QoS and Integrating issues of Real Time Traffic within Wireless Environment

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Abstract

Wireless technology in simple words is a technique that enables more than one user to share resources without having wiring. In comparison with wired local area network in which twisted pair cables, adapters and coaxial cables are used to connect multiple devices.

Wireless technology has enabled us to send and receive data through radio and infrared waves and a single access point in WLAN can easily accommodate many users in the same domain. In this era of technology we want everything to be simplified to the maximum and in regards to wireless technology we want to have voice over IP instead of analog phones this is what we call real time traffic.

In this Thesis report we have studied the WLAN technology in detail with special emphasis on QoS issues and tried to suggest the possibilities on how to integrate real time traffic on WLAN. Through simulation we will try to find improvements in this field.

Our main focus will be on CSMA/CA protocol of 802.11 and 802.11e standards, and different MAC schemes that are used to accommodate different types of traffic, special emphasis is given on DCF and EDCA.

Through simulation we will show the results that how these fields can affect the QoS of WLAN, these schemes enables more user capacity which means that we can increase the traffic and make wireless LAN more adaptive.

The simulation that we will do in this Thesis will be totally correlated with our research but it will not be practically implemented.
Acknowledgement

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Finally we would like to dedicate our Thesis to our parents and friends for their love, support and encouragement that they provided.
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1 Introduction

Wireless Local Area Network (WLAN) uses electromagnetic waves to transfer data between computer and networking devices. It was first used for defense purposes but with the passage of time it expanded over wider range. WLAN implementations can be seen in companies, campuses etc due to many advantages over wired Local Area Networks. WLAN is more robust, flexible, easy to implement and provides cost effective network setup. WLAN also provides freedom to users to roam within the network range and it has continued to grow at an incredible rate.

WLAN transmits using radio frequency and it is regulated by government bodies, WLAN has several standards supported by Institute of Electrical and Electronic Engineers (IEEE) 802.11. Commonly used standards are 802.11b which provides 11Mbps data rate and works under 2.4 GHz Industrial Scientific Medication (ISM) band and 802.11a which provides 54Mbps and works under 5 GHz ISM band.

In this research we will concentrate on 802.11 standard which uses Carrier Sense Multiple Access (CSMA/CA) protocol, originally 802.11 Medium Access Control (MAC) protocol was designed with two modes of communication for WLAN. The first one is Distributed Coordination Function (DCF) based on CSMA/CA, second is Point Coordination Function (PCF) that supports time sensitive traffic flow.

To ensure Quality of Service (QoS) for real time traffic and multimedia technologies IEEE provided a new standard 802.11e for QoS support. The main purpose of 802.11e is to enhance the 802.11 MAC-DCF and PCF which are known as Enhanced Distributed coordination Channel (EDCA) and Hybrid Control Channel Access (HCCA) for QoS control for voice and video applications.

1.1 Motivation

The idea that motivated us to carry out our Thesis in the field of WLAN was that wireless network are being deployed widely this can be seen in our daily life that how much we interact with this technology. Mergence of real time traffic over wireless networks have made it more attractive and this moving on to mobile networks. For the above reasons we were really interested in acquiring the in-depth knowledge about this field. The integration of real time traffic over wireless medium was also inspiring for us as QoS parameters should be managed in such a way that it gives the maximum output.

1.2 Problem Statement

How to make WLAN more adaptive in the present era of technology in regards with quality of service and real time traffic.
1.3 Thesis Structure

In the first chapter we have given the overview of WLAN technology and in next chapter we have discussed technical features of WLAN along with its architecture and how to manage it then we have also discussed legacy protocol DCF, that how it work and what were the loopholes in this protocol that led to the new version EDCA. We have discussed the QoS requirement real time applications like VoIP and VoD and the protocols that support them. In analysis section we have analyzed the performance of DCF that how the QoS parameters are affected by taking real time scenarios. Chapter 4 we have performed the simulation of DCF and EDCA for real time application where we created different scenarios in OPNET so to evaluate different QoS Parameters.
Technical Background of WLAN

In this chapter we have focused on the WLAN technology and its technical features, along with that our focus is on 802.11 MAC, DCF and EDCA protocols.

In the first section we have tried to understand the basic of WLAN technology like what is wireless environment, how does it work and how is it different from the previous wired technologies. WLAN architecture has also been discussed along with different standards that it has and the problems that are faced by this technology.

In the next section we have concentrated on the technical aspect of this technology like the medium access control, QoS requirements and we have tried to give a brief overview of real time applications over wireless medium. We have discussed MAC because during the time that the wireless networks were being evolved the technology that was being used for medium access was CSMA/CD. This technology worked with the basic concept of collision detection but with the passage of time it was known that there is a need for more sensitive mechanism like CSMA/CA. This works on the concept of collision avoidance and it has additional features like Ready to Send RTS and Clear to Send CTS. We have also discussed the protocol that is DCF which work with CSMA/CA technique so to make the wireless networks more adaptive.

We have also discussed that what are the QoS parameters and how they affect the overall performance. QoS consist of large collection of networking technologies and techniques for managing network traffic in cost effective manner to enhance users experiencing for their type of environments.

In the third section our main focus is on 802.11e standard and its MAC schemes and some additional feature in the scheme are discussed that help in achieving the desire QoS. Domain of legacy 802.11 is expanded by IEEE 802.11e which deals in real time application and QoS is addressed in this protocol of wireless devices.

Form this section we will be more specific by discussing MAC protocols. Having said that MAC layer is mandatory for executing transmission for forwarding data to physical channel and is accomplished through physical layer and data link layer. In legacy 802.11 DCF protocol is enhanced by IEEE 802.11e Hybrid Coordination Function HCF known as EDCA which provides controlled channel access functionality for real time applications running over WLAN.

The section one and two make the base of our thesis and in next chapters we will analyze and evaluate these protocols.

2.1 Wireless Network

The fundamental characteristic of wireless networking is ability to connect to a wireless network without physical contact and the availability of wireless network depends upon the signal range from wireless device.
The basic concept of wireless network consists of multiple mobile and fixed wireless stations (STAs) communicating with radio waves where it increases the mobility and provide access to data networks in user friendly environment. A wireless network incorporates several different network technologies, communication ranges and transmission bandwidths that can be deployed in home, campus and airports etc. [1, 2]

### 2.2 Difference between Wireless and Wired Networks

The phenomena of wireless networks is based on wired networks because in both cases data is transmitted in signals as electromagnetic waves but the dispersion of signals is totally different in case of wired networks. In wired networks signals are transmitted through cables whereas in wireless network they propagate through air.

In wireless networks number of factors can influence the transmission that takes between the communication parties like atmospheric conditions, interference between signals, and building and other obstacles, but in wired networks does not face these problems. The propagation of wireless signal based on the signal properties the ideal condition to calculate the signal strength is to create a vacuum where there are no obstacles. [1]

### 2.3 Wireless Local Area Network

The History of WLAN technology and radio communications came together for first time in 1971 at university of University of Hawaii for research project called ALOHANET [3]. WLAN uses radio wave which allows users to access and share data and network resources in the same way as in Ethernet LAN. In 1997 IEEE released 802.11 WLAN standards, which belong to group of IEEE 802.x standards currently three main operational standards of WLAN i-e 802.11a, 802.11b and 802.11g. [5, 6]

#### 2.3.1 Purpose of WLAN

The purpose of WLAN was to cut down the cost of Infrastructure LAN due to installations of cables and maintenance. WLAN are being developed to provide broadband communications to users in a limited geographical area. The IEEE 802.11 WLAN also known as Wireless Fidelity WiFi. [1]

#### 2.3.2 Components of WLAN

The architecture of WLAN is based on several components, STAs, Access Points (APs), Independent Basic Service Set (IBSS), Basic Service Set (BSS), Distribution System (DS) and Extended Service Set (ESS).

Wireless STAs contains a wireless card/adapter that might be internal or external which provide the wireless connectivity. In fig 2.1 shows how IBSS and DS connects the WLAN components to make wireless network. In IBSS which is known as peer to peer wireless network where at least two STAs are used for connectivity where there is no access to DS is available.

In BSS which is controlled by single wireless AP, where AP provides connectivity to the LAN and provides the functionality of a bridge when one STA start communicating to another STA.
Technical Background of WLAN

The BSS supporting one or multiple wireless clients is also sometimes known as an infrastructure wireless network. The ESS is set of two or more wireless APs connected to the LAN known as logical network bounded by a router. The DS provides the mobility to enable STAs to roam between APs while maintaining the same IP subnet. [1, 2]

Fig 2.1: Components Structure of 802.11 WLAN.

