Wireless LAN Medium Access Control Protocol: 2nd Update

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ABSTRACT

This contribution provides a 2nd updated description of a medium access control protocol for wireless LANs that can be characterized as follows.

- It is based on the MAC protocol framework proposed in [*NAT91a*] and revised in [*NAT92*] and retains its key characteristics.
- This update introduces a natural way to utilize **Listen-Before-Talk** capability in the MAC when required by different PHY layers available for wireless LANs.
- This updated-MAC is intended to speed convergence to a consensus WLAN MAC protocol within the 802.11 committee.

The medium access control protocol used is a hybrid of reservation and random access based protocols. Channel time is structured as a sequence of frames of equal duration. The protocol relies on the use of broadcast messages from a central controller that demarcates three intervals in a frame. In the first two intervals (known as the **Reservation** intervals: Period A and Period B), transmission is scheduled by the controller and is used for transfer all isochronous traffics as well as some asynchronous data traffic and control traffic. A distributed contention-based protocol is used in the third interval. This third interval (known as the **Contention** interval: Period C), is used for transfer of some asynchronous traffic as well as control traffic. An adaptively movable boundary separates the contention-free and contention-based intervals in each frame. This provides for flexibility of bandwidth allocation to meet a variety of asynchronous and isochronous services that are required in wireless applications. The MAC protocol is applicable to all the 5 PHY layers (SS FH, SS DS, IR, User-PCS, Single Channel PHY) that require support by a 802.11 MAC. Different PHYs will deploy different cell isolation techniques.

The communication architecture is flexible and permits several modes of operation. In particular, wireless communication is supported:

- When an infrastructure backbone network (i.e., a Distribution System) that facilitates extended coverage and mobility is available, and
- When there is no preexisting infrastructure to enable communication between mobile stations.

Introduction

The demand for wireless data communications is expected to grow in the coming years as a wide variety of user applications are developed and used in a number of operating environments. The following usage scenarios are expected to become increasingly common in the future.

Infrastructure-based LANs: The network architecture will consist of a finite number of *Access Points* that are attached to a *Distribution System*. The Distribution System, typically an IEEE 802 network, would enable:

- Communication between mobile stations and fixed destinations (ex, servers, applications, data etc) that are attached to the Distribution System. Mobile stations communicate to an Access Point (a fixed station) that acts as a "bridge" between the radio environment and the Distribution System. The Access Point relays messages from/to stations that request its services.
- Communication between mobile stations
  - If communication is between two mobile stations that are not within range of each other, this will occur utilizing the store-and-forward capability of one or more Access Points attached to a Distribution System.
  - If communication is between two mobile stations that are within range of each other, this can occur with direct or indirect support of an Access Point that can serve both of them.

Adhoc LANs: A primary requirement for a segment of user applications would be the capability to accomplish wireless communication without any dependence on a preexisting infrastructure. An adhoc LAN consisting of a set of mobile stations and shared resources like servers may be created, used for wireless communication and "dismantled" when the needs have been satisfied.

In this contribution we propose a communication architecture that is flexible and encompasses the several modes of usage scenarios outlined above. In particular, wireless communication among participating stations is supported:

- When an infrastructure backbone network (i.e., a Distribution System) that facilitates extended coverage and mobility is present and available for the mobile station to use, and
- When there is no preexisting infrastructure available to enable communication between mobile stations that wish to communicate.

The Revised-MAC scheme will allow the implementation of non-isochronous and isochronous applications.

Revised Scheme

The proposed MAC scheme is first described in the context of Infrastructure-based LANs. The same scheme is used in Adhoc LANs as described in a later section.

A half-duplex wireless link is assumed. The link is used in one of the following modes:

- Inbound traffic (Mobile stations to Access Point)
- Outbound traffic (Access Point to mobile stations)
- Peer-to-peer traffic (direct any-to-any station transfer)

Channel time is structured as a sequence of frames of equal duration. The duration of a frame is subdivided into three intervals as shown in Figure 1 on page 3.

- Conflict-free access (**Reservation-based**) is used in the first two intervals, and
- Random-access (**Slotted Aloha-based**) protocol is used in the third interval.

