# Department of Electrical and Computer Systems Engineering


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Medium Access Control (MAC) Schemes for Quality of Service (QoS) provision of Voice over Internet Protocol (VoIP) in 802.11 Wireless Local Area Networks (WLANs)


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# Medium Access Control (MAC) Schemes for Quality of Service (QoS) provision of Voice over Internet Protocol (VoIP) in 802.11 Wireless Local Area Networks (WLANs)

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## Contents

**Abstract**

Wireless local area network (WLAN) is becoming the edge network of choice in today's network infrastructure. The IEEE 802.11, which covers the Medium Access Control (MAC) and physical (PHY) layers, is so far the most widely used WLAN standard. However, it does not support Quality of Service (QoS) requirements of an increasing number of real-time services being used on the networks. This report proposes three MAC schemes that can offer QoS for real-time applications, especially Voice over Internet Protocol (VoIP). All the schemes work in circumstances with or without hidden station condition and ensure bounded delay for voice packets. The first two schemes guarantee no collision of packets; the second scheme provides service differentiation for an arbitrary number of traffic classes and the last scheme is backward compatible with legacy 802.11 Distributed Coordination Function (DCF) .

## Keywords

IEEE 802.11, Wireless Local Area Network, Voice over Internet Protocol, Quality of Service

## 1 Introduction

Over the past few years, many multimedia applications such as Voice over Internet Protocol (VoIP), streaming audio and video have become increasingly popular under the Internet Protocol (IP) networks. However, IP was not designed to support multimedia services with stringent requirements on minimum data rate, delay and jitter. The desire to use these multimedia applications over IP networks has led to the need for enhancing the existing networks with end-to-end Quality of Service (QoS) support. QoS is the ability to offer some persistent data transmission over the network with different treatment for different traffic classes. The Internet Engineering Task Force (IETF) is currently working on service differentiation at the IP layer to support various traffic classes. However, for optimal result, there is a need for QoS support from lower layers, especially Data Link Control (DLC) layer.

The IEEE 802.11 Wireless local area network (WLAN) standard [1], which covers the Medium Access Control (MAC) sublayer of the data link layer and the physical layer, is gaining growing popularity, acceptance and is being deployed everywhere, such as hot spots in coffee shops, hotels and airports. However, the 802.11 standard does not currently provide QoS support for multimedia applications. In this report, MAC schemes that offer QoS to real-time services, especially VoIP, are proposed. The report is organized as follows: Section 2 presents the assumptions and useful facts in the design of the access schemes. Section 3 describes a scheme that offers QoS for VoIP in a scenario with voice traffic only, based on the idea from [2]. This scheme can be extended to provide service differentiation for an arbitrary number of services. A scheme that supports voice and best-effort traffic is shown in Section 4. Section 5 describes a scheme for voice and legacy 802.11 best-effort traffic. Finally, the report concludes with a summary and future directions in Section 6.

# 2 Assumptions and Facts

## 2.1 Assumptions

The following assumptions are used in the design of new access schemes.

- The network is an infrastructure WLAN with one Access Point (AP) and a number of associated stations.
- All stations have been associated with the AP before the first packet transmission starts and proposed access schemes are only used for packet transmissions.
- Hidden stations might exist. If station A is hidden from B, then station B is also hidden from A.
- If a sender transmits a signal (a packet or an Energy Burst EB), then all entities which are not hidden from the sender always hear the signal.
- A station knows how long an EB is so that it can recognize when the channel actually becomes idle after receiving an EB of 2 slots from the AP. If this assumption is not realistic, then instead of an EB of 2 slots, the AP has to reply with an ACK for a successful transmission from a station. A station knows that the channel actually becomes idle after it hears a packet from the AP (either a voice, best-effort or ACK packet).
- Admission control is available.

## 2.2 Facts

Some useful facts in the design of the access schemes are described as follows.

