Medium Access Control Protocol for Radio LANs

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Abstract

The medium access control protocol concerns the use of broadcast messages from a central controller to demarcate three intervals: the first two intervals in which transmission is scheduled by the controller, and the third in which a decentralized contention-based medium access control protocol is used. The medium access control protocol is well-adapted, but not limited, to use with frequency-hopping methods of spread-spectrum radio transmissions.

1. Introduction

In indoor digital data radio systems, a key problem is providing efficient access to the channel, as that channel is limited in capacity and shared by all its users. In this contribution we assume a network architecture where a finite number of *Access Points* are attached to a *Distribution System*. The Distribution System enables:

- Communication between mobile stations and applications/data residing in the enterprise computing environment. A typical structure has mobile stations communicating to an Access Point (a fixed station) acting as a bridge between the radio environment and the Distribution System. The Access Point relays messages to other resources attached to the Distribution System.
- Communication between mobile stations. If communication is between two mobile stations, this can occur utilizing the store-and-forward capability of one or more Access Points attached to a Distribution System. An approach to setting up *ad-hoc* networks between mobile stations would require implementation of Access Point functions in software in mobile station adapter cards and a method for designating one of them to perform Access Point functions.

Each Access Point has processing and storage capability to perform store-and-forward functions. The Distribution System can, in general, be an IEEE 802 network. Each mobile station can communicate with a set of Access Points. Within each Basic Service Area the radio link is half-duplex that is shared between inbound (mobile stations to Access Point) and outbound (Access Point to mobile stations) traffic.

In this contribution, the transmission technique assumed is *spread spectrum*, authorized by the US Federal Communications Commission in its regulations, part 15.247, for use in certain frequency bands without user license. Specifically, the form of spread-spectrum considered is *frequency-hopping*, but the medium access control protocol can also be used with *discrete-sequence* systems. In a frequency-hopping system, the carrier frequency of the transmitter changes at intervals of time, remaining constant between those instants. The period of constant frequency is called an *hop* and it is only during these hops that messages may be exchanged. Because these hops are of finite duration they impose a structure on the use of the radio channel: *no transmission may cross a hop boundary*. Hops impose a framing structure on time.

Efficient radio channel usage is the basic requirement for a practical indoor radio data networks. The different types of traffic from various data terminals are usually bursty in nature and not predictable. Static channel allocation means such as frequency division or fixed time division are inefficient for many forms of computer-to-computer traffic, known to be bursty in nature. Furthermore, they are not well-suited for mobile communication systems with a dynamically changing population of mobile stations. Random access schemes (such as Aloha, Slotted Aloha, CSMA and its variants) are known for their short response time when channel load is light. With these schemes, the shared channel should not be heavily loaded to avoid potential stability problem. When channel load increases, random access schemes can introduce unacceptable delays and can become unstable if not suitably controlled.

Controlled access schemes, based on polling or reservation methods, achieve much better channel use efficiency when load is heavy. However, polling schemes may suffer from overhead unless care is taken to minimize the effective walk-time (i.e, time required to poll a mobile station) on the response time seen by the mobile stations. Controlled access schemes have the following desirable characteristics. They:

- allow the implementation of non-isochronous and isochronous applications.
- can ensure fairness of access to mobile stations. No mobile station is deprived of communication because of capture effects.

A number of comprehensive survey articles [*TOB*82] [*KUR*84] [*KLE*88] as well as text books [*HAY*84] [*BER*87] [*ROM*90] describe multiple access protocols for use in different communication environments.

2. Proposed Scheme

In order to reduce response time when traffic load is light and increase channel use efficiency when traffic load is intense, a hybrid of controlled access and random access scheme is desirable. The proposed medium access control scheme is based on a frame structure and can be used under FCC part 15 frequency hopping rules. The frame structure of the proposed scheme is as follows. The duration of a hop is subdivided into three intervals, such that a different medium access control protocol is used in each interval. Centralized control is used in the first two intervals and decentralized control in the third interval.