In the first two intervals (Period A and Period B), the link is used for transfer of all *isochronous* data, some reservation-based *asynchronous* data and of outbound control data (such as AH/BH). This includes outbound data transfer from the Access Point to mobile stations and inbound data transfer in the reverse direction as well as peer-to-peer traffic. In this interval, bandwidth is shared according to a reservation-based bandwidth allocation function performed by a SCHEDULER resident in the Access Point wireless adapter. Bandwidth is allocated in each frame for inbound/outbound/peer-to-peer isochronous and asynchronous transfers.

The third interval (Period C), is used for *asynchronous* data transmission from any Mobile Station to any other station (both mobile stations and Access Point) in a random-access (i.e., unscheduled) mode of operation. A Slotted Aloha protocol, optionally enhanced by a **Listen-Before-Talk** phase when required by the PHY layer constraints, is used in this interval. Control as well as data packets (or frames) will use this interval.

The control information for Periods A, B and C are AH, BH and CH respectively. The medium access control protocol is now briefly described with respect to Figure 1 below.

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|G|AH|    A    |BH|    B    |CH|       C                 |G|

|.|..||||||||||..||||||||||..||||||||    ...    |||||||.|

| |  |Reservat-|  |Reservat-|  |  Slotted Aloha (+ LBT)  | |
| |  |ion based|  |ion based|  |   Contention based      | |

| |  |From AP  |  |From MS  |  |     From MS to AP/MS    | |
| |  |to MS    |  |to AP/MS |  |                         | |

| |  |<- TA -> |  |<- TB -> |  |<--- TC ---------------->| |

     AH - Header for Period A    AP - Access Point
     BH - Header for Period B    MS - Mobile Station
     CH - Header for Period C
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Figure 1. Frame Structure of Revised-MAC Scheme

Periods A and B (Contention-free Intervals)

Headers AH and BH (*Broadcast from Access Point to mobile stations*) are the intervals during which the Access Point broadcasts a special message to all the mobile stations that identifies the beginning of Period A and B respectively, and contain additional control information shown in Figure 2 on page 5.

Period A (*Reservation-based Transfer from Access Point*) is the interval during which contention-free traffic is transmitted outbound.

Period B (*Reservation-based Transfer from Mobile Station*) is the interval during which contention-free traffic is transmitted inbound and peer-to-peer.

Header AH identifies the start of the information frame and contains the Network ID, the Access Point ID, the frequency / code / channel to be used in the next frame (PHY dependent parameter as described in [BAU93b]), a list of pairs <slots, Receiver> and other system control information. The Network ID helps distinguish between several collocated autonomous LANs.

Header BH contains a list of triplets <slots, Transmitter, Receiver> and other system control information.

In Periods A and B, the Access Point controls the scheduled transmissions among stations. The corresponding control information, Headers AH and BH, for these intervals are broadcasted by the Access Point. Each mobile station waits for the headers whose contents include those shown in Figure 2 on page 5. On correct reception of Header AH, each mobile station sets a timer for TA so that it knows when to receive Header BH and learn about the beginning of Period B. On correct reception of Header BH, each mobile station sets a timer for TB so that it knows when to receive Header CH and learn about the beginning of Period C. The parameters TA, TB and TC lets the mobile stations know how much time is allocated to the three intervals in the current frame. On correct reception of Headers AH and BH, each mobile station can determine whether or not it will transmit/receive packets in the current frame.

Header AH specifies a list of ordered pairs of the form <Si, Wi> that indicates that Si slots are sent from Access Point to mobile station Wi in the current frame.

Header BH specifies a list of ordered triplets of the form <Si, Vi, Wi> that indicates that Si slots are sent from Mobile Station Vi to mobile station Wi in the current frame. A mobile station that requested slot allocation in an earlier frame will check to see if it has been allocated any slots. Since the list (of pairs or of triplets) is ordered, the order in which they are allowed to transmit is known to the mobile stations. Since each mobile station knows the list of mobile stations that precede it and their allocations, it can determine when it should begin its transmission or reception. At its designated time, the source / destination mobile station transmits / receives for a fixed period of time whose duration depends on the number of slots allocated to it. Thus, contention-free transfer from source stations to destination stations occurs utilizing the slot allocation information specified in AH / BH. If a mobile station fails to receive AH or BH correctly, then it will not make use of any slots that may have been allocated to it in the current frame.