2.3.3 Architecture of WLAN

While setting up WLAN architecture there are many possibilities of spreading WLAN components into two modes i.e., Ad-hoc mode and Infrastructure mode. The Ad-hoc mode can also known as IBSS as shown in fig 2.1, in this mode the wireless devices create wireless network by communicating with each other. [2, 4]

The Infrastructure mode architecture is commonly used than Ad-hoc architecture where an AP functions as a bridge that connects the wireless devices to the existing wired network as shown in fig 2.1, in this mode wireless devices communicate directly with closet AP in a BSS. [2, 4]

2.3.4 WLAN Standards

Over past few years several WLAN technologies and standards have been developed where majority of devices being manufactured on IEEE 802.11(a/b/g). There are various modulation schemes, frequency ranges and data rates defined for IEEE 802.11 WLAN standards. The goal of IEEE 802.11 standard was to develop a MAC and physical layer for wireless connectivity for fixed and mobile wireless STAs. Some commonly used 802.11 WLAN standards. [5, 6]

802.11a: Released in 1999 also called WiFi5. It works in unlicensed ISM radio band and supports data rate from 6–54 Mbps which is five times greater than 802.11b and provides the indoor coverage range up to approximately between 25–75 feet which is lesser than 802.11b/g.

802.11b: Released in 1999 also called WiFi. It works in unlicensed 2.4 GHz ISM radio band and support data rate up to 11 Mbps and provides the indoor coverage up to approximately between 100–500 feet.

802.11e: Released in 2005 and was designed to improve the QoS and to enhance the WLAN application. 802.11e is the standard that is really important for delay sensitive applications like real time traffic over WLAN it enhances the 802.11 MAC. The upcoming changes in
Technical Background of WLAN

2.3.5 WLAN Protocol Architecture

The IEEE 802.x protocols are based on the Open System Interconnection OSI reference model developed by International Standard Organization ISO which provides the platform for LAN protocol architecture and framework for developing protocols standards. OSI layers consist of seven layers as illustrated in fig 2.2 where higher layers protocols i.e. Network to Application layers are independent of network architecture and mostly applicable to 802.x protocols. [1, 2]

![ISO OSI 7-layer Model](image)

![IEEE 802 standards](image)

**Fig 2.2:** IEEE 802.x Protocol Layer Compared to OSI Model.

The time when OSI was developed, IEEE exchange information during the development of 802.1x LAN standard and 802.11 WLAN standards. Like 802.1x standards, 802.11 standards also focus on the two lower layers of OSI model, Physical layer and Data Link layer. Technologies used by the IEEE 802.1x and 802.11 standards are based on IEEE 802.1x standard that defines port based, network access control used to provide authenticated network access for Ethernet network also correspondence to the Data Link Layer and Physical layer of OSI model. The 802.11 standard defines the specification for the Physical Layer, MAC Layer, and Logical Link Layer whereas IEEE refined the standard and divided the Data Link Layer into 2 sub layer known as LLC and MAC as illustrated in fig 2.2.[1, 2]

2.4 Problem in Different WLAN MAC Techniques

The MAC technique which is applied to LAN is based on Carrier Sense Multiple Access/Collision Detection CSMA/CD [2]. So when this technique was implemented upon the WLAN several issues were created like data transmission from sending STAs and propagation of signal strength from sender cannot be in the range of receiver. Several issues are considered in case CSMA/CD when data is transmitted between STAs like the Hidden Node Problem and Exposed Node Problem.
2.4.1 Hidden Node Problem

Hidden node problem is that when two nodes are separated so that they are out of each other’s range but at the same time communicate with the AP as shown in the fig 2.3. The two nodes A and B which are on the opposite side of the AP the problem arises when the two nodes start to communicate with the AP at the same time as they are out of each other range so CSMA/CA does not work in this scenario known as hidden node problem. [5]

Fig 2.3: Hidden Node Problem

2.4.2 Exposed Node Problem

This is a problem faced by the network when one node defers its transmission due to the fact that its neighboring node is also transmitting.

Scenario:
Suppose that there are four nodes namely A, B C and D out of which A and D are receivers and B and C are transmitters now the exposed terminal problem arises when B is transmitting to node A now the node C will defer its transmission after carrier sense however A and D and D and B are out of rage of each other this refers to exposed terminal problem. [1, 2]

Fig 2.4: Exposed Node Problem

2.5 CSMA/CA

CSMA/CA [16] with collision avoidance is a network contention protocol its functionality is to listen to the channel or network before transmitting, it sends a signal on to the network so to listen to the collision if it does listen to them, no device is allowed to send data over the medium this is where it is different from CSMA/CD.

In order to modify CSMA/CD there are several ways first don’t try to hold the medium for large amount of time first sense the channel if it is found busy just delay the transmission for a random period of time [17]. Both legacy DCF and PCF protocols perform their operations on CSMA/CA.
2.5.1 802.11 MAC Frame
MAC [34] frame has an important role for communication between STAs generally MAC frame has a certain format that is in fixed order for all frames which comprises of classes. These are management frame, control frame and data frame. Management frame which is used for STA association, disassociation, timing and synchronization and authentication. Control frame which is used for handshaking between STAs RTS/CTS and Acknowledgement ACK frame during Contention Period CP. Data frame is used for sending data packets during CP and Contention Free Period CFP.

![Fig 2.5: MAC Frame Format. [34]](image)

2.5.1.1 Timing Interval of MAC Frame
There are five timing intervals of IEEE 802.11MAC protocol by which both DCF and PCF are implemented. [23, 24]

1. **SIFS**: Short Interframe Space.
2. **Slot Time**.
3. **PIFS**: Priority Interframe Space.
4. **DIFS**: Distributed Interframe Space.
5. **EIFS**: Extended Interframe Space.

![Fig 2.6: Medium Access and Interframe Spacing. [34]](image)

SIFS is the shortest interval, followed by the slot time which is slightly longer. It is used to separate the frames in one single transmitting. PIFS is equal to SIFS plus one slot time which is used by PCF IFS where AP uses it to get control of the channel without letting anyone to interfere. DIFS is equal to the SIFS plus two slot times which is used by DCF STAs during the contention phase. EIFS is much larger than other IFS which is used when a frame receives errors during transmission. [34]

2.6 Distributed Coordination Function
The basic 802.11 MAC protocol is the DCF based on CSMA/CA where all STA implement DCF functionality. CSMA is a contention based protocol [3, 4] making certain that all STA work on scheme called listen before talk to avoid collision between STAs.
The description of CSMA/CA for DCF consists of CD mechanism, IFS and random Backoff BO regulations. In DCF each STA uses Clear Channel Assessment CCA and random BO algorithm to utilize each channel. CCA algorithm is used to sense if STA wanted to send frame by measuring signal energy at the antenna and determining the strength of received signal. If the strength of this signal is above a specific threshold value and the transmission on medium is occupied by other STA so no access is given to desired STA, it has to wait until medium is idle and if threshold of signal is below it starts its retransmission. The collision is avoided by this protocol because the receiver sends the ACK to sending STA that provides the error free transmission.

DCF function which supports data transmission which have the tendency to tolerate delay to an extent for example Email and File transfer Protocol FTP. DCF is also implemented in both Infrastructure and Ad-Hoc networks. In BSS both wireless STA and AP work in opposite direction DCF based wireless STA first look for medium to be idle for transmission of data packet. DCF can also be combined with PCF protocol where each wireless STA have equal share of the medium through contention. [3, 4]

2.6.1 Working of DCF
As DCF is based on CSMA and its protocol consist of two different schemes CSMA/CA and CSMA/CD.

The first scheme [18, 19] was useful in IEEE 802.3 Ethernet where the collision was avoided as the STAs detected the signals where its transmission was different from other nodes in a network. Therefore CSMA/CD was not useful in 802.11 wireless communication were a collision is detected when simultaneously two or more STA using the same medium at the same time are waiting for medium to become idle. So this causes the hidden node problem where STAs cannot hear while transmitting so to deal with this problem ACK was introduce where receiver sends ACK to sender after each successful transmission, this cause the transmission to be delayed.

![DCF Access Mechanism with IFS Timing](image)

Fig 2.7: DCF Access Mechanism with IFS Timing. [18]

The fig 2.7 shows the basic access mechanism where source is Time axis which shows the data transmitted by source STA, where receiver “Time axis” shows the ACK transmitted by recipient STA and other “Time axis” shows the network status viewed by other wireless STAs. Data packet [23, 24] transmitted by both sender and receiver not have the same priority for example
ACK has higher priority over data packet therefore IFS is assigned to each packet when medium turns idle for a time. Two types of IFS are used SIFS and DIFS where SIFS is shortest time interval than DIFS as shown in fig 2.7 and fig 2.8.

![Diagram of DCF with RTS/CTS Access Scheme](image)

Fig 2.8: DCF with RTS/CTS Access Scheme. [18]

In second scheme of CSMA/CA was deployed to avoid hidden node problem an optional RTS and CTS is added in scheme to prevent from collision if no ACK is returned.

In CSMA/CD where medium is occupied for transmitting data packet if collision occurs in between by other wireless STAs. In fig 2.8 RTS and CTS is included where wireless STA send RTS to reserve the medium before data packet transmission and destination replies with CTS if STA is ready to receive where medium is occupied for data packet transmission. When sender sends the CTS then it starts its data packet transmission and medium is reserved for the packet transmission. All other wireless STA in network update their Network Allocation Vector NAV when each wireless STA hear CTS and RTS or data packet both CTS and CTS can be disable by an attribute define in Management Information Base MIB called dot11threshold value [34] which define length of data frame that has to transmitted.

Fig 2.8 shows NAV is updated when it hear RTS from sender and CTS from receiver “Time axis”. The CA part of CSMA/CA consist of avoiding data packet transmission right after the medium is sensed idle for DIFS time to prevent it from collision with other waiting data packet.

