide QoS support to time-sensitive applications, such as, voice and video communications. Finally, we carry out a comparative study of legacy DCF and the IEEE 802.11e (EDCF), when supporting different services, such as voice, video, best-effort and background traffic.*

1. Introduction

The IEEE 802.11 Wireless LANs (WLANs) standard is gaining a lot of popularity in recent years because of its important role in building a wireless broadband computing environment. The standard is composed of both Physical Layer (PHY) and Medium Access Control (MAC) specifications for wireless LANs. Various task groups under the IEEE 802.11 Working Groups are also developing revisions of the standard. New PHY specifications now allow much higher data rates to be used (e.g., upto 11Mbps in 802.11b and 54Mbps in 802.11a), as compared to the 1Mbps and 2Mbps in the initial version. Higher data rates have paved the way for incorporation of a larger variety of new applications including multimedia applications in a wireless LAN environment. Use of both multimedia applications and traditional data applications in the same wireless LAN is likely to be common in many scenarios, such as in a home network or a cafe deploying a WLAN hotspot. However, without any traffic prioritization mechanism in MAC, high data rate alone may not be sufficient to meet Quality of Service (QoS) requirements imposed by certain applications such as real time voice, audio and video. Therefore, QoS for WLAN MAC has received much attention. IEEE 802.11e task group has defined the new Enhanced Distributed Coordination Function (EDCF) MAC access method as a standard for QoS enhancement of 802.11 MAC. The motivation of this work is to analyse and compare the network performance between EDCF as in the 802.11e draft and DCF as in 802.11 standard .

2. Overview of IEEE802.11 WLAN

The IEEE 802.11 MAC sub layer defines two medium access coordination functions , the DCF and the optional PCF . DCF is the basic access function for ieee802.11 and is based in a carrier sense multiple access with collision avoidance (CSMA/CA) algorithm with a contention (backoff) algorithm. PCF uses a centralised polling method requiring a node to play the role of a point coordinator (PC). The PC cyclically polls stations to give them the opportunity to transmit.
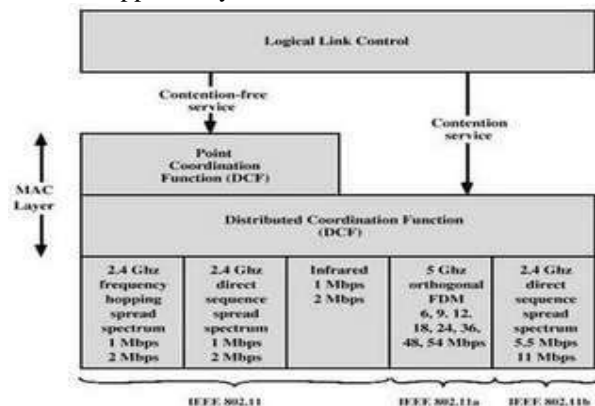

Fig 1:802.11MAC architecture

(A) 802.11 PCF

PCF uses a centralized polling scheme, which requires the AP as a point coordinator (PC). If a BSS is set up with PCF-enabled, the channel access time is divided into periodic intervals named beacon intervals. The beacon interval is composed of a contention-free period (CFP) and a contention period (CP). During the CFP, the PC maintains a list of registered STAs and polls each STA according to its list. Then, when an STA is polled, it gets the permission to transmit data frame. Since every STA is permitted a maximum length of frame to transmit, the maximum CFP duration for all the STAs can be known and decided by the PC, which is called *CFP_max_duration*. The time used by the PC to generate beacon frames is called target beacon transmission time (TBTT). In the beacon, the PC denotes the next TBTT and broadcasts it to all the other STAs in the BSS. In order to ensure that no DCF STAs are able to interrupt the operation of the PCF, a PC waits for a PCF InterFrame Space (PIFS), which is shorter than DIFS, to start the PCF. T s to the values of *FP_max_duration* time, or the remaining duration of CFP in case of delayed beacon. uring the CP, the DCF scheme is used, and the beacon interval must allow at least one DCF data frame to be transmitted.

When a PC polls an STA, it can piggyback the data frames to the STA together with the CF-Poll, and then the STA sends back data frame piggybacked not only the data frame to the destination, but also an ACK to the previous successful transmission. Note that almost all packet transmissions are separated by the SIFS except for one scenario: if the polled STA does not respond the PC within a PIFS period, the PC will poll the following STA. silent STAs are removed from the polling list after several periods and may be polled again at the beginning of the next CFP. At any time, the PC can terminate the CFP by transmitting a CF-End packet, then all the STAs in the BSS should reset their NAVs and attempt to transmit during the CP. Normally ,PCF uses a round robin scheduler to poll each STA sequentially in the order of polling list, but priority-based polling mechanisms can also be used if different QoS levels are requested by different STAs.