- HEADER AH
  - TA = Length of Period A
  - TB = Length of Period B
  - TC = Length of Period C
  - BSID = Unique Id of the Access Point
  - NET_ID = Network Id
  - NEXT_FRQ / NEXT_CODE / NEXT_CHNL
  - < Si, Wi > = Access Point transmits Si packets to user Wi.
- HEADER BH
  - TB = Length of Period B
  - TC = Length of Period C
  - < Si, Vi, Wi > = User Vi transmits Si packets to user Wi.

Figure 2. Control Information in Headers AH and BH

Period C (Contention Interval)

Header CH (*Broadcast from Access Point to mobile stations*) is the interval during which the Access Point broadcasts a special message to all the mobile stations signifying the end of the Period B and the beginning of Period C. It also contains additional control information shown in Figure 3.

Period C (*Slotted-Aloha -based Transfer between Stations*) is the interval during which mobile stations transmit using Slotted-Aloha (possibly preceded by **Listen-Before-Talk**) protocol. At the end of Period B, each mobile station waits for Header CH. When received, each mobile station sets a timer for TC so that it knows when the current frame ends and the next frame begins. All stations contend for the channel using Slotted-Aloha (possibly preceded by **Listen-Before-Talk**) and transmit a message without any explicit allocation from the Access Point. A preliminary Listen-Before-Talk step must be performed before transmission, if the PHY layer requests it (as the U-PCS band Etiquette).

- TC = length of Period C
- K = Current estimate of users actively attempting transmission in Random Access Section (expected to be much smaller than the number of users registered with the Access Point).

Figure 3. Control Information in Header CH.

Period C is used for the following types of information:

- Control messages as:
  - Request messages for registering with an Access Point
  - Bandwidth reservation requests from mobile stations (asynchronous and isochronous)
- Data packets (or frames) - A MAC-frame is transmitted using Slotted-Aloha protocol. The MAC-frame may or may not be segmented depending on the size of the frame.

Registration with Access Point

The process by which a mobile station introduces itself and requests the services of an Access Point is called *Registration* [BAU93a]. The set of registered users at an Access Point will change dynamically with time. An Access Point does not assume *a priori* knowledge about the number or the identity of mobile stations desiring its services.

After a mobile station has monitored the radio environment and chosen an Access Point to register with, it sends a Request Registration Control Packet as shown in Figure 4. The packet contains the Access Point ID as well as the Network ID of the LAN that the mobile station wishes to join. Other information included are the mobile station MAC address, and other information that may be required for access control purposes.

Control packet Request Registration	Network ID	Access Point ID	Mobile Station MAC Address

Figure 4. Request Registration Packet

On receipt of a Request Registration control packet such as shown in Figure 4, the designated Access Point processes the request. It responds to the mobile station with a message called Registration Response packet shown in Figure 5. If the registration request is accepted, then the Access Point becomes the *Owner* of the mobile station. An Access Point provides the MAC functions for all mobile stations for which it is the owner. Ownership of a mobile station can change if it roams within an Extended Service Area and a handoff sequence is initiated.

Control packet Registration Response	Network ID	Access Point ID	Mobile Station MAC Address	Mobile Station ID	Action Code

Action taken could be Accept or Deny request. If request is denied, indication of reason for denial may be included.

Figure 5. Registration Response Packet

Reservation Requests for Bandwidth

Isochronous services are supported by transmitting the appropriate bandwidth reservation request to the Access Point. If bandwidth is available, the Access Point grants the requested number of slots in each subsequent frame for facilitating isochronous data transfer. Asynchronous services are supported by transmitting the appropriate slot reservation request to the Access Point. Asynchronous slot reservation requests are granted for use only once.[1] Mobile stations request bandwidth for transmission in contention-free Interval (Periods A and B). The reservation requests are control messages that are transmitted in Period C using the slotted Aloha protocol. The Access Point receives reservation requests and processes them according to the SCHEDULER allocation algorithm. Allocations based on reservation requests are specified in the AH and BH headers of the subsequent frames. The allocations for isochronous traffic are typically slots that occur periodically in a sequence of frames whereas the allocation for asynchronous traffic corresponds to slots allocated once.