### 2.7 QoS Requirements for WLAN

#### 2.7.1 QoS Parameters

While maintaining high QoS for end to end for real time applications the network element performances are defined within the scope of QoS that include bandwidth, delay, latency, jitter and packet loss. These parameters are considered for time sensitive application because they require constant bit rate of delivery.

The application i-e file manager, web access, email and remote login require high reliability that means there should be no bits lost they all should be transmitted correctly. Some applications have low QoS requirements this mean that they can achieve QoS with low bandwidth but on the other hand the real time application have high demand for bandwidth and applications are delay sensitive.
2.7.1.1 Bandwidth
Bandwidth is the data rate support by the network this is measured as bit/sec the network resources or bandwidth is one of the most important factor that needs to be managed properly among different applications ruining over the network [8]. Different applications have different requirements for bandwidth like real time traffic requires more bandwidth as compares to other applications like FTP, email and web browsing.

2.7.1.2 Delay
This is the time that a packet takes to reach the destination or the total time from source to destination this is also referred to end to end delay, there are two main categories for delay fix and variable. [8]

2.7.1.3 Packet Loss
Packet [8, 7] loss also known as Error Rate in data transmission normally measured in bps. Generally packet loss is measurement of packets that are transmitted to receiver where some packets are lost during data transmission that can affect the quality of application and sometime disrupts the service. This problem can be caused at the network level due to congestion created at router or gateway, and bit errors due to noisy channel environment.

2.7.1.4 Jitter
Jitter can be defined as variation in delay or as displacement in certain aspects of high frequency. Digital signals displacement can be in amplitude, phase, timing and width of signal. When we talk about real time traffic it refers to the time variation according to which the packets arrived [8]. This variation can be due to congestion or route change as real time application are sensitive and cannot tolerate much jitter.

2.7.2 Real Time Applications
Voice over IP VoIP and Video on Demand VoD are the most used real time applications, now the VoIP is taking over the traditional phones because VoIP provides certain features that are very attractive like low cost. VoD is also being deployed because it will make the office work easier but at the same time these applications have very strict requirement for QoS. In the following section we will investigate the VoIP and VoD, how can they be used along with the protocols and codec’s that support them.

2.7.2.1 VoIP
VoIP is typically an extension of the technology in which the voice was transmitted through the IP systems and the analog and digital voice communication. There are certain benefits that it provides according to a research carried out by Forrester more than, 40 percent of North America and 30 percent of Europe enterprises have developed VoIP or they are in the process of doing
that. One of the most important benefit of VoIP is that it provides mobility as this is the one the aspects that is on the rise in the business world because as the employees enjoy the era of technology by having the WLAN that they can access the internet and transfer files as they are moving.[14]

2.7.2.2 VoD
For the last five years the wireless network and the applications that access them have made the user more flexible and demanding, so this had imposed new challenges for the developers so to make wireless network as reliable as wired ones.
VoD has higher requirements so that the user has a satisfactory experience, each application running on wireless has their particular QoS requirements as voice needs sufficient bandwidth, but it can withstand some delay. On the other hand if we talking about video it require high bandwidth, low rate of jitter, reduced latency and extended coverage if these things are kept in mind only then the reliable output can be delivered to the end user. [10, 11]

2.7.3 Real Time Protocols
As we have discussed previously that VoIP means to transmit voice as packets over the IP network and mainly IP was designed to transport data so there is a need for some kind of protocol that can manage both voice and video over the IP in other words that protocol that can handle real time traffic over an IP.

2.7.3.1 Real Time Transport Protocol
Real Time Transport Protocol RTP is a protocol that is suited for applications transmitting real time data over the medium, one important feature of RTP is that it does not support address reservation. RTP itself does not provide any QoS but it relies on the lower layers services to provide that. RTP has basically two major parts one that of real time protocol so that to carry data that has real time properties and the second is RTCP so that to monitor QoS and also to exchange information about the ongoing session. [14]

2.7.3.2 Real Time Control Transport Protocol
Real Time Control Transport Protocol RTCP is the sister protocol of RTP its basic functionality is the same as defined in RTP one of the advantage of RTCP is that it provides out of band statistics and the control information for RTP flow. Its primary functionality is to provide QoS in media distribution by periodically sending statistics information to all the users involved in multimedia session. [15]

2.7.3.3 Session Initiation Protocol
Session Initiation Protocol SIP the foremost requirement for VoIP is session control protocol to locate the user, its presence along with that to setup, modify and terminate the session for that we have SIP defined by the Internet Engineering Task Force under the RFC-3261.
SIP was specifically designed for IP telephony and other internet services, SIP session may involve more than one parties and may use unicast or multicast communication. Another feature of SIP is that it is a text based protocol which uses UTF 8 encoding and it is highly extensible. [19]

2.7.4 Codec’s
There are two type of codec’s for voice and video which are used by real time applications that are used to encode and decode the signal at the sending and receiving end. Audio Codec encodes the audio signal so that it can be sent and is decoded at the receiving end back into the audio signal. There are several codec available like G.711 it was released in 1998 by the ITU it encodes the telephone audio on a 64kbps channel, the compression used in G.711. It compresses each data into 8 bit word which gives a bit rate of 64kbps it has been recommended to use this standard in VoIP [12]. Same functionality performed by the video codec which encodes and decodes the image at the sender and receiver end. Mostly video codec’s available in market are H.261 and H.263 [13].

2.7.5 QoS Limitation in DCF
Some of the following limitations in conventional DCF are as follows. [36]
- DCF relies on CSMA/CA procedure which allows single STA at a time to share medium on network.
- DCF does not grantee QoS because there is no concept to prioritize traffic (real time traffic). Due to single queue same priority is provided to STAs in DCF while utilizing the medium.
- DCF does not grantee any differentiation mechanism for bandwidth, packet delay and jitter for higher priority station with real time traffic.
- Lack of throughput when some heavy load of traffic is on network.
- The factor of contention window CWmin is double to CWmax when some collision is interrupted during transmission by STA hence new BO interval is selected.

2.8 Features of 802.11e Standard
A lot work has being done to meet the QoS requirements of 802.11 networks. Both legacy DCF and PCF does not differentiates between traffic types or sources. IEEE proposed a new version 802.11e known as HCF that support two channel access mechanism as shown in fig 2.9 to make enhancements in conventional 802.11 MAC to facilitate QoS that could improve performance of real time application in WLAN [31]. As with original 802.11 MAC the 802.11e amendments are designed to work with all physical layers (802.11a, 802.11b and 802.11g).

The IEEE 802.11e draft defines set of technologies for prioritizing traffic and preventing packets from collisions and delays which could improve experiences of users accessing real time application. In this standard [33] four different Access Categories (AC) (Voice, Video, Background and Best Effort) are mapped with eight priority levels (from 0-7) which presents the type of data on transmission wireless medium.
Characteristics of 802.11e
Following are the characteristic of 802.11e [34] are explained in following sections below.
- Prioritized Traffic differentiation
- Parameterized service
- Arbitration Inter-Frame Space
- Concept of Transmission Opportunity
- Traffic specification

2.8.1 Hybrid Coordination Function
Hybrid Coordination Function HCF protocol works in two periods for its channel access methods and functionality supported by HCF channels are CP and CFP is illustrated in fig 2.10. HCF contention free channel access HCCA supports CPF for contention free data transfer and used for Integrated Services and HCF contention based channel access EDCA for contention data transfer and used for the Differential Services requirements.

2.8.1.1 QoS levels supported by HCF
The devices working in 802.11e implement QoS levels of 1,2 and 3 where level 1 and 2 implement 8 priorities which is 3 bit filed define in MAC service AP and operates in CP. Level 3 allows 8 priorities per connection with parameterized QoS and operates in CFP as illustrated in table 2.1 further details below sections.
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<table>
<thead>
<tr>
<th>QoS levels</th>
<th>Channels Access mechanism</th>
<th>Scheduling policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>HCF(EDCA and HCCA)</td>
<td>Parameterized</td>
</tr>
<tr>
<td>2</td>
<td>HCF(EDCA and HCCA)</td>
<td>Prioritized</td>
</tr>
<tr>
<td>1</td>
<td>HCF(EDCA only)</td>
<td>Prioritized</td>
</tr>
<tr>
<td>0</td>
<td>DCF,PCF(Conventional)</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 2.1 QoS levels supported by HCF protocol.

2.8.1.2 Components of HCF

Consequently in 802.11 both legacy DCF and PCF protocols where components does not support QoS features in all STA. Legacy STAs with DCF and optional PCF are called non supporting QoS STA where there is only single queue based on First In First Out FIFO implemented at MAC layer and all applications has same priority to transmit data over network. The 802.11e HCF applications like voice, video and data have independent transmission Queues which allows the traffic to be prioritized according to the user requirements under the network conditions. The table 2.2 shows the components difference between the 802.11 and 802.11e.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>QoS station (QSTA)</td>
<td>Wireless STA with QoS support for 802.11e standard</td>
</tr>
<tr>
<td>QoS Access Point (QAP)</td>
<td>Wireless AP with QoS facility for 802.11e standard</td>
</tr>
<tr>
<td>Hybrid Coordinator (HC)</td>
<td>Located in AP and performs PC for HCF</td>
</tr>
<tr>
<td>QoS Basic Service Set (QBSS)</td>
<td>A BSS that support QoS facility for 802.11e standard</td>
</tr>
<tr>
<td>QoS Independent Basic Service Set (QIBSS)</td>
<td>An IBSS that support QoS facility for one or more STAs for 802.11e standard</td>
</tr>
</tbody>
</table>

Table 2.2 The components of IEEE 802.11e.