- All stations can hear from the AP and the AP can hear from all stations.
- The channel might be error-free or might have error.
- VoIP packets are sent at constant interval during talkspurts and no packets are sent during silence period (ON/OFF model). A VoIP application usually requires low delay (less than 30 ms in WLAN), low jitter and low bandwidth (8-64 kbps).
- For any extension (11a, 11b, 11g), the slot time is the sum of RX-to-TX turnaround time , MAC processing delay, and Clear Channel Assessment (CCA) detect time (including the propagation delay). The CCA detect time is the minimum time the CCA mechanism has available to assess the medium within every time slot to determine whether the medium is busy or idle. The following relationship also holds: $PIFS = SIFS + slot$ and $DIFS = PIFS + slot$.
- For 802.11a [3], slot time is 9 $\mu s$ and SIFS is 16 $\mu s$. For 802.11b [4], slot time is 20 $\mu s$ and SIFS is 10 $\mu s$. For 802.11g [5], slot time is 9 $\mu s$ (11g stations only) or 20 $\mu s$ (mixed with 11b stations) and SIFS is 10 $\mu s$.

# 3 Access scheme for a scenario with voice traffic only

## 3.1 Contributions

- The access scheme works in circumstances with or without hidden stations. This is an improvement compared to some schemes, which assume there must be no hidden stations.
- There is absolutely no collision of packets. If a packet is received with error, it can be retransmitted immediately without contention. There is also no random backoff. Therefore, the delay of packets is bounded.
- There is no need for an ACK frame to indicate a successful packet transmission and no need for RTS/CTS frames to solve hidden station problem. Hence, the overhead is reduced, the throughput is increased and more voice stations can be supported.
- The AP has more chance for transmission than stations and after gaining channel access, the AP keeps transmitting until its buffer is empty without having to contend again, thus reducing the overhead. This is to reflect the fact that there are more traffic in downlink direction (from the AP to stations) than uplink direction (from stations to the AP) and there are usually a number of packets in the AP buffer as compared to only one packet in a station buffer.

## 3.2 Descriptions

The access scheme for the AP and voice stations in a scenario with voice traffic only is shown in Figure 1

### 3.2.1 Overview

- Each voice session consists of traffic in both downlink (from the AP to a station) and uplink (from a station to the AP) directions. If there are $N$ voice sessions, on average the AP buffer has $N$ times as many the number of voice packets as each station buffer has. The proposed access scheme gives the AP priority over other stations. The AP has to wait for a shorter period of time than a station before contending for channel access. Even if both the AP and a station contend for channel access at the same time, the AP always win the contention. After gaining channel access, the AP keeps transmitting packets until its buffer is empty.
- Among stations, the contention for channel access is based on their unique identifications (IDs) given to them by the AP during call setup. Because stations might be hidden from each other but all stations can hear from the AP and the AP can hear from all stations, the AP must coordinate the channel access of stations. After each contention cycle, only one station with the highest ID wins channel access. This station transmits a packet without collision.