Reservation Request packet	
Mobile Station ID	MSID
Network ID	
Access Point ID	APID
Reservation Request Size	REQ_SIZE
Type of Service (Iso / Async)	SERVICE TYPE

Figure 6. Reservation Request Control Packet

Reservation requests have the form shown in Figure 6. Such a request means a mobile station with identifier MSID requests Access Point APID to allocate REQ_SIZE slots for transmission in contention free mode. Successful (i.e. collision-free and error-free) reception of reservation requests are acknowledged by the Access Point. The field SERVICE_TYPE indicates the type of service needed. The field specifies the following: simplex or duplex, direction of transfer (inbound/ outbound/ peer-to-peer) and isochronous / asynchronous traffic. For isochronous traffic, REQ_SIZE slots will be allocated in every frame until a cancellation of the request is indicated in a subsequent control packet from the MSID station.

The SCHEDULER maintains a queue of pending requests for isochronous and asynchronous data transfer, each request containing information shown in Figure 7 on page 8. If there is not sufficient bandwidth to satisfy the reservation request in a frame, then the reservation request will be either a) denied (a Blocked Call) or b) the boundary between the A, B and C Periods will be adjusted to make room for the new call. Whatever policy decision is made, the Access Point processes the reservation request and communicates it as part of the A and B period headers in the next frame.

[1] They can be viewed as special case of Isochronous data transfer with periodicity = 1 frame. They are nevertheless necessary to guarantee the delivery of a large frame segmented into numerous packets.

MSID	Request Size	Iso / Async Type

Figure 7. An Entry in the Queue of Outstanding Reservation Requests

Since asynchronous data, and control messages such as reservation and registration requests must have short response time, TC, the length of the random access (contention interval) portion of a frame, is always lower bounded by a value, *TC_MIN*. *TC_MIN* is the minimum fraction of a frame that is always available for use in contention mode (eg, TC_MIN = 20% of the frame length).

At the end of each frame, the Access Point may have outstanding packets to be transmitted to mobile stations registered with it. The isochronous portion of this traffic are transmitted in Periods A according to the slots allocated by the SCHEDULER. The asynchronous portion of the traffic is also transmitted in Period A.

MAC Operation over PHY layers

Operation in ISM band

For FH or DS spread spectrum PHY layers (which offer cell isolation techniques), the scheme previously introduced can be simply used as is. As all the PHY channel users follow the same MAC protocol, it is not necessary to have a LBT phase before transmission within a slot of the C Period. If it were used, then the channel would be always sensed as idle even if two or more stations intend to transmit in the same slot: the channel is kept idle at each slot boundary whereas it may be busy within each slot.

IR with channelization

The scheme previously introduced can be used as is, thanks to the cell isolation capability resulting from channelization. For the same reasons as in the ISM band, a LBT phase is not used for channelized IR PHY layer.

For IR products that do not offer channelization, two possible approaches can be followed. Either the scheme described in "MAC Operation in Single Channel PHY" on page 9 is used (for the cases where collocated networks are expected), or it is assumed (mainly due to the limited range and to the propagation properties of IR) that networks will not overlap, so that the scheme previously introduced can also be used as is.