(B) 802.11 DCF

The basic service set (BSS) is the fundamental building block of IEEE 802.11 architecture. The geographical area covered by the BSS is known as the basic service area (BSA), which is similar to a cell in a cellular network. IEEE 802.11 supports both the ad hoc network and infrastructure network architecture. The DCF is based on CSMA/CA and it only provides asynchronous access for

best effort data transmission. DCF consists of both a basic access method and an optional channel access method using RTS/CTS exchanges.

1. The basic access method

In 802.11, priority access to the wireless medium is controlled by the use of inter-frame space (IFS) time between the transmission of frames. Total three IFS intervals have been specified by 802.11 standard: short IFS (SIFS), point coordination function IFS (PIFS), and DCF-IFS (DIFS). The SIFS is the smallest and the DIFS is the largest. The station may proceed with its transmission if the medium is sensed to be idle for an interval larger than the Distributed Inter Frame Space (DIFS). If the medium is busy, the station defers until a DIFS is detected and then generate a random back-off period before transmitting. The back-off timer counter is decreased as long as the channel is sensed idle, frozen when the channel is sensed busy, and resumed when the channel is sensed idle again for more than a DIFS. A station can initiate a transmission when the back-off timer reaches zero. The back-off time is uniformly chosen in the range $(0, w\text{-}1)$. Also $(w\text{-}1)$ is known as Contention Window (CW), which is an integer with the range determined by the PHY characteristics CW_{min} and CW_{max}. After each unsuccessful transmission, w is doubled, up to a maximum value $2_m \cdot W$, where W equals to $(CW_{min}+1)$ and $2_m \cdot W$ equals to $(CW_{max}+1)$.
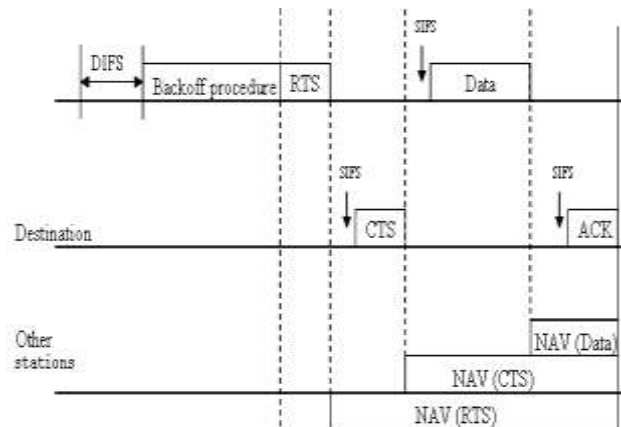

Fig 2. 802.11 DCF protocol.

Upon having received a packet correctly, the destination station waits for a SIFS interval immediately following the reception of the data frame and transmits a positive ACK back to the source station, indicating that the data packet has been received correctly (Fig.2). In case the source station does not receive an ACK, the data frame is assumed to be lost and the source station schedules the retransmission with the CW for back-off time doubled. When the data frame is transmitted, all the other stations

hearing the data frame adjust their Network Allocation Vector(NAV), which is used for virtual CS at the MAC layer, based on the duration field value in the data frame received correctly, which includes the SIFS and the ACK frame transmission time following the data frame.

2. The RTS/CTS access method

In 802.11, DCF also provides an optional way of transmitting data frames that involve transmission of special short RTS and CTS frames prior to the transmission of actual data frame. As shown in Fig.3, an RTS frame is transmitted by a station, which needs to transmit a packet. When the destination receives the RTS frame, it will transmit a CTS frame after SIFS interval immediately following the reception of the RTS frame. The source station is allowed to transmit its packet only if it receives the CTS correctly. Note that all the other stations are capable of updating the NAVs based on the RTS from the source station and the CTS from the destination station, which helps to combat the *hidden terminal* problems. In fact, a station able to receive the CTS frames correctly, can avoid collisions even when it is unable to sense the data transmissions from the source station. If a collision occurs with two or more RTS frames, much less bandwidth is wasted when compared with the situations where larger data frames in collision.
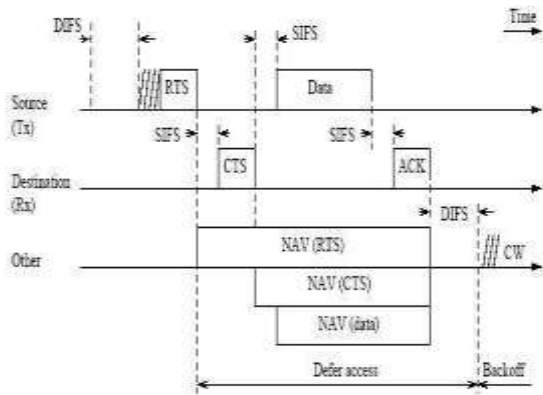

