A Review of Packet Reservation Multiple Access

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Abstract

The rapid technological advances and innovations of the past few decades have pushed wireless communication from concept to reality. The popularity of wireless communication systems can be seen almost everywhere in the form of cellular networks, WLANs, and WPANs. Packet-switched technology has been demonstrated as effective in cellular radio systems with short propagation delay, not only for data, but also for voice transmission. In fact, packet voice can efficiently exploit speech on–off activity to improve bandwidth utilization over time division multiple access (TDMA). Such an approach has been first suggested in the packet reservation multiple-access (PRMA) technique, an adaptation of the reservation ALOHA protocol to the cellular environment. PRMA can be viewed as a combination of TDMA and slotted ALOHA protocols. Recently modified versions of the PRMA protocol have been the subject of extensive research. This paper reviews a number of variations of PRMA protocol in literature.

Keywords: Medium Access Control, PRMA, Slotted Aloha, TDMA

1. Introduction

The rapid technological advances and innovations of the past few decades have pushed wireless communication from concept to reality. Advances in chip design have dramatically reduced the size and energy requirements of wireless devices, increasing their portability and convenience. These advances and innovations, combined with the freedom of movement, are among the driving forces behind the vast popularity of wireless communication. This situation is unlikely to change, especially when one considers the current push toward wireless broadband access to the Internet and multimedia content. With predictions of near exponential growth in the number of wireless users in the coming decades, pressure is mounting on government regulatory agencies to free up the RF spectrum to satisfy the growing bandwidth demands. Given the slow reaction to such demands and the high cost of licensing, wireless users are typically forced to make due with limited bandwidth resources, which have put an emphasis on efficient access mechanisms to the wireless medium.

The wireless medium is a broadcast medium and therefore multiple devices can access the medium at the same time. Multiple simultaneous transmissions can result in garbled data, making communication impossible. A medium access control (MAC) protocol moderates access to the shared medium by defining rules that allow these devices to communicate with each other in an orderly and efficient manner.

The rest of this paper is organized as follows. This section is divided into three subsections. An introduction of MAC protocols and their classification is presented in 1.1. PRMA protocol is explained in 1.2. Model of PRMA is described in 1.3. Section 2 describes the multimedia characteristics of PRMA. Section 3 describes different variations of PRMA protocol. Finally, some concluding remarks are given in Section 4.

1.1 Medium Access Control (MAC) Protocols

The role of the MAC protocol [1] is to determine when a node is allowed to transmit its packets. It typically controls all access to the medium. Wireless MAC protocols have been studied extensively since the 1970s. The initial protocols were developed for data and satellite communications. We are now witnessing a convergence of the telephone, cable and data networks into a single unified network that supports multimedia and real time applications like voice and video in addition to data.

The two major objectives of a multiple access protocol are maximization of the channel capacity utilization and minimization of latency between a station deciding to transmit and able to transmit. There is an inherent tension in these two desirable goals. Other goals which might be

equally important in some cases could be fairness and stability.
The specific functions associated with a MAC protocol vary according to the system requirements and application. Design and complexity as well as performance are also affected by the network architecture, communication model, and duplexing mechanism employed.
Depending on the system requirements and application, the MAC protocol should provide the following main features:

- *High throughput*- A high network throughput, or high efficiency, is achieved when the protocol has low overhead and low collision probability. It is also equivalent to low frame delay.
- *Scalability*- The network throughput should be unaffected by increases in number of nodes. Naturally, the per-node throughput decreases as the number of active nodes increases but ideally, this should follow a linear decrease.
- *Topology independence*- The network throughput should be transparent to network topology changes. In high mobility scenarios, where the rate of nodes joining and leaving the network is high, as well as node velocity, the protocol should be able to maintain a high network throughput.
- *Fairness*- The protocol should not give priority to particular nodes over the others.
- *Quality of Service (QoS)* - When multiple traffic classes are defined, the protocol should be able to manage the bandwidth resources in order to assign different priorities to real-time and best-effort nodes.
- *Energy efficiency*- The complexity of the MAC protocol should be low to yield low power consumption.