Fig 2.11 shows the differences between the components and the channel access function of 802.11 and 802.11e for Ad Hoc network.

![Fig 2.11: Components differences between the legacy 802.11 and enhanced 802.11e protocols. [37]](image-url)
2.8.2 Mac Frame Format of 802.11e

Along with other fields in MAC header IEEE added a new subtype field called QoS Control for classification of QoS data frames and QoS control illustrated in fig 2.12. The frame control filed inside the MAC header defines the type of data and type of QoS control to support the control messages. [34]

**Fig 2.12:** IEEE 802.11e MAC frame with QoS control field. [40]

Each QoS data mapped by MAC Service Data Unit MSDU is classified by another field inside QoS Control called Traffic Identifier TID which deals with single type of traffic at a time of transmission. TID consist of 3 bits on which two different types of traffic are mapped further TID subtype is extended to range of 15 bits.

<table>
<thead>
<tr>
<th>Bits 0-3</th>
<th>Usage</th>
<th>Access Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-7</td>
<td>User priority for prioritize traffic</td>
<td>EDCA</td>
</tr>
<tr>
<td>8-15</td>
<td>TSPEC ID for Parameterized service</td>
<td>HCCA</td>
</tr>
</tbody>
</table>

**Table 2.3:** TID specification

There are two types TID specification in MAC header.

1. Prioritized Traffic differentiation
2. Parameterized service

### 2.8.2.1 Prioritized Traffic Differentiation

Priority to support QoS EDCA based on eight Queues which overcome this problem to provide the faster access to the medium and supporting QoS by defining different traffic priorities from user and prioritizing between them by using queue called as ACs.
The table 2.4 shows that voice is given higher priority over video rather than data whereas these priorities are directly mapped from upper layers [33]. The priorities in medium access can be defined by parameter set of EDCA by setting IFS, maximum and minimum value of CW and other parameters per ACs.

<table>
<thead>
<tr>
<th>Priority</th>
<th>User priority in 802.11e</th>
<th>Access Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>1</td>
<td>AC[0]</td>
<td>BK, Background</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>AC[0]</td>
<td>BK, Background</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>AC[1]</td>
<td>BE, BestEffort</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>AC[1]</td>
<td>VI, Video</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>AC[2]</td>
<td>VI, Video</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>AC[2]</td>
<td>VI, Video</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>AC[3]</td>
<td>VO, Voice</td>
</tr>
<tr>
<td>Highest</td>
<td>7</td>
<td>AC[3]</td>
<td>VO, Voice</td>
</tr>
</tbody>
</table>

Table 2.4: Classification of user priorities and Access Categories [33]

2.8.2.2 Parameterized Service
The 802.11e provides another scheduling concept which support by HCF protocol and provides the highest QoS level. In Parameterized QoS model traffic over network based on set of QoS parameters (bandwidth, delay, delay jitter and packet loss etc). To support Parameterized QoS [32] in 802.11e QAP and QSTA a setup is created along with traffic characteristics and QoS requirements for particular link which allows QAP to generated Transmission Opportunity TXOP to the corresponding QSTAs.

Due to variation in channel capacity and network topology it is difficult to provide Parameterized QoS in legacy WLAN and Ad-Hoc networks which face difficulties due to mobility of wireless STA. There is possibility to provide Parameterized QoS in infrastructure wireless network due to its connectivity to stable backbone.

End to End Parameterized QoS
To support End to End Parameterized QoS provisioning in wireless network where QSTA send message request to QAP through HCF contention based channel access EDCA which defines the traffic specification TSPEC and traffic type.

QAP decides whether to support the traffic flow if it decides then it send to another QAP along with traffic flow and its destination whereas admission control checks whether it satisfies the QoS requirements [32]. Therefore to reduce the admission control process the highest EDCA priority is assigned to signaling message.

2.8.3 Transmission Opportunity
The concept of TXOP is one of distinctive feature of 802.11e MAC protocol which defines the starting time and maximum duration of a particular QSTA which has initiated the transmission [35]. TXOP allows multiple data frames exchanges of a QSTA which can be separated by SIFS time period. So this feature improves the QoS of network when there is possibility when QSTA
wanted to send all possible data frames but there is possibility that desired QSTA faces delay due to another QSTA transmission. There are two types TXOPs [34].

1. EDCA TXOP: This type performs its functionality in EDCA and is explained under heading EDCA and section 2.9.5.
2. Polled TXOP: This type performs its functionality in HCCA [34].

2.9 Enhanced Distributed Coordination Channel

EDCA is not a separate function coordination function it is part of a HCF coordination function of 802.11e MAC. The legacy 802.11 DCF does not differentiate between frame transmissions all has same priority. DCF provides distributed services were all STA in DCF mode contending for channel access with equal probability. Therefore the emerging EDCA provides distributed and differentiated access over the network for QSTAs which implements AC mechanism according to the priorities defines by QSTA.

An 802.11e QSTAs implements four ACs which is enhance variant of DCF as shown in fig 2.13 where users priorities are mapped (from 0 to 7) as shown in table 2.4, which shows that voice has higher priority than video, besteffort and background.

EDCA [38] control available bandwidth for particular AC by using admission control mechanism which is important to fulfill the QoS of the network under congested traffic that discard a particular AC.

EDCA mechanism can minimize the problem of delay and guarantees bandwidth but does not guarantees jitter and variation in bandwidth utilization. EDCA also remove the per frame ACK scheme of conventional DCF and combine ACK frame in a multiple frame to indicate the recipient status. It also supports direct communication between devices either sending data frames to QAP this feature increase the bandwidth of the medium.

![Fig 2.13: Four Enhanced Distributed Channel Access Function (EDCAF) for EDCA. [38]](image)

Every MAC data frame arrives at MAC from upper OSI layer which contains specific priority value where QoS field in MAC header contains the user’s priority value mapped onto AC as shown in table 2.4. So every QSTA have access over the medium according to corresponding AC that mapped onto the QoS data frame. [38]
2.9.1 EDCA Parameters
Basically channel access function EDCA uses AFIS[AC], CWmin[AC] and CWmax[AC] are called EDCA parameter set instead of DCF legacy parameters DIFS, CWmin and CWmax. Contention based channel uses these parameters to transmit packet according to the respective AC. [38]

2.9.2 Arbitration Inter-Frame Space
Arbitration Inter-Frame Space AIFS is shorter than DIFS where DCF uses fix BO value but in case of AIFS the BO values are variable depending on type of AC (AIFS[AC]). AIFS provides the minimum time period for medium when it sensed to be idle before QSTA starts its transmission. AFIS[AC] is derived from the following equation.

\[ AIFS[AC] = aSIFSTime + AIFSN[AC] * SlotTime \] [38]

Where a SlotTime is a slot time, aSIFSTime is SIFS time and Arbitration Inter Frame Space Number AIFSN is used to determine the length of AIFS. So the value of AIFSN[AC] is an integer value, for QAPs the value must be greater than 0 and for legacy APs the value must be greater than 1[38]. The EDCA parameters are announced by the wireless QSTA or by APs via beacon frames where both dynamically perform changes in EDCA parameter set, for a desired AC according to network conditions are illustrated in table 2.5.

<table>
<thead>
<tr>
<th>Access category(AC)</th>
<th>CWmin</th>
<th>CWmax</th>
<th>AIFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC[0]</td>
<td>aCWmin</td>
<td>aCWmax</td>
<td>7</td>
</tr>
<tr>
<td>AC[1]</td>
<td>aCWmin</td>
<td>aCWmax</td>
<td>3</td>
</tr>
<tr>
<td>AC[2]</td>
<td>(aCWmin + 1) / 2-1</td>
<td>aCWmax</td>
<td>2</td>
</tr>
<tr>
<td>AC[3]</td>
<td>(aCWmin + 1) / 4-1</td>
<td>(aCWmax + 1) / 2-1</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2.5: EDCA Parameter set announced by QAP or wireless QSTA in beacon frame. [38]

802.11e QSTAs implements four transmission Queues or four Independent Enhanced Distributed Channel Access Functions EDCAFs which are used to mapped four ACs separately as shown in fig 2.13. So each AC behave like enhance DCF and adopt AIFS[AC] and maintains its own BC. According to the network conditions if values of both AIFSN[AC] and CWmin[AC] are smaller corresponding priority mapped onto AC which causes smaller delay and provide more capacity over the wireless link.