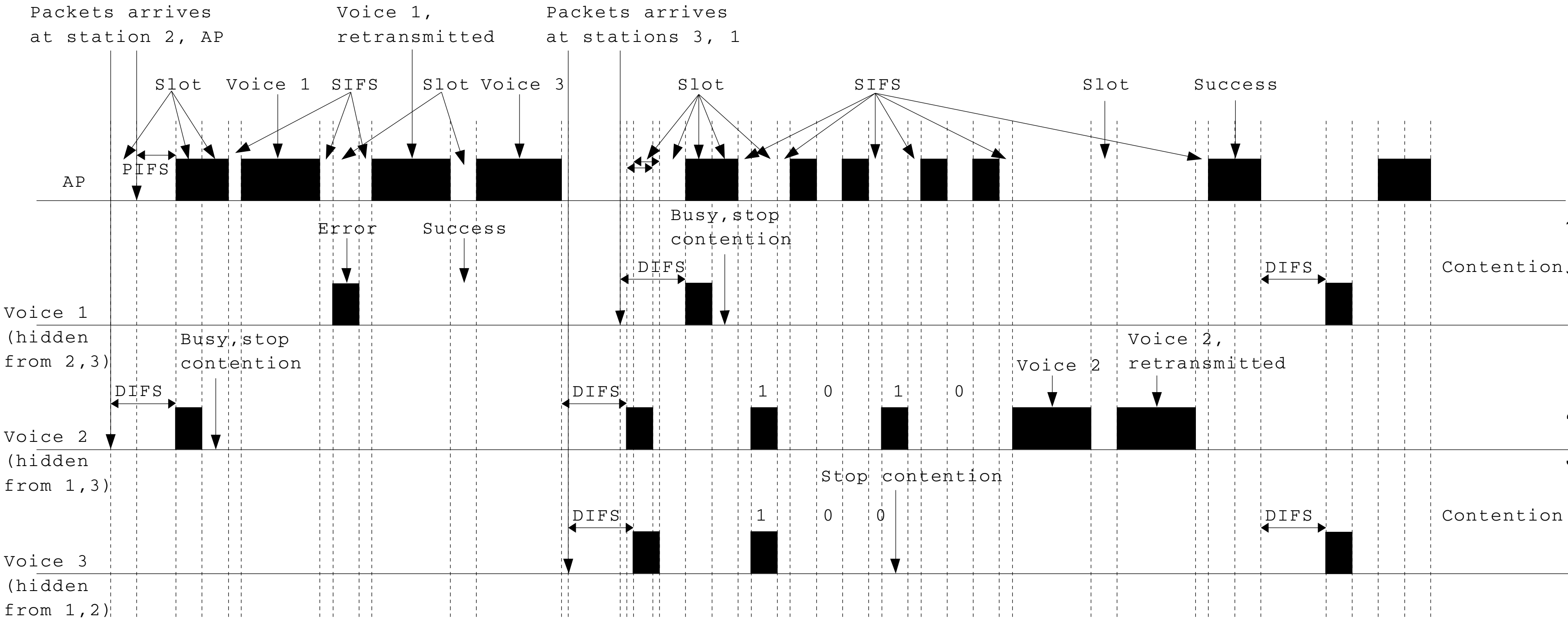


Figure 1: Access scheme for the Access Point and voice stations in a scenario with voice traffic only

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- The AP and stations contend for channel access by waiting for the channel to be idle for a certain time and jamming the channel with an EB. If the AP or a station hears an EB before sending their EBs, they defer from contention. The EB from the AP is longer than that from other stations, therefore even if the AP and a station transmit EBs at the same time, the AP still wins channel access. Among stations, they contend for channel access in a contention cycle consisting of a number of stages, each stage is based on a component in its ID. Only stations that survive the previous stage continue contention in the next stage. After the final stage, there is only one winning station.

- The AP always know when the channel is idle or busy. However, because there might be hidden stations, a station is only sure that the channel is actually idle if it hears the end of a packet transmitted from the AP or the end of an EB of 2 slots, which is also transmitted from the AP. A station, which either previously drops out of contention or has a new packet to transmit, only starts contending for channel access if it is sure that the channel is idle.

#### 3.2.2 Access procedure of the AP

- Whenever the AP has a packet to transmit, it monitors the channel. After the channel has been idle for PIFS, the AP transmits an initial EB with duration of 2 slots, waits for SIFS, then transmits the packet.

- At a receiving station, if a packet received from the AP has error, the receiving station waits for SIFS and replies with an EB of 1 slot. The AP receives this EB from the station, waits for SIFS and retransmits the packet. If the packet received from the AP has no error, the receiving station does nothing. After 1 slot, if the AP does not hear an EB, it means that the packet has been received successfully and the AP transmits another packet until its buffer is empty.

- When the number of retransmissions at the AP has reached the retry limit, whether the packet is received with error or not, the receiving station does nothing as if the packet has been received successfully. Otherwise, if the receiving station replies with an EB of 1 slot, all stations hearing this EB will not start contending. If the AP has no more packet to transmit, then no stations will be able to transmit.

