Study of QoS in IEEE 802.11 Networks

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Abstract :IEEE 802.11 is developed as a simple and cost-effective wireless technology for best effort services. However, due to the lack of built-in quality of service support, IEEE 802.11 experiences serious challenges in meeting the demands of multimedia services and applications. Hence various QoS schemes are designed to meet these challenges by providing the necessary enhancements for the required QoS like service differentiation in the MAC layer, admission control and bandwidth reservation in MAC and higher layers, and link adaptation in the physical layer. Also there is a demand for end-to-end QoS guarantee to be provided in today's heterogeneous wired-cum-wireless network stages in loop. Thispaper presents study of various 802.11 QoS schemes and mechanisms for providing the necessary enhancements for the required QoS.

Index Terms - *QoS, 802.11MAC , CSMA/CA, DCF, PCF, EDCF, WMM.*

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I. Introduction

WLANs are flexible data communication systems that can be used for applications in which mobility is required. In the indoor business environment, although mobility is not an absolute requirement, WLANs provide more flexibility than that achieved by the wired LAN. WLANs are designed to operate in industrial, scientific, and medical (ISM) radio bands and unlicensed-national information infrastructure (U-NII) bands. WLANs can provide data rates up to 11 Mbps, but the industry is making a move toward high-speed WLANs. Manufacturers are developing WLANs to provide data rates up to 54 Mbps or higher. High speed makes WLANs a promising technology for the future data communications market.[6] The IEEE 802.11 committee is responsible for WLAN standards. WLANs include IEEE 802.11a (WiFi 5), IEEE 802.11b (WiFi), IEEE 802.11g and IEEE 802.11n. The deployment of WLANs can provide connectivity in homes, factories, and hot-spots. WLANs are flexible data communications systems implemented as an extension or as an alternative for wired LANs. Using radio frequency (RF) technology, WLANs transmit and receive data over the air, minimizing the need for wired connections. Thus, WLANs combine data connectivity with user mobility.Compared with a wired infrastructure, wireless LAN (WLAN) has unique advantages, such as broadband bandwidth capability and low deployment cost. WLANs can be built with either of the following topologies, Peer-to-peer (ad hoc) topology, Access point-based topology, Point-to-multipoint bridge topology.The technologies available for use in a WLAN include infrared, UHF (narrowband), and spread spectrum implementation. Each implementation comes with its own set of advantages and limitations. With WLANs being deployed in an unlimited way as access points, wireless users can access real-time and Internet services virtually anytime, anywhere, while experiencing the flexibility of mobility and guaranteed connectivity.

IEEE 802.11 is designed for best effort services only. The lack of a built-in mechanism for support of real-time services makes it very difficult to provide quality of service (QoS) guarantees for throughput-sensitive and delay-sensitive multimedia applications. Therefore, modification of existing 802.11 standards is necessary[1].

This paper discusses study of various 802.11 QoS schemes. The paper is organized as follows. Section II gives the brief overview of IEEE 802.11, 802.11 MAC, section III discusses QoS parameters, and WiFi Multimedia, section IV discusses QoS Mechanisms and section V concludes the paper.

II. Brief Overview of IEEE 802.11

IEEE 802 is a family of IEEEstandards dealing with local area networks and metropolitan area networks. The services and protocols specified in IEEE 802 map to the lower two layers of the seven-layer OSI networking Reference model i.e. Data Link Layer and Physical layer . IEEE 802 splits the OSI Data Link Layer into two sub-layers LLC Sublayer and MAC Sublayer. IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication. The three physical layers are an IR baseband PHY, an FHSS radio in the 2.4 GHz band, and a DSSS radio in the 2.4 GHz. All three physical layers support both 1 and 2 Mbps operations.

The 802.11 family consists of a series of half-duplex over-the-air modulation techniques that use the same basic protocol. 802.11-1997 was the first wireless networking standard in the family, but 802.11b was the first widely accepted one, followed by 802.11a, 802.11g, 802.11n, and 802.11ac. Other standards in the family (c–f, h, j) are service amendments that are used to extend the current scope of the existing standard, which may also include corrections to a previous specification.