Fig.3 RTS/CTS access mechanism in DCF

3. QoS (Quality of Service)-What and Why?

In general terms , QoS is the ability of a network element (e.g. an application, a host or a router) to provide some levels of assurance for consistent network data delivery. Good QoS services include guaranteed features of

       Required Bandwidth
       Faster Response Time
       Minimal Error Rate

    Consistent connectivity
In the recent past, web services using multimedia applications have grown fast as a necessity. They include the services such as transmission of high speed video, audio, graphic files, animated files, 3D games, etc. These services require guaranteed QoS support from the network.

(A) IEEE 802.11 QoS Limitations

(1) QoS Limitation of DCF

DCF supports only the best effort service and does not provide any QoS guarantees. Typically, time-bounded services such as voice over IP or audio/video conferencing require specified bandwidth, delay, and jitter, can tolerate some losses.
In DCF mode, all the STA's in one BSS compete for the resources and channel with same priorities where as priorities should be assigned depending on the type of data flow.
There is no differentiation to guarantee bandwidth, packet delay and jitter for high priority STAs or multimedia flows.

(2) QoS Limitation of PCF

Although PCF has been designed to support time bounded multimedia applications, this mode has some problems that lead to poor QoS performances.
Central polling scheme. All the communication between two STAs in the same BSS has to go through the AP (Access Point), thus some of the channel bandwidth is wasted. As traffic increases a lot of channel resources are wasted.
The cooperation between CP and CFP modes may lead to unpredictable beacon delays.
No mechanisms for the stations to communicate their QoS requirements to the AP.

4. New Enhanced Schemes for QoS guarantees

The original 802.11 standard was not designed to provide differentiation and prioritization based on the traffic type, thus providing less than optimal user experience for voice and video over WLAN applications. Voice applications require no dropped calls or bad connections. Video/audio applications require enough bandwidth to maintain high quality video/audio streams. Email and file-sharing applications require ensuring delivery of error-free files. To fulfill these requirements, the IEEE 802.11e has added several QoS features and enhancements to WLAN.

The IEEE 802.11e is currently defining enhancements to the 802.11 MAC access methods (DCF and PCF), providing the classes of service, enhanced security and authentication mechanism. These enhancements are defined in 802.11e which introduces a new access method called Hybrid Coordination Function (HCF). It includes two new schemes namely the Enhanced Distributed Coordination Function (EDCF) and HCF Controlled Channel Access (HCCA).

(A)   Hybrid Coordination Function (HCF)

In order to support both integrated service and differentiated service QoS approaches in 802.11, TGe has defined a new mechanism called HCF. This mechanism is backwardly compatible with legacy DCF and PCF. It has both polling based and contention based channel access mechanisms in a single channel access protocol. HCF consists of two access methods, Enhanced Distributed Coordination Access (EDCA) - a distributed channel access scheme; and called HCF Controlled Channel Access (HCCA) - a polling-based scheme.
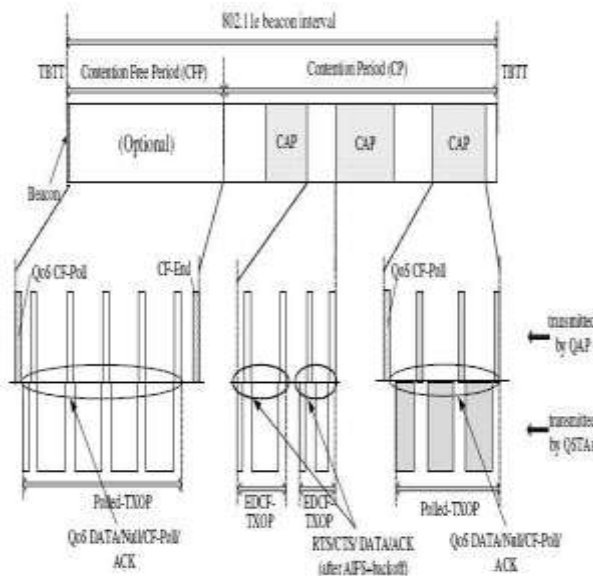

Fig.4. IEEE 802.11e HCF Beacon interval.

(B)Enhanced   Distributed   Coordination Function (EDCF)

The EDCF is designed for the contention-based prioritized QoS support. Each QoS-enhanced STA (QSTA) has 4 queues (ACs), to support 8 user priorities (UPs) as defined in IEEE 802.1D. Each AC queue works as an independent DCF STA and uses its own backoff parameters.