- Whenever the AP has a packet and the channel has been idle for PIFS, it always has channel access to transmits this packet. There is also no collision of packets transmitted from the AP. During the AP transmission of packets, the maximum idle time is 2 slots (for stations that are hidden from the receiving stations), therefore all stations cannot start contention until the AP has finished transmitting all packets in its buffer.

- If the channel has been idle and the AP receives initial EBs from stations before generating its EB, it knows that stations are contending and it will coordinate the channel access of stations, as described below.

### 3.2.3 Access procedure of stations

- Whenever a station has a packet to transmit, it monitors the channel. After the channel has been idle for DIFS, the station transmits an initial EB with duration of 1 slot and monitors the channel during the next slot. If the channel is busy during the next slot, the station drops out of the contention. This might happen if the AP transmits an EB of 2 slots at the same time. For example, if the channel has been idle for DIFS, the station already has a voice packet in its buffer when the channel first becomes idle, while a voice packet only arrives from above layer at the AP after 1 slot. If the channel is idle during the next slot, the station continues the contention cycle.

- It might happen that two or more stations are hidden from each other and they might transmit initial EBs at different times. For example, if the channel has been idle for $DIFS + \delta$, station 1 already has a packet in its buffer when the channel first becomes idle, while a packet arrives from above layer at station 2 after channel has been idle for $\delta$, and station 1 and 2 are hidden from each other. If more than one initial EBs are transmitted, the AP receives all these initial EBs, waits for 1 slot and replies with an EB of 2 slots. No station will start contending after the AP has transmitted its EB of 2 slots. If another station hidden from all contending stations transmits an initial EB of 1 slot at the same time with the EB of 2 slots from the AP, this new contending station will drop out of contention.

- Each station is given a unique ID (during call setup), and this ID is expressed as a n-digit binary number, therefore there are $2^n$ unique IDs. The integer n is chosen to be the smallest integer such that the number of unique IDs is enough for the number of voice stations. For example, if there are between 9 and 16 stations, then n = 4; a station with ID 13 is written as 1101, while a station with ID 5 is written as 0101. The number of digits in IDs can be announced by the AP in its beacon frame. Stations use their IDs to contend for channel access. The station with the highest ID wins the channel access.

- The binary expression of the ID is read from left to right (most significant bit to least significant bit). When a station continues the contention cycle, after receiving the EB of 2 slots from the AP, if there is a 0's at that position, the station does not transmit anything and listens to the channel. If there is a 1's at that position in its ID, the station waits for SIFS and transmits an EB of 1 slot. After transmitting the EB, the AP monitors the channel in the next slot. If the channel is idle, it means that all stations have 0's at that position in their IDs, then the AP transmits an EB of 1 slot after this idle slot. All stations know this and continue the contention cycle. If in the next slot, the AP finds the channel busy, it means that at least one station has 1's at that position in their IDs. The AP receives all EBs from stations, waits for SIFS and replies with an EB of 1 slot. Stations with 1's at this position continue the contention cycle, while stations with 0's at this position drop out of the contention cycle.

- After receiving the last EB from the AP, the only winner of the contention cycle waits for SIFS and transmits its packet. At the AP, if the packet is received without error, the AP waits for SIFS and replies with an EB of 2 slots. If the packet is received with error, the AP does nothing. If the sending station does not hear an EB after 1 slot, it knows the packet has not been received successfully and retransmits the packet. When the number of retransmissions at the station has reached the retry limit, if the packet is received with error, the AP still replies with an EB of 2 slots, so that all stations can start contending for channel access.

# 4 Access scheme for a scenario with voice and non-legacy best-effort traffic

## 4.1 Contributions

- The new access scheme has all the characteristics of the scheme described in previous section: it works in circumstances with or without hidden stations, there is no collision of packets, there is no need for ACK frame or RTS/CTS frames, and the AP has higher priority than stations.
- The new scheme can provide service differentiation to voice and best-effort traffic and it can be extended for an arbitrary number of traffic classes.