Based on the transmission technologies and operatingspectrum, the later revisions of 802.11 can beclassified into three categories: 802.11a (orthogonal frequency-division multiplexing, OFDM, 5 GHz), 802.11b (high-rateDSSS, HR/DSSS, 2.4 GHz), and 802.11g (OFDM, 2.4 GHz). 802.11b is based on HR/DSSS and operates at the 2.4 GHz industrial, scientific, and medical (ISM) band with transmission rate from 1 to 11 Mb/s. 802.11a is based on OFDM and uses 5 GHz unlicensed national information infrastructure (U-NII) band in America with a transmission rate of 6–54 Mb/s. 802.11g is also based onOFDM but uses the 2.4 GHz ISM band and was formally ratified by the IEEE Standards Association'sStandard Board in June 2003. This standard specifies a maximum transmission rate of 54 Mb/s, the same as

802.11a. However, since 802.11g uses the same spectrum between 2.4 and 2.4835 GHz and is inherently backward compatible with 802.11b, it may attract more attention from industry than the earlier standardized 802.11a. Nevertheless, 802.11a possesses one noteworthy advantage: the unlicensed radio spectrum (5.15–5.35 and 5.725–5.825 GHz) it operates within israrely used, while the 2.4 GHz spectrum for 802.11b and g has already been taken by many home electronic devices such as cordless phones, microwave ovens, and garage door openers.

A. IEEE 802.11 Data Link Layer

The data link layer within 802.11 consists of two sublayers: logical link control (LLC) and media access control (MAC). 802.11 uses the same 802.2 LLC and 48-bit addressing as the other 802 LAN, allowing for simple bridging from wireless to IEEE wired networks, but the MAC is unique to WLAN. The sublayer above MAC is the LLC, where the framing takes place. The LLC insertsinserts certain fields in the frame such as the source address and destination address at the head end of the frame and error handling bits at the end of the frame. The 802.11 MAC is similar in concept to 802.3, in that it is designed to support multiple users on a shared medium by having the sender sense the medium before accessing it. For the 802.3 Ethernet LAN, the carrier sense multiple access with collision detection (CSMA/CD) protocol regulates how Ethernet stations establish access to the network and how they detect and handle collisions that occur when two or more devices try to simultaneously communicate over the LAN. In an 802.11 WLAN, collision detection is not possible due to the near/far problem. To detect a collision, a station must be able to transmit and listen at the same time, but in radio systems the transmission drowns out the ability of a station to hear a collision[6].

B. IEEE 802.11 Medium Access Control

Wireless local area networks operate using a shared, high bit rate transmission medium to which all devices are attached and information frames relating to all calls are transmitted. MAC sublayer defines how a user obtains a channel when he or she needs one. MAC schemes include random access, order access, deterministic access, and mixed access. The random access MAC protocols are: ALOHA (asynchronous, slotted), carrier-sense multiple-access (CSMA) (CSMA/collision-detection (CD), CSMA/collision-avoidance (CA), non-persistent, and p-persistent). The slotted ALOHA protocol is simple, but not very efficient. Most WLANs implement a random access protocol, CSMA/CA with some modification, to deal with the hidden node problem. When the traffic becomes heavy, it degrades badly. The way of dealing with that situation is to use p-persistent. Most mobile data networks also use random access protocol, usually one that is simpler than CSMA, namely slotted ALOHA. Deterministic MAC schemes improve throughput and response time when traffic is heavy. They offer the guaranteed bandwidth for isochronous traffic. In mixed cases such as CSMA/TDMA, the frame is divided into a random access part and a reserved part. When the traffic is light, it is left to be mostly random. When the traffic is heavy and throughput is in danger of declining or if a node requires isochronous bandwidth, the control point allocates bandwidth deterministically. CSMA/TDMA approaches CSMA performance under light traffic, so it has fast access time. It approaches TDMA performance when the traffic becomes heavy[6].