Priority	Access Category (AC)	Designation (Informative)
1	0	Best Effort
2	0	Best Effort
0	0	Best Effort
3	1	Video Probe
4	2	Video
5	2	Video
6	3	Voice
7	3	Voice

Table 1 : Priority To Access Category Mapping

In EDCF, relative priorities are provisioned by configuring the time to access the channel once it is sensed idle and by changing the size of the contention window. EDCF uses the contention window to assign priority to each traffic category. Indeed, assigning a short contention window to a high priority TC ensures that in most cases, high priority TC is able to transmit a-head of low priority one. Thus, the CWmin and CWmax parameters can be set differently for different traffic categories, such as, a high priority TC with small values of CWmin and CWmax.
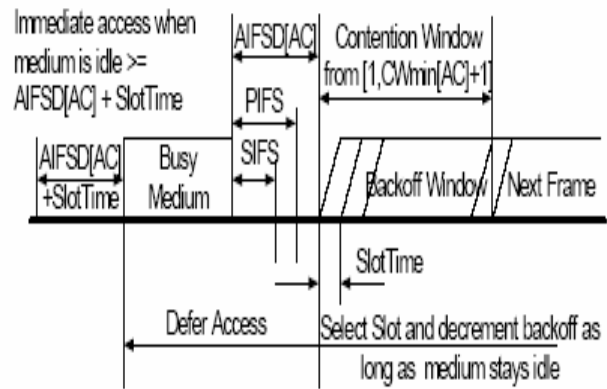

Fig 5 : IEEE 802.11e EDCF Channel Access

Basically, the smaller AIFS [AC] and CWmin [AC], the shorter the channel access delay for the corresponding priority, and hence the more capacity share for a given traffic condition. However, the probability of collisions increases when operating with smaller CWmin [AC]. These parameters can be used in order to differentiate the channel access among different priority traffic.
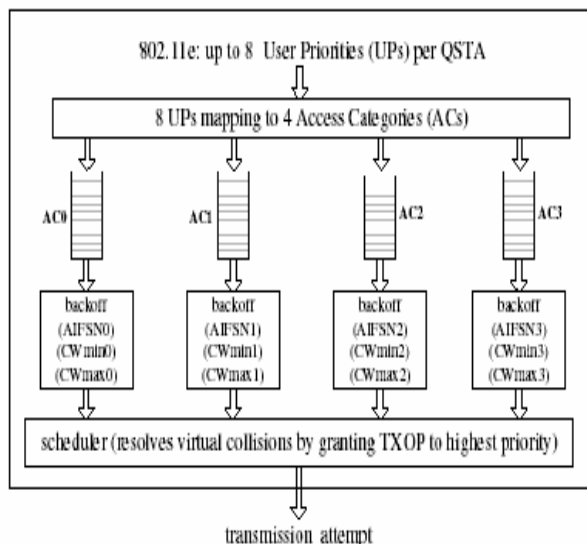
Fig6 : Internal Contention of four Access Categories

Figure 6 shows the 802.11e MAC with four transmission queues, where each queue behaves as a single enhanced DCF contending entity, i.e., an AC, where each queue has its own AIFS and maintains its own Backoff Counter (BC). When there is more than one AC finishing the backoff at the same time, the collision is handled in a virtual manner. That is, the highest priority frame among the colliding frames is chosen and transmitted, and the others perform a backoff with increased CW values.

For further differentiation, various interframe spaces (IFS) can be used by different traffic categories. Instead of using a DIFS, as a minimum specified idle duration time as defined in DCF, a new kind of interframe space called Arbitration Interframe Space (AIFS) is used. Thus, a traffic category (TC) with a small AIFS has a high priority.

6. Conclusion

The applications like video conferencing, voice applications in wireless networks, are becoming more common these days. Therefore there arises a need for finite delay and dedicated bandwidth. The user needs more quality of service for these applications. Providing such QoS support in 802.11 is a challenge. So the key motivation behind this analysis was to evaluate the benefits of IEEE 802.11e QoS draft (EDCF) over the existing IEEE 802.11 standard (DCF). The major benefit provided by EDCF vs. DCF is the introduction of eight distinct traffic classes. EDCF combines a collision based channel access and priority packet scheduling in order to deliver qualitative QoS services. Higher priority traffic can get higher throughput and lower MAC access delay. The key parameters, maintained in each traffic category, that enable priorities are AIFS, CW, and PF. EDCF provides significant improvements for high-priority QoS traffic. EDCF improves wireless bandwidth efficiency and packet overheads. EDCF is completely distributed, has better performance than DCF, and is less complex.

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