2.9.3 EDCA Channel Access
If the channels is busy and QSTA wants to transmit a frame either becomes busy before AIFS[AC] expires so the BO procedure is invoked that is different from legacy DCF. Therefore first BO occur at the end of AIFS[AC] interval, either BO countdown or frame transmission occurs at the end of each idle slot. In legacy DCF after DIFS interval first countdown occur at the end of first slot so the frame is transmitted when BC reaches 0 [38]. Fig 2.14 shows timing interval of EDCA channel access.
2.9.3.1 Backoff Procedure in EDCA
In EDCA mechanism the BO procedure is selected as Backoff Time = Random() * SlotTime, where the Random() is random number drawn from uniform distribution function over the interval (0,CW[AC]) and CWmin[AC] ≤ CW ≤ CWmax[AC]. During data Transmission if size of CW increase by (((oldCW[AC] + 1 * PF) – 1)), where PF value is default and set to 2. The value of BC decreases when medium is deducted idle for AIFS[AC]. When the BC of more than two access functions ends at the same time, the highest priority [39] frame is selected to be transmitted among the colliding frames while remaining access functions perform BO procedure with increased CW values.

2.9.4 Collisions in EDCA

2.9.4.1 Internal Collision
There is possibility of internal collision among the four EDCAF's of one QSTA because each AC has its own CW and its BO value for its EDCAF [39]. There is a probability when BC of two ACs mapped with highest priority within a STA reaches zero at the same time cause collision within a STA known as Internal Collision. Sometimes collision occurs when two ACs assigned to STA are mapped with AC_VO (highest priority) and second with AC_BE (lowest priority) therefore size of CW with low priority AC is doubled and new BO value is selected whereas high priority AC continues with same CW along with its BO value.

2.9.4.2 External Collision
There is possibility of External Collision when BC of two ACs assigned with highest priority for particular STA within network reaches zero at the same time which make both ACs to increase their CWs size and selects a new BO value [39].

2.9.5 EDCA-TXOP
The concept of EDCA-TXOP is initiated when channel access function EDCA determine the frame exchange sequences of STA (or by EDCAF of a QSTA) in a network. TXOP provides a time limit for AC of a QSTA to transmit its frames which enhance the communication efficiency. Along with EDCA parameter set the limit of TXOP length under contention based channel access is generated by QAP for corresponding STA via beacons.
The value of TXOPlimit for particular AC represented as TXOPlimit[AC] that allows QSTA to send multiple frames for a particular AC under desired time period. The default values of TXOPlimit[AC] of four ACs shown in table 2.6 with SIFS time gap between ACK and subsequent frame transmission fig 2.15 shows transmission of two QSTAs.

<table>
<thead>
<tr>
<th>Access categories AC</th>
<th>TXOPlimit 802.11b</th>
<th>TXOPlimit 802.11a/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC_VO</td>
<td>3.264ms</td>
<td>1.504ms</td>
</tr>
<tr>
<td>AC_VI</td>
<td>6.016ms</td>
<td>3.008ms</td>
</tr>
<tr>
<td>AC_BE</td>
<td>0ms</td>
<td>0ms</td>
</tr>
<tr>
<td>AC_BK</td>
<td>0ms</td>
<td>0ms</td>
</tr>
</tbody>
</table>

Table 2.6: TXOPlimits in EDCA Parameter set announced by AP and wireless stations in beacon frame. [39]

Data frames assigned with users priority during an EDCA-TXOP where entire transmission time of ACK and two frames is less than EDCA TXOPlimit. So the problem of BO time of particular AC is slightly reduced and multiple frames can be transmitted by source STA by fragmenting the frame under TXOPlimit. [39]

![Timing structure of EDCATXOP.](image)
3 QoS Analysis for 802.11 MAC

In this chapter we will be going to analyze the integrating issues of real time traffic over WLAN. Our main focus will be on DCF where we will study its performance in different scenarios and also analyze that how the QoS parameters are affected. The technologies that are in our scope are the real-time applications like Video and Voice, we have discussed both of these technologies separately and we will put light on the integration issues evolved when these technologies are forced to work together. In this chapter we will try to analyze the integration issues, this will be the first part of the analysis then we will show by the graphical representations to what value or extant the work has been done related to these issues and to what extent these issues are eliminated. Basic focus is on the QoS when the technologies are integrated and the primary focus is on QoS parameters such as delay, packet loss and throughput.

3.1 Integrating Issues of Real Time Traffic

In this section we will show which of the issues directly affects the integration of voice and video over WLAN. The section is divided into three sub sections that are Voice, Video and Voice plus Video. There are some problems with wireless environment like it can be shared by the devices like Bluetooth or other 802.11 devices so it is bottlenecked [20]. Two most important issues of real time applications regarding QoS which is affected due to failure of Congestion and Priority management in network. Congestion management in a network is directly proportional to the available bandwidth and queuing mechanism as real time application acquires more bandwidth as compared to data traffic. Congestion can occur at source end or the destination end because at source end when number of user enters in a network increasing the total capacity causes collapse in network. Where delay and packet loss are generated, mostly packet loss is due to limited queue length if more packets are transmitted by STA and pervious are still in the bucket causes the bucket overflow and packet latency will be increased which affect the QoS of delay sensitive applications. Subsequently at destination end when there are more than one APs come into range of source, causes handovers between APs causes the congestion in network if all resource of AP are utilized and there is no further connectivity of source if new source come into range of AP causes congestion for all connected nodes in network.

Furthermore, all real time application works on the priority basis and the thing that matters here is the high priority not the data rates. So the domain of real time application working in wireless environment is queuing mechanism. Extra concepts that will be discussed here will be the delay and packet loss in codec’s selection in different environment.
In the following table, the QoS recommendations have been summarized for real time application by (ITU -2001), which can be experienced by the common end-user of a network. [30]

<table>
<thead>
<tr>
<th>Medium</th>
<th>Application</th>
<th>Type of communication</th>
<th>Data rates</th>
<th>One way delay</th>
<th>Delay variation</th>
<th>Packet loss</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Voice</td>
<td>Full Duplex</td>
<td>4-64 kbit/s</td>
<td>&lt; 150 ms</td>
<td>&lt; 1 ms</td>
<td>&lt; 3 %</td>
<td>Low</td>
</tr>
<tr>
<td>Audio</td>
<td>Voice messaging</td>
<td>Half Duplex</td>
<td>4-32 kbit/s</td>
<td>&lt; 1 s for Playback and &lt; 2 s for record</td>
<td>&lt; 1 ms</td>
<td>&lt; 3 %</td>
<td>low</td>
</tr>
<tr>
<td>Audio</td>
<td>High Quality</td>
<td>Primarily Half Duplex</td>
<td>16-128 kbit/s</td>
<td>&lt; 10</td>
<td>&lt; &lt; 1 ms</td>
<td>&lt; 1 %</td>
<td>low</td>
</tr>
<tr>
<td>Video</td>
<td>Videophone</td>
<td>Full Duplex</td>
<td>16-338 kbit/s</td>
<td>&lt; 150 ms</td>
<td>&lt; 1 %</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Video</td>
<td>One-way</td>
<td>Half Duplex</td>
<td>16-384 kbit/s</td>
<td>&lt; 10 s</td>
<td>&lt; 1 %</td>
<td>high</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.1: Table of QoS recommendation for Real Time Application [30]**

From the above QoS recommendations to improve the QoS for real time application, one way delay for voice and video depends upon the echo control. This depends upon long-term target values which may not be met by current technology. Typical data rate is totally dependent on the codec selection and data rate to reduce the packet loss where best algorithm must be selected to improve QoS.

**3.1.1 Voice over WLAN**

Some of the issues still prevail when voice is running over wireless networks. When implemented, perceived quality worsens and it worsens so much that it is not acceptable to the listener when number of call increase. As in the case of many APs involved in a call, here call has to migrate from one AP to another and it is obvious that this migration will also consume some time that in some cases is 70ms and this delay is well noticed by human ears. These APs also effects good delivery of voice as they possess limited functionality.

Background traffic also irritates the listener because of the noise created by this [21]. In many cases it has been witnessed that radio channels are overwhelmed and the communicating parties are not able to listen.

In VoIP call there should always be a good power supply. In case of mobiles they have their own battery that is not a good source to rely upon and on the other hand in wired networks they have good supply of power for all the time. Bandwidth allocation is also a problem as sometimes the
demand of bandwidth increases then the available bandwidth, which in turn cause delay and jitter.

3.1.2 Video over WLAN
There have been a lot of efforts to satisfy QoS of video over wireless medium as there are schemes present to satisfy them like DCF but lesser effort are put into addressing issues in multimedia traffic. Most important concept here is the efficient allocation of bandwidth as there is a heterogeneous traffic mixed in a mobile network. Network topology plays an important role in wireless networks for videos to be streamed, as in the case of mesh network where all nodes act like a router so there can be multiple paths and the packets can be strayed out. [22]
Service time is directly proportional to the packet size and it is known that multimedia traffic has a larger size so that it can have more delays than that of voice. Difference in APs from different vendor is evident as Cisco has worked more on providing good bandwidth [21]. If one knows the characteristic of AP then the service time can also be known before handshake and Video communication witness more delay, jitter and packet loss as traversing through the routers or any other equipment part of the environment [23]. Low latency videos are always difficult to handle as they have a variable nature in wireless environment. [20]

![Fig 3.1: Video streaming and components of delay [21]](image)

This diagram [21], shows packet transmissions in video calls and here each of the component contribute in delay and all of the components must be intact to keep the stream running.