IEEE 802.11 uses a modified protocol known as carrier sense multiple access with collision avoidance (CSMA/CA) or distributed coordination function (DCF). CSMA/CA attempts to avoid collisions by using explicit packet acknowledgment (ACK), which means an ACK packet is sent by the receiving station to confirm that the data packet arrived intact. The CSMA/CA protocol is very effective when the medium is not heavily loaded since it allows stations to transmit with minimum delay. But there is always a chance of stations simultaneously sensing the medium as being free and transmitting at the same time, causing a collision. These collisions must be identified so that the MAC layer can retransmit the packet by itself and not by the upper layers, which would cause significant delay. In the Ethernet with CSMA/CD the collision isrecognized by the transmitting station, which goes into a retransmission phase based on an exponential random backoff algorithm. While these collision detection mechanisms are a good idea on a wired LAN, they cannot be used on a WLAN environment for two main reasons: Implementing a collision detection mechanism would require the implementation of a full duplex radio capable of transmitting and receiving at the same time, an approach that would increase the cost significantly. In a wireless environment we cannot assume that all stations hear each other (which is the basic assumption of the collision detection scheme), and the fact that a station wants to transmit and senses the medium as free does not necessarily mean that the medium is free around the receiver area. To overcome these problems, the 802.11 uses a CA mechanism together with a positive ACK. The MAC layer of a station wishing to transmit senses the medium. If the medium is free for a specified time, called distributed interframe space (DIFS), then the station is able to transmit the packet; if the medium is busy (or becomes busy during the DIFS interval) the station defers using the exponential backoff algorithm. This scheme implies that, except in cases of very high network congestion, no packets will be lost because retransmission occurs each time a packet is not acknowledged. This entails that all packets sent will reach their destination in sequence. The 802.11 MAC layer provides for two other robustness features: cycle redundancy check (CRC) checksum and packet fragmentation. Each packet has a CRC checksum calculated and attached to ensure that the data was not corrupted in transmit. A simple send-and-wait algorithm is used at the MAC sublayer. In this mechanism the transmitting station is not allowed to transmit a new packet until it receives an ACK for the packet, or decides that packet was retransmitted too many times and drops the whole frame.

C. 802.11 MAC Sublayer

The 802.11 MAC supports two basic medium access protocols:contention-based distributed coordination function (DCF) and optional point coordination function (PCF). When PCF is enabled, the wireless channel is divided into superframes. Each superframe consists of a contention- free period (CFP) for PCF and a contention period (CP) for DCF. At the beginning of CFP, the point coordinator (usually the access point, AP) contends for access to the wireless channel. Once it acquires the channel, it cyclically polls high-priority stations and grants them the privilege of transmitting DCF is based on carrier sense multiple access with collision avoidance (CSMA/CA) instead of CSMA with collision detection (CSMA/CD) because stations cannot listen to the channel for collision while transmitting. In

IEEE 802.11, carrier sensing (CS) is performed at both PHY and MAC layers: physical CS and MAC layer virtual CS.

Several extensions to the basic 802.11 standard have been introduced by IEEE to provide higher data rates or QoS guarantees. 802.11a, 802.11b, and 802.11g focus on higher data rates whereas 802.11e is aimed at providing QoS guarantees.

III. Quality of Service (QoS)

QoS refers to the capability of a network to provide differentiated service to selected network traffic over variousnetwork technologies. It is the capability to provide resource assurance in a network. QoS is defined as the measure of performance for a transmission system that reflects its transmission quality and service availability. Service availability is a crucial element of QoS. Before QoS can be successfully implemented, the network infrastructure must be highly available. The network transmission quality is determined by variousQoS Parameters such as Bandwidth, Delay, Packet loss rate, Jitter etc.[5]