Operation in User-PCS band

The U-PCS band has two subbands - the Isochronous band (1910-1920 MHz) and the Asynchronous band (1920-1930 MHz) [WIN93]. The two bands will be referred in the rest of this paper as I-Band and A-Band respectively. The Revised-MAC operates as follows. When the Access Point is first turned on, it performs a Listen-Before-Talk in the I-Band and acquires a channel H. Initially A single channel H is acquired

It is sufficient to transmit the headers AH/BH (for reservation-based intervals) and CH (for contention interval) of the Revised-MAC frame. Headers AH and BH include the reservation control information for isochronous and asynchronous traffic. The Access Point will emit headers AH and BH frequent enough so that it has channel H permanently (or until it is turned off). Before emitting header CH, the Access Point senses the A-Band and identifies what it thinks is an "idle" channel (Intuitively, an idle channel is one in which the average energy sensed over the last X microseconds is very small, ex, X= 30 microseconds). Let F be such an idle channel within the 10 MHz A-Band. The information F is contained in the CH header along with length of the C Period. At the end of the B Period all stations (Mobile station as well as Access Point) switch to operate in channel F of the A-Band for the current frame. These stations operate using a LBT phase before transmission using slotted Aloha and together occupy the C period for a maximum total duration of MAXbusy (=10) msecs. This constraint addresses two requirements: transmission is limited to 10 msecs in the A-Band, and non-preemptable idle periods are limited to 10 msecs in the I-Band. During the C Period, stations will transmit data frames as well as control messages such as Registration Request control packets as well as Isochronous bandwidth and asynchronous reservation requests. Transfers are in peer-to-peer or to the Access Point, depending on option used. At the end of the C Period, all stations switch to channel H in the I-Band and the Access Point transmits the AH Header and the next frame is started. The width of the H channel may have to be increased depending on whether isochronous bandwidth requests were made or not.

This is like a FH system, where the hopping pattern has only two frequencies, both of which are determined dynamically by the Access Point using LBT mechanism of the etiquette.

MAC Operation in Single Channel PHY

Assume a single channel of width B Hz centered at frequency CF. The Access Point divides time into frames of equal duration. There are three intervals : Period A and Period B for reservation-based traffic and Period C for contention-based traffic. The operation of the protocol is similar to that described above with the following exceptions.

LBT to acquire channel CF is done by the Access Point before each AH header transmission. Reservation based traffic is transmitted according to slot allocations transmitted in the AH and BH Headers. At the end of the reservation intervals, the CH Header containing length of C interval is issued. Asynchronous data traffic as well as control packets (isochronous bandwidth and asynchronous reservation requests as well as Registration requests) are transmitted using a Listen-Before-Talk phase before slotted Aloha transmission. At the end of the C period, the Access Point senses the channel with a LBT phase and then issues the AH header for the next frame and the sequence of frames is repeated.

Problems may arise if overlapping cells exist with independent scheduling of slots done by different Access Points for members of their cells. Collisions may occur even if slots have been allocated for use in the A and B Periods for reservation-based traffic. The extent of the collision is very dependent on the presence of overlapping cells with both containing stations that need reservation-based transmissions.

Note: The information found in the headers AH and BH is similar in purpose to the one proposed in [BIB93] to build a Net Allocation Vector.

The key point to note is that some asynchronous traffic can still be transmitted in the overlapping cells, because they use the LBT-protocol. The presence of the overlapping cell manifests itself only as potentially more asynchronous traffic load offered to the system by members of all the overlapping cells put together.

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References

[*NAT91a*] K. S. Natarajan, C. C. Huang and D. F.Bantz, *Medium Access Control Protocol for Radio LANs*, IEEE 802.11 Working Group paper, 802.11/91-74, July 1991.

[*NAT92*] K. S. Natarajan, C. C. Huang and D. F.Bantz, *Medium Access Control Protocol for Radio LANs: An Update* , IEEE 802.11 Working Group paper, 802.11/92-39, March 1992.

[*BAU93a*] F. Bauchot and K. S. Natarajan, *Registration Scenarios for Wireless LAN MAC Protocol*, , IEEE 802.11 Working Group paper, 802.11/93-2, Jan. 1993.

[*BAU93b*] F. Bauchot, *Wireless LAN MAC Protocol: PHY layer transparency* , IEEE 802.11 Working Group paper, 802.11/93-30, March 1993.

[*BIB93*] P. Belanger and K. Biba, *The Wireless Hybrid Asynchronous Time-Bounded MAC Protocol*, IEEE 802.11 Working Group paper, 802.11/93-40, March 1993.

[*WIN93*] WINTech/93.02.23.20 Document, WINForum Etiquette.