3.1.3 Voice plus Video over WLAN
Here we are talking of the mobile phones on which call and the video is running simultaneously, example of this type is video conferencing. This is the combination of the previous two so it will include all of the integrating issues of voice and video. When the real time applications are integrated with WLANs then they have to suffer like, if both are running simultaneously some of the calls may drop or there is some breakage of the video pixels. So this can be assumed that QoS parameters must apply on multimedia traffic to make it more reliable.

3.2 QoS Parameters Evaluation for Real-Time Applications
As discussed in the above section there has been some deficits in real-time applications when running over the wireless network, there has been some negligence in providing QoS. In this section we will try to show these deficits especially regarding QoS that still prevail. This is the basic part of our analysis and by the help of graphical representations we will be more specific
and try to evaluate which scheme will be the best to serve the purpose. Real time applications are divided in three categories that are Voice, Video and Voice plus Video over WLAN. In following scenarios we will be analyzing Load and Codec selection.

3.2.1 Voice
In this section we will try to analyze the issues related to QoS and how is this compromised through graphical representation. The scenarios will be explained how delay, jitter, through put and packet loss prevail in contemporary systems.

3.2.1.1 Scenario 1 Load
In this test environment Optimized Evaluation Network Engineering Tool OPNET has been used as a tool to analyze the performance of DCF. In this paper [24] Modified DCF is used but in our analysis we will only focus on DCF traffic. Three categories of traffic load are defined but here we will only take higher traffic such that over 11Mbps load as performance is evaluated only how system performs in tough environments.

In this scenario voice traffic has the higher priority than other traffics. QoS of service parameters to be represented here is delay, through put and packet loss. All of these graphs are plotted against time taken in seconds.

**Fig 3.2:** Through put of voice in High Load. [24]

The above fig 3.2 shows throughput in high traffic load. The blue line shows DCF traffic delay, dotted is the Modified DCF overlapping window and yellow line shows the Modified DCF non-overlapping window. As we are focusing on DCF so we will only consider the blue line. [24]

This shows that throughput increases when the conversation is initiated and with the passage of time and when time reaches 30s and afterwards the line maintains its course. So this graph also shows that time in high traffic also influences the traffic throughput.
In fig 3.3, delay in high load possesses the same characteristic as that of throughput which is as the time increases delay also increases. Therefore we can say that time is directly proportional to delay. For instance, we have noticed that initially delay was at its minimal level that is around 0.5s and 1s but reaches to 1.5s and above as the conversation time increases.

Blue line in fig 3.4 donates DCF traffic delay, the dotted line is the Modified DCF overlapping window, Modified DCF non-overlapping window. It is observed that DCF is functioning well from other two methods introduced. So it can be assumed that traffic is less delayed, there is lesser packet loss and the traffic availability with the passage of time gets better to lesser packet loss and delay. So the devised ways are not effective than that of the normal DCF.

3.2.1.2 Scenario 2 Codec’s Selection
As we are evaluating legacy IEEE 802.11 we would here be talking of the 802.11a and 802.11b. The codec selection is also an important aspect one should use the best codec depending upon the scenario. Here we will evaluate three codec’s G.729, G.711 and G.723.1. The explanation for packet interval is given in [25].
Fig 3.5: Codec’s functioning in 802.11 b. [25]

Fig 3.5 and fig 3.6 shows that when all of the Codec’s are compared in a given environment it was clear that G.729 served the purpose well as the communication was good. Mean Opinion Scores MOS states that G.729 is the best codec for voice transmission than that of its competitors. Number of call that is handled here by G.729 in both 802.11a and 802.11b shows its significance.

Fig 3.6: Codec’s functioning in 802.11 a. [25]

3.2.2 Video

In this section we will try to analyze the issues related to video and how QoS parameters are affected in the scenario through graphical representation.

3.2.2.1 Scenario 1 Load

The scenario is taken from [24], traffic load is divided in three categories but here we will only take high traffic that is over 11Mbps load as performance of the system is evaluated. In this scenario video traffic is evaluated and QoS parameters to be represented here is delay and throughput. Packet loss will always be there but we cannot eliminate the whole effect of it.
3.2.2.2 Scenario 2 Codec’s

H.264 is the emerging codec for video transmission. Hence, in this test environment we will try to evaluate H.264 with different codec’s available nowadays that are MPEG-2 and H.263. MPEG-2 and H.263 were developed by University of California at Berkeley and University of British Colombia [27] [28]. These parameters are taken form [29].
Fig 3.9 and 3.10: Comparison between H.264 and MPEG-2 Rate-PSNR for CAROUSEL and CIF Paris sequence Encode respectively. [29]

In the fig 3.9 and fig 3.10 red lines denotes H.264 and the blue lines denotes the MPEG-2 from these figures it can be derived that H.264 has a gain in coding of approximately 50% over MPEG-2. Paper [29] shows some of the tables depicting the coding gains. This means that H.264 has a greater functionality than that of MPEG-2.

Fig 3.11 and 3.12: Comparison between H.264 and H.263 Base Line and CHS encoders. Rate-PSNR for CIF Paris and QCIFS FOREMAN sequence Encode respectively. [29]

In the fig 3.9 and fig 3.10 red lines denotes H.264 and the blue lines denotes the MPEG-2 from these figures it can be derived that H.264 has a gain in coding of approximately 50% over MPEG-2. Paper [29] shows some of the tables depicting the coding gains. This means that H.264 has a greater functionality than that of MPEG-2.

Fig 3.11 and fig 3.12 shows the comparison between H.264 and H.263. In this the gain in coding is also prominent by H.264 which is also around 50%. Hence it can be derived that H.264 is far more enhanced than its competitors.
3.2.3 Voice plus Video
In this we will try to evaluate how the combination of both real-time applications operates and to what extent QoS is compromised. Taking three scenarios as described above that are load, and the codec’s. QoS specified are delay, packet loss and throughput and discuss the affects when running simultaneously.

3.2.3.1 Scenario 1 Load
In this scenario load is increased after each instance and evaluating what is the effect on throughput, delay and packet loss. The parameters are taken from [26] which derive these figures shown below.

Form fig 3.13 it can be derived that as the load increases there is a change in throughput but it increases gradually. But due to the higher priority, voice and video move on the same track and the throughput is maintained. While on the other hand it is observed that throughput declined due to lack of priority management.
Fig 3.14 shows the delay in the frames being received as there is variation in Load. As seen by the figures real time application has the minimum delay and work well in any condition such that load but there is a little drift witnessed at maximum load. It is quite clear from fig 3.15 that there is less packet or frame loss of video other than the other traffic as priority of video is high.

**Summary**

As we see that wireless network is widely deployed and with the passage of time when more research is gathered to know as to what extent the wireless networks can be relied upon. This has opened a new horizon for real time traffic over wireless medium now we widely see the use of VoIP and video conferencing.

Whenever we are talking about real time traffic the first thing that is of immense importance is that how the QoS parameters are dealt with. Our main concern is how to prioritize this whole traffic in such a way that the traffic which is more sensitive regarding QoS parameters is served first and on the other hand the remaining traffic does not starve for bandwidth.

In this chapter we have analyzed the main categories of traffic namely voice, video and voice plus video. First we have analyzed that how the QoS parameters behave in high load so that the performance of contention based on DCF can be understood. We have seen that under high load the throughput of the network is influenced by time factor. This is also the same for the voice and video and for voice plus video where the throughput experiences a change when load is increased. The delay is same as throughput for voice.

We have also studied that it is of much importance when selecting Codec’s by user they are able to select the best codec using MOS that is a rating scheme.

We have also analyzed that G.729 severs the best for voice and H.264 for video, as have different scenarios so to compare their functionality.
Performance and Evaluation

This chapter will describe the simulations made between the two IEEE 802.11 MAC, contention based protocols namely DCF and EDCA by using OPNET where we generate two types of traffic which is voice and video and our main focus is on QoS parameters.

4.1 Simulation Study

In the previous sections we have given the specifications of the protocols on which we are focused upon. This evaluation will be between contention based channels of Legacy IEEE 802.11 DCF and IEEE 802.11e HCF EDCA at MAC Layer.

In this chapter we will evaluate both of them by showing graphical representations of them. In our simulation study we will evaluate DCF and EDCA for real time traffic and we will show which is better among them.

We have accomplished simulations results in OPNET and focusing on QoS parameters like Throughput, Delay and Drop rate, these are the ones that deteriorate the whole system performance. The type of network environment used here is infrastructure with one BSS which consist of a fixed AP which is connected to Ethernet server of LAN and mobile STAs transmitting voice and video respectively under the limited radius for network coverage illustrated in fig 4.1.

We have used 802.11b Physical standard were all MAC parameters are dependent on physical layer [41]. Where all STAs can transmit data frames at rate of 11Mbps which is highest transmission rate of 802.11b under bandwidth capacity of 1000 KHz and frame size value depends on type of application. Here our main focus is on wireless network load, within one BSS, single AP and mobile STAs are wirelessly connected to AP. We will analyze the performance of both DCF and EDCA protocols by gathering results for QoS of network. We will also analyze the Congestion as we increase the number of mobile STAs in BSS and see how STAs would face collisions as load on network increases.

Firstly, we will explain DCF scenario for three and five STAs (without QoS support) with voice only and then with same number of STAs for video.