It is extremely difficult to design a MAC protocol with all mentioned features. In practice, MAC protocols are usually tweaked towards only a subset of features depending on the architecture and application requirements. For instance, sensor networks put a high emphasis on energy efficiency and less on QoS or topology independence while densely populated broadband networks have stringent QoS and scalability requirements.
There are various MAC schemes in literature which can be classified as-

a) Contention free (fixed assignment) set will have schemes like TDMA, CDMA and FDMA. The nodes access the shared medium in a predetermined way. FDMA gives users an individual allocation of one or several frequency bands, or channels. TDMA allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity. CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code) to allow multiple users to be multiplexed over the same physical channel.
These protocols lack the flexibility in allocating resources and thus have problems with configuration changes. This makes them unsuitable for dynamic and bursty wireless packet data networks. These types are mostly applicable to infrastructure based wireless network.

b) *The contention based* (random assignment) class consisting of ALOHA and CSMA is very flexible and is what is predominantly used in wireless ad-hoc and sensor networks. Random access schemes provide each user station with varying degrees of freedom in gaining access to the network whenever information is to be sent.
There are systems designed using one or more of these classes. For instance cellular networks use ALOHA to get the code when entering a cell and CDMA for subsequent communication.

c) The reservation based protocols- A node has to reserve one or more time slots within a frame before the actual packet transmission can take place. Contention occurs during the reservation phase. A certain number of slots form a frame and frames are repeated. Stations compete for empty slots. Once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send.

1.2 Packet Reservation Multiple Access (PRMA)

Owing to limited radio resources, an efficient MAC protocol is essential in wireless systems, especially in wireless systems that are expected to provide broadband services for mobile users. The MAC protocol employed should allow for integrated transport of voice, video and data over the same radio channel**.** The protocol should aim at increasing channel capacity by multiplexing as large a number of sources as possible, while still satisfying QoS constraints.
The packet reservation multiple access (PRMA) protocol is a MAC protocol proposed by Goodman et al. [2] for packet voice transmissions. This reservation protocol, a modification of reservation ALOHA (R-ALOHA), is suitable for speech terminals since conversational speech produces multiple packet messages during talk spurt. Several variations of PRMA were proposed for diverse traffic types. In the PRMA protocol, time is divided into

frames and each frame is further divided into time slots. PRMA is a slotted protocol where frame duration, is a design variable parameter divided into a set of slots. Number of these slots depends on both frame size and transmitted packet size. Frame size is related to frame duration and channel transmission rate. Packet size is related to source bit rate.

The basic principle of PRMA is to occupy a time slot only during speech talkspurts and release the channel during silence periods. In each frame, time slots are dynamically reserved for packets from active voice terminals. As a consequence, the terminals with reservation share the channel in a manner closely resembling time division multiple access (TDMA).

Each of the uplink slots is recognized as reserved or available. At the beginning of a talk spurt, an MT contends for an available slot using the slotted-ALOHA protocol. If the first packet of a talk spurt is transmitted successfully in one of the available slots without any collision, the BS reserves that slot in the following frames for the MT and send an acknowledgement message to the MT. At the end of the talk spurt, the MT releases the slot by leaving it empty. If the first packet of a talk spurt is not received successfully by the BS, then the MT continues to retransmit the packet with probability q in subsequent available slots until the packet is successfully received by the BS. The probability q is referred to as the permission probability which is a design parameter. Upon successfully contending for channel access, a terminal that generates a sequence of packets obtains a reservation for uncontested use of subsequent time slots. The terminals with reservations thus share the channel as in TDMA.

A PRMA packet consists of a header and speech or data information. The header provides the base station the information it needs to forward the packet to its destination. If the base station is able to decode a header correctly, the packet transmission is considered successful. If in a particular slot, the base station is unable to decode a header correctly, it announces unsuccessful reception. In a wireless mobile radio environment, a channel suffers from noise and fading errors. Therefore these errors in the packet header have a negative effect on the performance of PRMA.

In the PRMA protocol, a collision occurs if two or more MTs contend for the same available slot, that is, two or more MTs transmit packets in the same available slot. These MTs will retransmit the packets. Retransmissions of packets due to collisions will increase the traffic, which will in turn increase the probability of a collision especially under heavy load. As the load continues to increase, the effective channel utilization will decrease because of increased collision probability.

Since conversational speech requires prompt packet delivery, packets delayed beyond a certain time limit are useless and are dropped by the system. The speech quality gradually degrades with increased packet dropping. The system performance measure of main interest is therefore the packet dropping probability. PRMA capacity is defined in to be the maximum number of terminals that can share a common channel with an average value of packet dropping probability consistent with speech quality objectives. The system throughput is also defined as the fraction of system time slots that carry useful information.

Even though PRMA was once used for speech traffic, it can also be used for data users due to its bandwidth efficient, random access and reservation nature. The reservation nature

can provide data users with continuous transmission while the random access nature is bandwidth efficient for low to medium bit rate bursty data traffic. The flexibility of PRMA for accepting different traffic bit rates also makes it a good candidate for multi-rate data traffic.