## 4.2 Descriptions

The access scheme for the AP and stations is shown in Figure 2

- The AP always know when the channel is idle or busy. However, because there might be hidden stations, a station is only sure that the channel is actually idle if it hears the end of a packet transmitted from the AP or the end of an EB of 2 slots. A station, which either previously drops out of contention or has a new packet to transmit, only starts contending for channel access if it is sure that the channel is idle.
- The access procedures of the AP and voice stations are the same as in the scenario with voice traffic only, with only the following differences.
- The AP with a voice or best-effort packet has to monitor the channel for $VIFS\_ap = SIFS + slot$ and $BIFS\_ap = SIFS + 3 \times slots$, respectively. A station with a voice or best-effort packet has to monitor the channel for $VIFS\_sta = SIFS + 2 \times slots$ and $BIFS\_sta = SIFS + 4 \times slots$, respectively.
- When the AP successfully transmits a best-effort packet, it does not transmit another best-effort packet immediately without contention. This is so that the AP or other stations can transmit if they have voice packets in their buffer.
- A voice station is given higher priority than a best-effort station. During contention cycle, after receiving the EB of 2 slots from the AP for its initial EB, a contending station waits for SIFS and transmits an EB of 1

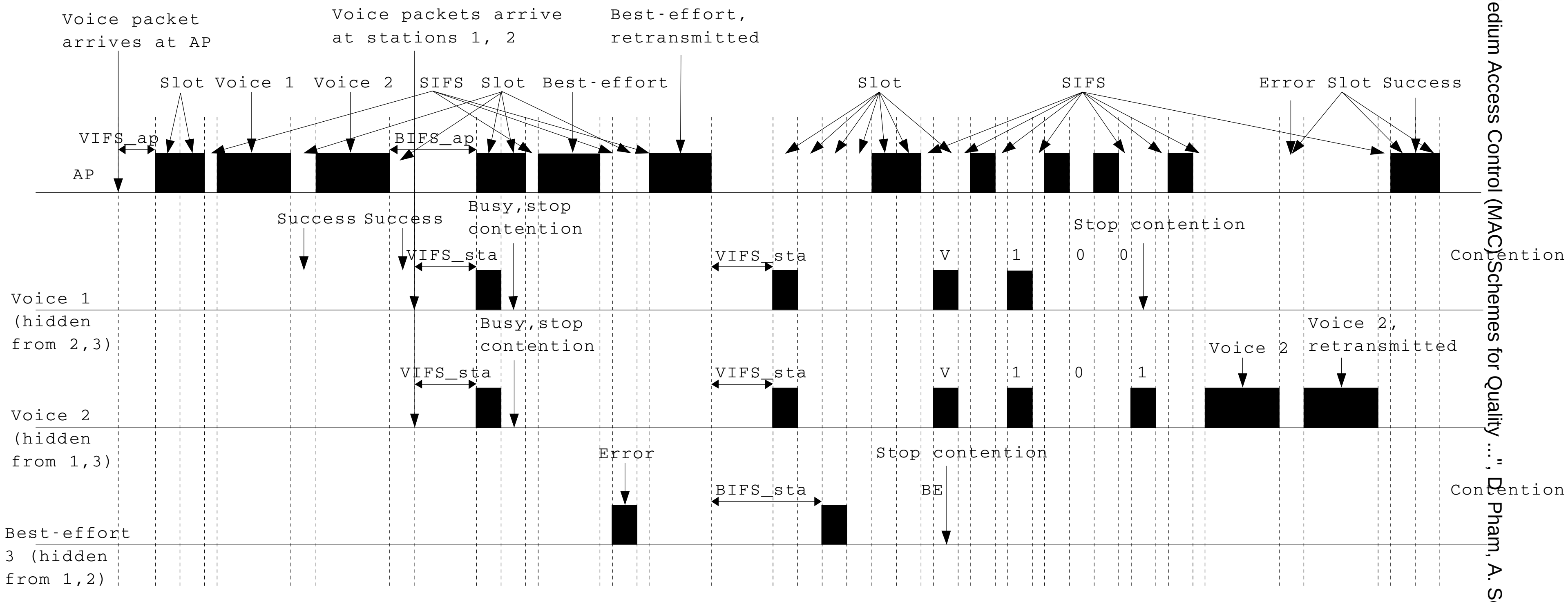


Figure 2: Access scheme for the AP and stations in a scenario with voice and best-effort traffic