Secondly it will be the comparison between different numbers of STAs with same traffic running over wireless network then with the changed traffic.

Finally there will be the comparison between DCF and EDCA (with QoS support STAs) which shows which serves the purpose best, as under various traffic loads the priorities for voice and video applications are high and low respectively.
Performance and Evaluation

Fig 4.1: OPNET Network Model.

In our simulation the physical MAC parameters settings for 802.11b are used for DCF STAs, for 802.11e are used for EDCA STAs are illustrated in table 4.1 and 4.2 respectively.

<table>
<thead>
<tr>
<th>SIFS(usec)</th>
<th>DIFS(usec)</th>
<th>SlotTime(usec)</th>
<th>CW_{min}</th>
<th>CW_{max}</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>50</td>
<td>20</td>
<td>31</td>
<td>1023</td>
</tr>
</tbody>
</table>

Table 4.1: Physical MAC parameters for 802.11b [42]

In table 4.2 is completely different from the table 4.1 because 802.11e provides the priority and extra feature of TXOP, which define the time limit for frame to be segmented between paired STAs at a time.

<table>
<thead>
<tr>
<th>Station type</th>
<th>Priority</th>
<th>AIFSN[AC]</th>
<th>CW_{min}</th>
<th>CW_{max}</th>
<th>TXOPLimit(ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>7</td>
<td>3</td>
<td>7</td>
<td>15</td>
<td>3.264</td>
</tr>
<tr>
<td>Video</td>
<td>5</td>
<td>2</td>
<td>15</td>
<td>31</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 4.2: Physical MAC parameters for 802.11e [42]

In following scenarios all voice and video STAs are generating voice and video traffic with following parameter settings which we used in our simulations are illustrated in table 4.3.

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Frame Size (Bytes)</th>
<th>DataRate (Mbps)</th>
<th>StartTimeOffset (Avg. in s)</th>
<th>Modulation</th>
<th>Codec’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>97</td>
<td>1</td>
<td>Constant(5)</td>
<td>DSSS</td>
<td>GSM</td>
</tr>
<tr>
<td>Video</td>
<td>1503</td>
<td>5.5</td>
<td>Constant(10)</td>
<td>DSSS</td>
<td>H.323</td>
</tr>
</tbody>
</table>

Table 4.3: Traffic types and their characteristics
Here traffic is constantly distributed for voice and video depend upon type of load on network. As we know that both voice and video are delay sensitive applications can tolerate some frame loss but requires some error free transmission. To overcome some delay for such application we use buffer size of 25Kbits and 1.3Mbits for voice and video respectively.

4.2 Evaluation of DCF for Real Time Applications

4.2.1 Scenario 1: Low Load with Voice Stations
The scenario is for voice and number of STA is three focusing on delay, throughput, load and data dropped. This is for legacy DCF evaluating them by the variation in the number of STAs. Here every voice frame arrives at physical MAC after every 20ms at transmission queue whereas the voice frames are transmitted after contention and we run the simulation for 25min.

![Fig 4.2(A): DCF Delay with time (s)](image1)

![Fig 4.2(B): DCF Data Drop with (bps)](image2)

![Fig 4.2(C): DCF Load with time (s)](image3)

![Fig 4.2(D): DCF Throughput with (bps)](image4)
As seen in fig 4.2(A) it is seen that there is variation in delay initially is at low value but with the passage of time the value increases but does not exceed the 20ms which is highest value for DCF. The graph shows the nature of delay that has a lot of variation in it. Data drop in fig 4.2 (B) is at its lowest value that and it maintains its course. Fig 4.2(C) is the load, which shows the load on the network that ranges from 250,000 bits/s to 270,000 bits/s. Throughput in fig 4.2(D) shows that the load on network was less and there was no significant affect on the throughput of network initially, then after 3min it raises to 250,000bits/s which witness little bit change in it. This is obvious that throughput is directly related to the load of the network. In this scenario the load on network is idealistic where there is no chance of congestion, and transmission by STAs does not face any collisions.

### 4.2.2 Scenario 2: High Load with Voice Stations

The scenario is for voice and number of STA is five focusing on delay, throughput, load and data dropped. Here every voice frame arrives at physical MAC after every 20ms at transmission queue whereas the voice frames are transmitted after contention. Here the voice frames are uniformly distributed over time and we run the simulation for 15min.

![Fig 4.3(A): DCF Delay with time (s)](image1)

![Fig 4.3(B): DCF Data Drop with (bps)](image2)
Performance and Evaluation

4

This scenario is for five STAs, as seen in fig 4.3(A) it is seen that there is variation in delay starting from the lowest value but with the passage of time the value increases and exceeds to 26ms which causes some delay in voice quality but soon witnesses the drift in its course. The graph shows the nature of delay that has a lot of variation in it and hence number of STAs increase by two there is more delay.

Data drop in fig 4.3(B) shows that there is no data drop since time reaches 6min to 8min STAs witness huge data loss but after this patch it comes to normal. Fig 4.3(C) is the load, which shows the load on the network that ranges from 400,000bits/s to 450,000bits/s as more STAs are introduced to the network. So we can analyze as we put more load on network, there is significant difference between the throughput of network.

Throughput in fig 4.3(D) initially was less then after 2min it raises to 250,000bits/s and the maximum value attained here is 320,000bits/s but with a lot of variations in it, as the spiral move up and down often. In this scenario the load on network is not idealistic where there is chance of congestion, and transmission by STAs would face some collisions due lack of priority in legacy protocol.

4.2.3 Scenario 3: Low Load with Video Stations

The scenario is for video and numbers of STAs are three focusing on delay, throughput, load and data dropped. Here every video frame arrives at physical MAC after every 20ms at transmission queue here the video frames are uniformly distributed over time and higher data rate of 5.5Mbps are given to video frames as compare to voice frames, we run the simulation for 5min.
On the other hand when video traffic is considered there is a great shift in QoS parameters. All of four QoS parameters have an increase in them. As seen in fig 4.4(A) it is seen that there is variation in delay initially there is no delay but with the passage of time till time reaches 2min the value increases. The graph shows the nature of delay that has a lot of variation in it.

While running video application delay for somehow can be afforded by system but video application cannot afford the data drop in fig 4.4(B) shows that there is no data drop and it maintains its course till time reaches 2min there is sudden drift and the value of data dropped increases significantly.
Fig 4.4(C) is the load, when video conferencing is initiated there is lesser load on the system but as this progress and more system jump into it the load increases.
The throughput in fig 4.4(D) initially was less then after 2min it raises to 6,000,000bits/s which witness little bit change in it, this is obvious that throughput is directly related to the load of the network. It has a good throughput but the negative impact on the system is that load and data drop increases.
In this scenario the load on network is idealistic where there is some chance of congestion, and transmission by STAs does face some collisions when running heavy video application.

4.2.4 Scenario 4: High Load with Video Stations
The scenario is for video and number of STA is five, focusing on delay, throughput, load and data dropped. Here every video frame arrives at physical MAC after every 20ms at transmission queue. The video frames are uniformly distributed over time and higher data rate of 5.5Mbps are given to video frames as compare to voice frames, we run the simulation for 5min.

Fig 4.5(A): DCF Delay with time (s)  
Fig 4.5(B): DCF Data Drop with (bps)
When video traffic is considered for five STAs there QoS parameters delay, throughput, data drop and load witness a change. All of four QoS parameters have an increase in them when these are compared with video traffic for three STAs.

As seen in fig 4.5(A) show initially there is no delay but with the passage of time till time reaches 2min the value increases, a lot of variations is shown afterwards.

Fig 4.5(B), fig 4.5(C) and fig 4.5(D) shows data drop, load and delay respectively and all of them show the same nature that is not having any impact on them initially but with a passage of time all of them witness a rise and the value increases significantly. In this scenario the load on network is not idealistic where there is chance of congestion, and transmission by STAs does face some collisions when running heavy video application.

### 4.3 Performance Comparison between EDCA and DCF

In this section of the chapter we will analyze the performance of both contention based channels of 802.11 and 802.11e MAC respectively.

#### 4.3.1 Scenario 5: With Voice and Video Stations

Here we will evaluate DCF and EDCA while both of the real time applications are running on the wireless network simultaneously. Previously we have shown the evaluation of DCF with different number of STAs and how the QoS parameters were affected. They depicted a lot of variations as far as the QoS parameters that are throughput, delay and drop rate are concerned.

Every voice and video frame arrives at physical MAC after every 20ms at transmission queue as in DCF there is only one queue based on FIFO which means one kind of traffic from mobile STA at a time.
In EDCA there are independent transmission queues of each mobile STA for each AC but here we are focusing more on voice and video and its CW parameters for each AC are adjust as illustrated in table 4.2 and maintains its own BO counter, the value of AIFS we adjusted in this simulation are set according to traffic priority. For voice AC we set the smallest value as compared to video because the minimum value we adjust for AIFS, more we get improvements in throughput of system.

An extra concept we explain in above chapter is TXOP time limit for each application transmitting by mobile STA here we adjust the maximum time limit for video as compared to voice because size of video application is larger than of voice. So each video frame can be transmitted in 5ms to avoid some packet loss. Here for both DCF and EDCA the data rates and frame size for voice and video applications are same so to analyze which one is better to support QoS of the system, we run the simulation for 10min.