A. QoS Parameters

- With QoS, bandwidth can be managed more efficiently across LANs, including WLANs and WANs. QoS supports dedicated bandwidth for critical users and applications.
- Latency (or delay) is the amount of time it takes for a packet to reach the receiving endpoint after being transmitted from the sending endpoint. This time period is called the end-to-end delay and can be divided into two areas:

  i) Fixed network delay—Includes encoding and decoding time (for voice and video), and the finite amount of time required for the electrical or optical pulses to traverse the media en route to their destination.

  ii)Variable network delay—Generally refers to network conditions, such as queuing andcongestion, that can affect the overall time required for transit.
- Jitter (or delay-variance) is the difference in the end-to-end latency between packets. For example, if one packet requires 100 ms to traverse the network from the source endpoint to the destination endpoint, and the next packet requires 125 ms to make the same trip, the jitter is calculated as 25 ms.
- Loss (or packet loss) is a comparative measure of packets successfully transmitted and received to the total number that were transmitted. Loss is expressed as the percentage of packets that were dropped.

B. QoS importance to Real-Time Traffic over WLAN

The WLAN used for both packet transmission and reception is unlicensed, unprotected, and unshielded. Multiple specifications, protocols, and devices take advantage of unlicensed and no-cost media (radio frequencies) by a WLAN. Consider a scenario. A tablet user in a business office is using Bluetooth to print a document. Another laptop user in the same office is using 2.4 GHz frequency Wi-Fi for a video conference and presentation. A new guest user, in the lobby, is using a smartphone to check email on the Wi-Fi network. The Wi-Fi network must prioritize the 2.4 GHz radio frequency shared by the three devices, to give real-time video conference application priority over the guestsmartphone user and tablet user. In addition, the Wi-Fi network must also address the tablet Bluetooth transmission interference.

C. WLAN queue and schedule mechanism

802.11 WLAN has its own queue and schedule mechanism, which is divided into four access categories (ACs). These four Wi-Fi AC queues provide differentiated access to the Wi-Fi channel. The voice packets are placed in queue with the highest priority for WLAN depending on voice access category. Voice and video packets from a voice or video call have quicker and more frequent access to the Wi-Fi channel than data packets. There will be packet collisions between the phone call and data application, because Wi-Fi is a shared medium. Wi-Fi QoS prioritizes the backoff and packet retry logic for both real-time voice and video traffic and data traffic, based on configuration values in the WLAN enhanced distributed coordination function (EDCF).

D. Wi-Fi multimedia

The Wi-Fi QoS protocol is known as Wi-Fi Multimedia (WMM). WMM is a subset of the 802.11e specification. The 802.11e specification was approved in 2005; however, it was extensively used by Wi-Fi Alliance and Microsoft even before 2005. With the 802.11e specification, devices required new drivers to become Wi-Fi QoS capable with no hardware changes. The legacy devices without QoS have specialized hardware designs with limited firmware memory[5].

Wi-Fi MultiMedia (WMM), formerly known as Wireless Multimedia Extensions, refers to QoS over Wi-Fi. QoS enables Wi-Fi access points to prioritize traffic and optimize the way shared network resources are allocated among different applications. There are three considerations for WMM implementation:

- WMM access,
- WMM classification,
- WMM queues

A .WMM access

WMM is a Wi-Fi Alliance certification of support for a set of features from an 802.11e draft. This certification is for both clients and APs, and certifies the operation of WMM. WMM is primarily the implementation of enhanced distributed coordination function (EDCF) component of 802.11e.

B. WMM classification

WMM uses classification scheme which has eight priorities, which WMM maps to four access categories: These accesscategories map to the four queues that are required by a WMM device.

C.WMM queues

The figure 1 shows the queuing that is performed on a WMM client or AP.