slot if it is a voice station; it does not transmit anything and listens to the channel if it is a best-effort station. Therefore, if there are both voice and best-effort station contending for channel access, only voice stations continue while all best-effort stations drop out of contention. Stations continue to contend for channel access with their IDs as described in the scheme with voice traffic only.

- An arbitrary number of traffic classes can be supported. After receiving the replying EB of 2 slots from the AP, if stations go through $n$ stages, then $2^n$ traffic classes can be supported. In each stage, each station either transmits an EB of 1 slot or does nothing and listens to the channel. After $n$ stages, only stations with highest priority traffic continue contention. For example, with $n = 2$, 4 traffic classes can be supported. Voice can be assigned with code 11 (transmits an EB in both stages); video with code 10 (transmits an EB in first stage and does nothing in second stage); best-effort with code 01 (does nothing in first stage and transmits an EB in second stage); background with code 00 (does nothing in both stages).
- The differentiation between a best-effort packet from the AP and a voice packet from stations is based on waiting time only. If the AP with a best-effort packet and a voice station start contention at the same time, then the AP wins contention. However, after this best-effort packet from the AP has been transmitted, other best-effort packets from the AP can only be transmitted after the voice station has finished transmitting its voice packet.

# 5 Access scheme for a scenario with voice and legacy 802.11 best-effort traffic

## 5.1 Contributions

- The access scheme works in circumstances with or without hidden terminal condition.
- The access scheme is compatible with legacy 802.11 DCF, which has a huge base already. The access scheme gives voice higher priority over best-effort traffic, without any modification in the legacy 802.11 DCF.
- There is no collision of voice packets transmitted from the AP. The AP can transmits all its voice packets in its buffer without any interruption from other stations.
- There is only collision between a voice packet and a best-effort packet or among best-effort packet. After a collision between a voice packet and a best-effort packet, the voice packet is always guaranteed to be transmitted immediately, therefore guarantee the bounded delay of voice packets.

## 5.2 Descriptions

- The AP always know when the channel is idle or busy. However, because there might be hidden stations, a voice station is only sure that the channel is actually idle if it hears the end of a packet transmitted from the AP (voice packet or ACK) or the end of an EB of 2 slots. A voice station, which either previously drops out of contention or has a new packet to transmit, only starts contending for channel access if it is sure that the channel is idle.

- The access procedure of the AP: whenever the AP has a voice packet to transmit, it monitors the channel. If the channel has been idle for PIFS, the AP transmits an EB of 2 slots and listens to the channel in the next slot. If the channel is idle during this slot, the AP transmits the voice packet. If the packet has error, the receiving station waits for SIFS and replies with an EB of 1 slot. The AP receives this EB, waits for SIFS and retransmits the voice packet. If the packet has no error, the receiving station does nothing. If after a slot, the AP does not receive an EB, it knows that the transmission has been successful and the AP transmits another voice packet until its voice buffer is empty. The maximum interval between two transmissions of the voice packets (assume that the EB of 1 slot from the receiving station is not received by some hidden stations) is 2 slots, which prevents other stations from contending for the channel access.