**Fig 4.6(A):** DCF Data Drop with (bps)

**Fig 4.6(B):** EDCA Data Drop with (bps)
Fig 4.6(C): DCF Delay with time (s)

Fig 4.6(D): EDCA Delay with time (s)

Fig 4.6(E): DCF Load with time (s)

Fig 4.6(F): EDCA Load with time (s)
Fig 4.6(C) and fig 4.6(D) shows the voice and video delay for both DCF and EDCA, from graph it is obvious that there is more delay in DCF as time increases to 2mins then EDCA for voice and video applications. The delay with DCF is not acceptable as compared to EDCA where the priorities are managed and the video delay is seen to have been decreased remarkably which is a good sign.

Delay and data drop as shown in fig 4.6(A) and fig 4.6(B) for voice it is seen that both DCF and EDCA witness the same drift when time reaches to 3mins this is because of the frame size as frame size of voice packets are smaller than that of videos. When it comes to video there is significant change and EDCA performs well having lesser delay and data drop.

Video works on the rate of 5.5Mbps, and it can well be seen that EDCA serves the purpose well than DCF as there are a lot of data or frame drop in it as shown in fig 4.6(A) that there is a great change when time increases. Data drop is often due to the buffer overflow so it is seen in case of voice there will be bit lesser data drop in EDCA than DCF, but in our case it has the same as the size of the buffer is infinite so there is no data drop.

When it comes to load as shown in fig 4.6(E) and fig 4.6(F) and it is seen that there is more of the system load in EDCA and on the other hand DCF has relatively lesser load on the system. Fig 4.6(E) shows that when time increases the course of video traffic faces more delay as compared to the video traffic in fig 4.6(F) where there is still variation in video traffic but this can be expectable at receiver end. Due to the external collision it is seen that the throughput of DCF is lesser than that of EDCA as shown in fig 4.6(G) and fig 4.6(H).

Fig 4.6(G) shows that when time reaches to 2mins the video traffic reaches to maximum value is 550,000bit/s which utilizes maximum throughput of network but in fig 4.6(H) shows the
variation in video spiral and the maximum value reaches to 550,000bits/s when time reaches to 10mins but it is not consistent and there is variation between 100,000bits/s to 50,000bits/s and shows that it utilizes less throughput under high load.

Another important aspect is that there is a lot of contention for the allocation of resources and due to no priority mechanism in DCF it witness lesser throughput in voice but in EDCA has good throughput as the priority of voice is high. There have been lesser frame losses of video in EDCA so the throughput increases significantly.

**Summary**

Main focus of the thesis was to explore the contemporary technologies in WLANs and how real time applications are favored by Wireless technologies. We have tried to gather all of the information related to this and then we have analyzed what are the prevailing issues that need to address.

In this thesis we have compared DCF with EDCA which is part of HCF and have derived that EDCA from functioning point of view by far is the best. We have tried to eliminate the Delay, data drop and increase the throughput of the system but it is known that the best system will have some data drop rate. EDCA is far more enhanced than DCF due to the introduction of priority mechanism in it as the traffic with no priority mechanism can be left behind and can starve for resource. We can configure it as we like just by adjusting the priority and by this throughput can be enhanced. It has also lessened the delay and data drop rate significant.
5 Conclusion

Wireless networks are being adopted widely because they have certain additional features like mobility, low cost and they require less maintenance. This thesis research mainly focuses on working of WLAN along with the QoS parameters and the integrating issues that arouse when real time traffic is generated with other background traffic.

The integration of real time traffic opened new horizons as the user requirements were increased there was a high demand for QoS so that the users can have a consistent service for real time traffic over wireless networks.

In this thesis research we have tried to understand this technology with special emphasis on QoS regarding real time traffic we started with 802.11 standard that had two different MAC schemes PCF and DCF. They were not that robust in handling real time traffic as DCF does not guarantees QoS because there is no concept to prioritize real time traffic due to single queue. In DCF same priority is provided to STAs while utilizing the medium so that was the basis for developing a new standard 802.11e.

The 802.11e standard had features to handle real time traffic, the simulation that we have performed is for a single BSS we have evaluated DCF and EDCA to check how the QoS parameters are effected for voice and video and according to our results gathered from the simulation and the theoretical study that we carried out we have drawn the conclusion that EDCA is far better than DCF.

EDCA has a priority mechanism that helps it to sustain in conditions of high load so that there is a non congested environment so to achieve the desired QoS. In DCF the contention window has static parameters which in certain scenarios have a negative effect on QoS especially in case of real time applications, but in EDCA the contention window is dynamic where we can adjust its Maximum and Minimum values so to achieve the desired output.

EDCA has a mechanism to prioritize the traffic in a way that voice and video gets the highest priority but EDCA does not provide 100% guarantee that there would an environment where there would be no packet loss. There is also an important aspect that has to be considered for real time applications that are the codec selection, there are many types of codec available in the market that can be used to modulate and demodulate the signals we have used GSM for voice and H.323 for video.

5.1 Future Work

Future work for this research that we have conducted can be on the EDCA mechanism enhancement in case of contention window adjustment and as we have also studied different MAC protocols like adaptive AEDCF, DFS, Black Burst and improved power saving MAC protocol which is an extra feature provided by 802.11e standard. So a lot of research should be carried out in order to make the wireless medium more reliable and robust especially for real time traffic.
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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Access Categories</td>
</tr>
<tr>
<td>ACK</td>
<td>Acknowledgement</td>
</tr>
<tr>
<td>AEDCF</td>
<td>Enhanced distribution Coordination Function</td>
</tr>
<tr>
<td>AIFS</td>
<td>Arbitration Inter-Frame Space</td>
</tr>
<tr>
<td>AIFSN</td>
<td>Arbitration Inter Frame Space Number</td>
</tr>
<tr>
<td>AP</td>
<td>Access point</td>
</tr>
<tr>
<td>BC</td>
<td>Backoff Counter</td>
</tr>
<tr>
<td>BO</td>
<td>Backoff</td>
</tr>
<tr>
<td>BSS</td>
<td>Basic Service Set</td>
</tr>
<tr>
<td>CAP</td>
<td>Controlled Channel Access Phase</td>
</tr>
<tr>
<td>CCC</td>
<td>Clear Channel Algorithm</td>
</tr>
<tr>
<td>CCA</td>
<td>Clear Channel Assessment</td>
</tr>
<tr>
<td>CFP</td>
<td>Contention Free Period</td>
</tr>
<tr>
<td>CP</td>
<td>Contention Period</td>
</tr>
<tr>
<td>CSMA/CA</td>
<td>Carrier Sense Multiple Access/Collision Avoidance</td>
</tr>
<tr>
<td>CSMA/CD</td>
<td>Carrier Sense Multiple Access/Collision Detection</td>
</tr>
<tr>
<td>CTS</td>
<td>Clear to Send</td>
</tr>
<tr>
<td>CW</td>
<td>Contention Window</td>
</tr>
<tr>
<td>CWmax</td>
<td>Contention Window Maximum</td>
</tr>
<tr>
<td>CWmin</td>
<td>Contention Window Minimum</td>
</tr>
<tr>
<td>DCF</td>
<td>Distributed Coordination Function</td>
</tr>
<tr>
<td>DS</td>
<td>Distribution System</td>
</tr>
<tr>
<td>EDCA</td>
<td>Enhanced Distributed Channel Access</td>
</tr>
<tr>
<td>ESS</td>
<td>Extended Service Set</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communication Commission</td>
</tr>
<tr>
<td>FHSS</td>
<td>Frequency Hopping Sequence Spectrum</td>
</tr>
<tr>
<td>FIFO</td>
<td>First In First Out</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>HC</td>
<td>Hybrid Coordinator</td>
</tr>
<tr>
<td>HCCA</td>
<td>HCF Controlled Channel Access</td>
</tr>
<tr>
<td>HCF</td>
<td>Hybrid Coordination Function</td>
</tr>
<tr>
<td>IBBS</td>
<td>Independent Basic Service Set</td>
</tr>
<tr>
<td>IFS</td>
<td>Inter-Frame Space</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial, Scientific and Medical</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standard Organization</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LLC</td>
<td>Logical Link Layer</td>
</tr>
<tr>
<td>MAC</td>
<td>Media Access Control</td>
</tr>
<tr>
<td>MF</td>
<td>Multiplicative factor</td>
</tr>
<tr>
<td>MIB</td>
<td>Management Information Base</td>
</tr>
<tr>
<td>MOS</td>
<td>Mean Opinion Score</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
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<td>Network Interface Card</td>
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<td>PF</td>
<td>Persistence Factor</td>
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<td>Ready to Send</td>
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<td>Traffic Identifier</td>
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<td>Traffic specification</td>
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<td>Transmission Opportunity</td>
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<td>Voice over IP</td>
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<td>Wired Equivalent Privacy</td>
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<td>Wireless Fidelity</td>
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<td>Wireless Metropolitan Area Network</td>
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<td>WPAN</td>
<td>Wireless Personal Area Network Wireless</td>
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<tr>
<td>WWAN</td>
<td>Wireless Wide Area Network</td>
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