Frame Structure

The medium access control protocol is now briefly described with respect to Fig. 1 below. In Fig. 1, the labelled intervals are:

- G - the interval during which the transmitter carrier frequency is changing, of duration H.
- Period A -
  - AH (*Broadcast from Access Point to mobile stations*) - the interval during which the Access Point broadcasts a special message to all the mobile stations that identifies the beginning of Period A and contains additional control information (see below).
  - A (*Broadcast from Access Point to mobile stations*) - the interval during which outbound traffic is transmitted. The Access Point broadcasts packets and mobile stations receive packets addressed to them.
- Period B -
  - BH (*Broadcast from Access Point to mobile stations*) - the interval during which the Access Point broadcasts a special message to all the mobile stations signifying the end of the Period A and the beginning of Period B. It also contains additional control information (see below).
  - B (*Contention Free Transfer from Mobile stations to Access Point*) - at the end of Period A, mobile stations take turn to transmit according to the slot allocation specified in BH.

- Period C -
  - CH (*Broadcast from Access Point to mobile stations*) - the interval during which the Access Point broadcasts a special message to all the mobile stations, identifying the end of the Period B and the beginning of the Period C. The message also conveys the TC, length of the Period C.
  - C (*Random Access from Mobile stations to Access Point*) - the interval during which any station may contend for the channel and transmit a message without the consent of the Access Point. A Slotted-ALOHA protocol can be used in this interval. This interval is used for the following types of information:
    - Registration requests that enable mobile stations to identify themselves and request the services of the Access Point. This is necessary because the set of mobile stations accessing the wireless LAN can change dynamically with time. An Access Point can not assume *a priori* knowledge about the number or the identity of mobile stations desiring its services.
    - Request bandwidth for transmission in Contention Free mode (Period B). Both isochronous or non-isochronous services can be supported by transmitting the appropriate bandwidth reservation request to the Access Point. Allocations based on reservation requests are specified in the AH and BH headers of the next frame.
    - Transmission of bursty data (single packet messages).

Period A operation - Each mobile station waits for Header AH corresponding to Period A. The header specifies the lengths of all three intervals (TA, TB and TC) and the lengths of their corresponding headers (TAH, TBH and TCH). 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. Header AH identifies the start of the information frame, carries an unique identification of the Access Point, specifies the frequency hopping pattern and carries other system control information.

In Period A the Access Point controls the transmissions outbound to the mobile stations. The corresponding header (AH) control information for this interval is broadcasted by the Access Point and received by all mobile stations.

On correct reception of the above control information Header AH, each receiving mobile station can receive packets broadcasted by the Access Point that are addressed to it. The remaining packets are discarded by the mobile station.

Period B operation - At the end of Period A, each mobile station waits for Header BH corresponding to Period B. It contains the lengths of Periods B and C (TB, TC) and the lengths of their corresponding headers (TBH, TCH). When received, 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 contention interval. Header BH also specifies such control information as which mobile stations may transmit, the number of packets allocated to each of them and the sequence in which they can transmit in the current frame. The mobile stations transmit packets to the Access Point according to the allocation information received in BH. If a mobile station fails to receive BH correctly, then it will not make use of any slots that may have been allocated to it in the current frame.

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

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

  |   |  |  Broadcast   |  | Contention Free|  | Contention      |   |

  |   |  | Access Point|  | Mobiles to      |  | Mobiles to     |   |
  |   |  | to Mobiles  |  | Access Point    |  | Access Point   |   |

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

   AH - Header for Period A
   BH - Header for Period B
   CH - Header for Period C
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Figure 1. Frame Structure of Medium Access Control Scheme

Period C operation - At the end of Period B, each mobile station waits for Header CH corresponding to Period C. The header contains TC, the length of the third interval. When received, each mobile station sets a timer for TC so that it knows when to schedule its next frequency change.

Hopping considerations - Broadcast reception of messages is not guaranteed, only likely. Radio conditions may be such that a particular mobile station does not hear the broadcast message AH. If a mobile station does not hear Header AH, then it refrains from participation in the current frame by remaining quiet for the entire hop. Instead, it remembers the hop length of the last frame to set a timer so that it knows when to hop, and it will listen in the next frame for the AH message. If no AH message is heard for a number of consecutive frames the mobile station must assume that it has lost hop synchronization with the rest of the system, and enter a synchronization acquisition mode (to be discussed below).