- If during the next slot, the channel is busy, it means that at least one legacy station is transmitting. This might happen if the channel has been idle for more than DIFS, for example, the channel has been idle for DIFS + 1 slot, the legacy station backoff window is 1 slot, and the AP only has a voice packet arriving from above layer after the channel has been idle for 2 slots. The AP will defer from transmitting, waits until the channel is idle for PIFS before contending again by sending an EB of 2 slots. The legacy station will not receive an ACK from the AP and will time out and will have to retransmit its packet. If during the legacy transmission of the packet, another hidden legacy station transmits a packet, this legacy station will not receive an ACK from the AP and will time out. If another hidden voice station transmits an initial EB burst, it will also time out if it does not receive an EB of 2 slots from the AP after the idle slot.

- Access procedure of voice stations: a voice station with a voice packet monitors the channel. If the channel has been idle for DIFS, the station transmits an EB of 1 slot and listens for the next slot. If during the listening, the channel is busy, it means that the AP is transmitting the initial EB at the same time, then the voice station drops out of contention. Another possibility is that another legacy station is transmitting a packet at the same time, for example, the channel could be idle for DIFS + 1 slot, the legacy station backoff window is 1 slot, and the voice station only has a voice packet arriving from above layer after 1 slot. If another hidden station is transmitting, the AP waits until the channel is idle again, waits for SIFS and transmits an EB of 2 slots. Each contending voice station has a timer, if it does not receive an EB from the AP for 2 slots after its initial EB, it drops out of contention. If the channel is idle, the AP waits for 1 slot and replies with an EB of 1 slot. After the voice station receives the EB of 2 slots from the AP, it continues contention cycle as specified in the scenario with voice traffic only.

- After the AP replies with an EB of 2 slots, no stations can interrupt the contention cycle, since the maximum idle time during this contention cycle is 2 slots. After the contention cycle, the only winning station transmits a voice packet. However, this voice packet might collide with a packet from a legacy station. If the voice packet is transmitted and received successfully without error, the AP waits for SIFS and replies with an EB of 2 slots. If the voice packet is transmitted with no collision but has error, the AP waits for SIFS and replies with an EB of 1 slot. The voice station waits for SIFS and retransmit the voice packet. After a number of failed transmissions, the voice packet is dropped.

- If during the voice packet transmission, another hidden legacy station transmits, then the AP will wait until the channel is idle, waits for SIFS and replies with an EB of 2 slots. The voice station has already timed out, upon receiving this EB, will waits for SIFS then retransmits the collided voice packet. The collided packet is guaranteed transmission, so its delay is minimized. However, this retransmitted voice packet may have error and may need to be retransmitted.

- As with the scenario where there is only voice traffic, for the last retransmission of a voice packet, the receiving identity (the AP or voice station) will act as if it is a successful transmission. The reason is stated before, to prevent the situation in which no stations might be able to start contention for channel access. (This may not be true, because we have legacy stations as well).

# 6 Conclusions

In this technical report, three access schemes have been presented. In the first scheme, there is voice traffic only. The scheme works in circumstances with or without hidden stations, guarantees no collision of packets and gives the AP higher priority over stations. The second scheme extends the first one by adding best-effort traffic. In addition to all characteristics of first scheme, the second scheme can provide service differentiation for voice and best-effort traffic. Its principle can be extended to provide service differentiation to an arbitrary number of traffic classes. In the last scheme, the service differentiation is provided to voice and legacy 802.11 best-effort traffic. Some improvements for the proposed schemes and directions for further research are outlined as follows.

- The assumption that stations are mutually hidden from each other may be generalized. It is possible that station A cannot hear from station B, but station B can hear from station A.

- The schemes depend on the fact that EBs sent by the AP and stations are received by all entities within range. This assumption may be generalized, so that the schemes can work even if some of the EBs are not received by the AP or some of the stations.

- The schemes described are mainly based on the parameters of 802.11b. For 802.11a or 802.11g, modifications in the waiting time of a packet before contention and time between reception and transmission of EBs are required.

- There might be collision of voice packet with best-effort packet from a hidden legacy station. A possible solution is the AP transmits a CTS frame before a voice packet is transmitted, so that all stations defer contention until the voice packet has been received successfully.

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