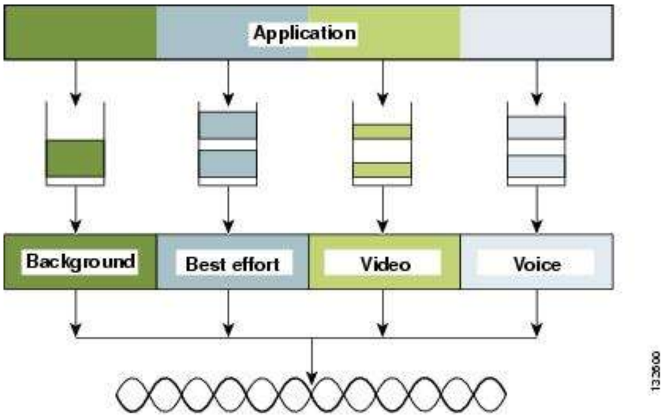

Figure 1. WMM Queues[5].

There are four separate queues, one for each of the access categories. Each of these queues compete for the wireless channel, with each of the queues using different interframe space, contention window (CW) minumum (CWmin) and contention window maximum (CWmax) values as defined by EDCF. If more than one frame from different access categories collide internally, the frame with the higher priority is sent, and the lower priority frame adjusts its backoff parameters as though it had collided with a frame external to the queuing mechanism.

IV. QOS MECHANISMS

Most existing QoS mechanisms for 802.11 can be classified into three categories: Service differentiation, Admission control and bandwidth reservation and Link adaptation.[1]

A. Service Differentiation (MAC)

Research has been done to provide certain DCF-based QoS enhancements that mainly address effective support of service differentiation. These mechanisms do not provide any QoS guarantee, only better than best effort services. Basically, service differentiation is achieved by two main methods:Priority and fair scheduling. Priority binds channel access to different traffic classes by prioritized contention parameters, fair scheduling partitions the channel bandwidth fairly by regulating waittimes of traffic classes in proportion according to given weights. The tunable parameters for both approaches are CW size, backoff algorithm, and interframe space.E.g. EDCF- It prioritizes traffic categories by different contention parameters.

B. Admission Control and Bandwidth Reservation (MAC)

Service differentiation is helpful in providing better QoS for multimedia data traffic under low to medium traffic load conditions. However it does not perform well under high traffic load conditions. In this case, admission control and bandwidth reservation become necessary in order to guarantee QoS of existing traffic. The extremely large saturation delay may lead to failure to support multimedia applications. The Bandwidth Reservation consist of the maximum RF Bandwidth and the reserved roaming bandwidth , priority reservation and allocation of channels. In Admission Control decisions are based on the status of network , such as throughput and delay.(measurement based and calculation based schemes).

C. Link Adaptation (PHY)

802.11 specifies multiple transmission rates that are achieved by different modulation techniques in the PLCP header of the PHY layer. However, it intentionally leaves the rate adaptation and signaling mechanisms open. Since transmission rates differ with the channel conditions, an appropriate link adaptation mechanism isdesirable to maximize the throughput under dynamically changing channel conditions. Metrics include SNR/CIR, received power level, transmission acknowledgements, adaptive PN code, frame retry count, packet error rate etc.

V. Conclusion

IEEE 802.11 WLANs have been successfully applied as the last mile technology in the increasingly pervasive computing environments where wireless/mobile users accesses Internet services via the access point (AP). With more and more real-time multimedia applications subscribed to by mobile users, there is an urgent demand for end-to-end QoS guarantee to be provided in wired-cum-wireless heterogeneous networks. There are some approaches that focus on the interoperability of protocols at the AP. Since MAC protocols are prevalent in IEEE 802.11 WLAN, cross-layer interaction is necessary for both network and MAC layers to share the flow QoS characteristics and network topology information without duplicative efforts. In addition to roaming and horizontal handoff among 802.11 WLANs, supporting QoS anytime, anywhere, and by any media requires seamless vertical handoffs between different wireless networks such as WLAN, mobile ad hoc network (MANET), Bluetooth, Universal Mobile Telecommunications System (UMTS), and wideband code-division multiple access (WCDMA). These topics and issues combined extend the concepts of QoS guarantee in 802.11 and make it better suited for today's high-speed high mobility wireless networks.

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