Each frame period of length T = (TAH+TA+TBH+TB+TCH+TC) can also be a frequency hopping period for implementation under FCC part 15. A fixed length of T is recommended but is not necessary. Fixed length of T has following useful characteristics:

- When several frequency hopping patterns are used in overlapped operation in an Extended Service Area (multiple Access Points plus a Distribution System) and each Access Point uses a fixed length T per hop, then interference separation may be achieved by appropriate choice of hopping sequences for the Access Points.
- If all radios in a system are hopping with the same pattern, a fixed length of T permits different Basic Service Areas to hop in synchronism but at different phases of the hopping pattern. This eliminates interference between Basic Service Areas.

A tradeoff needs to be made in selecting the length of T. A large T makes the system overhead smaller and a small T makes the system response time smaller.

By varying TA+TB, the Access Point can expand or contract the contention interval. If the system is very lightly loaded and most of the traffic is inbound to the Access Point, it is advantageous to mobile response time to lengthen TC. Conversely, if the system is heavily loaded and most of the traffic is outbound, TC should be minimized. TC should not be reduced to zero, however, as it is the only mechanism by which a newly activated mobile station can register itself to the Access Point.

Synchronization acquisition

The issue of how a newly activated mobile station acquires synchronization with the Access Point with respect to hopping must be resolved. A method for sync acquisition is the following. A mobile station that needs to get in sync could monitor a single frequency for an AH message. Once received, the mobile station can now predict the time of the next frequency change (from the content of the AH message) and can thus hop in synchronization. It is essential that the mobile station check the AH message for the identification of its permanent owner: otherwise the mobile station may synchronize to the wrong Access Point. Alternatively, the mobile station may hear multiple AH messages and choose a Access Point by measuring signal strength and choosing the strongest. The mobile station can then register itself to the Access Point by transmitting a message to the Access Point in the contention interval. Note that the entire hop time is (TAH + TA + TBH + TB + TCH + TC).

Handoff between Access Points in a Frequency Hopping System

A basic problem in providing transparent communication service for mobile stations in an Extended Service Area is *handoff*. A mobile station needs to know when, how, and to which Access Point to handoff. In order to achieve this goal, information has to be gathered at the mobile station about the current status of all the potential new Access Points around it such that it can make an appropriate handoff decision.

In order to collect handoff information from surrounding Access Points, a mobile station must have knowledge of:

1. Who are the handoff candidates (i.e., which surrounding Access Points can serve the mobile station) ? How many of the candidates should be monitored ?
2. For each handoff candidate Access Point,
   - when can its handoff information be collected ?
   - which state of its frequency hopping pattern it will be in?

Furthermore, the Access Points involved in a handoff and the mobile station must cooperate according to a well defined protocol for accomplishing the handoff function. We have considered different methods with varying degree of requirement on network synchronization among the Access Points. In one method, Access Points are tightly synchronized with each other. In another method, each Access Point can operate independently of other Access Points without any need for tight global synchronization. Details on key issues related to handoff will be described in a future contribution.

Implementation

A partial implementation of the protocol has been done in software. A software implementation is consistent with the performance requirements of slow frequency hopping, which by FCC regulations limits the duration of an hop to 400 milliseconds. Mobile stations need to have the capability of receiving broadcast messages. This can be done by adopting the convention used in some data-link-level protocols, namely, an address of all ones, or any commonly-agreed-to address, signifies a broadcast address.

3. Summary

The proposed medium access control protocol uses broadcast messages to demarcate three intervals within an hop: two intervals during which the Access Point has control, and a third interval during which access is gained by contention. The timing of the broadcast messages controls whether the system appears predominantly contention-based or controlled by a central controller. As the load on the system increases the Access Point can switch to a controlled method of medium access, unconditionally stable. The protocol meshes well with the constraints of slow frequency hopping, although it can be used with any signalling technique (spread-spectrum or not).

The protocol has the following desirable characteristics:

- short access time if the channel is lightly loaded
- good channel utilization if the channel is heavily loaded
- unconditionally stable
- simple implementation
- matched well to typical traffic patterns, where most traffic is outbound from an Access Point attached to a Distribution System to mobile stations.

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