An advantage of PRMA is that it requires little central control. Since hand-overs require minimal base station intervention, an active voice terminal that moves into another cell loses its slot reservations. It therefore needs to recontend with other terminals to transmit its remaining voice packets. The terminal also needs to register with the new base station. The resulting delay, may force the terminal to drop voice packets, thereby degrading its performance.

One of the main advantages of the packet multiple access protocol is that it could be combined with existing TDMA or CDMA based systems and can also be integrated with the next generation WCDMA systems. PRMA based protocol suits well for multimedia traffic because of its flexible and dynamic bandwidth allocation procedure.

1.3 The PRMA Model

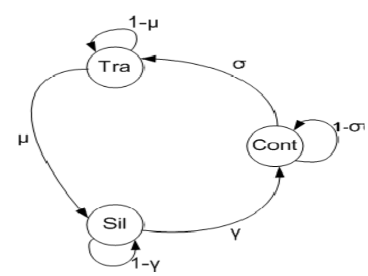

Figure 1: PRMA terminal state transition diagram

We assume a PRMA communication system with N homogeneous independent terminals, M slots per frame and p is the permission probability which is the probability that a terminal attempts to transmit a packet in an available slot when a terminal is in state Cont. Any terminal can have the following three states:

Sil the silent state
Cont the contending state
Tra the transmission state

The states can change according to the terminal's Markov state transition diagram in Fig.1. The state transition probabilities are described as following:
ζ one frame period including an uplink subframe and a downlink subframe

γ the transition probability of a terminal from state Sil to state Cont at the instant just before uplink subframe starting: If the terminal has no packet in the buffer when uplink subframe starts, it stays in state Sil; otherwise, it leaves state Sil and enters state Cont.

σ the probability of a terminal successfully transiting from state Cont to state Tra during one uplink subframe duration: We assume each terminal only attempts once during one uplink subframe. If a terminal successfully transmits the first packet, it transits from state Cont to state Tra.

μ the transition probability of a terminal from state Tra back to state Sil at the instant of the next uplink subframe starting: If there is no packet in its buffer when the next the uplink subframe starts, the terminal lets the reserved slot idle and returns state Sil. This is the way how the terminal releases channel reservation in the conventional PRMA protocol [14].
The PRMA data system is modeled as a discrete time Markov process with system state space and one-step transition probability matrix P.
$X = \{X_n = (S_n, C_n, T_n) | n \geq 0\}$
where, Sn, Cn and Tn denote the number of terminals in state Sil, Cont, Tra at time n, respectively. The state transition takes place only at the instant of uplink subframe starting.

2. Multimedia Traffic Characteristics in Support of PRMA

The efficiency of radio spectrum usage depends on a number of design parameters; one of them is the accessing technique to support a variety of traffic types. The goal of multimedia integration is to share network resources efficiently between different classes of traffic types while satisfying the individual performance requirements. PRMA is implemented on the air interface between mobile station (MS) and base station (BS) as a type of statistical multiplexing, to make full usage of the available bandwidth in transmitting different types of traffic as possible [3]. The channel is divided into time slots and the slots are organized into frames. The frame rate coincides with the arrival rate of a periodic voice packet.

2.1 Voice Traffic Representation over PRMA

Voice traffic must be delivered as a continuous stream in almost real time. More importantly, the delay must be nearly constant throughout the duration of each talk spurt. For each call duration, the talkspurt represents forty percent only because there are pauses between sentences, phrases, and even syllables. Therefore, using a speech activity detector (SAD), the information from a single source can be divided into talkspurt and silence periods. In the talkspurt period, the voice encoder generates voice packets at a constant rate, while in the silent period detected by the SAD, empty packets are generated which can be deleted at the user network interface.
With PRMA protocol and at the beginning of each talkspurt period, a user contends for an idle slot if his permission probability is within a predetermined level. Permission is granted according to the state of a pseudo random number generator. If the user succeeded in accessing a free slot, his success is acknowledged in the control information relayed in the downstream traffic from the BS to the MS. Thereafter he reserves this slot in all subsequent frames until the end of his talkspurt. The broadcast acknowledgment in the downstream traffic also informs other users of the status of the slot. When a slot, received at the BS is empty, the BS recognizes that the user relinquishes his reservation and declares the state of the slot as available for contention by other users. If the permission probability of the contending user is within the permissible value but he failed to get a free slot, the user will continue the contention process in the next frames. If the delay time of the contending packet exceeds the bounded time, it will be lost and the user will continue the contention process for the next voice packet of the talkspurt [3].
The capacity of PRMA network can be defined as the maximum number of terminals that can share the channel satisfying the required constraints. The important constraint to look at on dealing with voice traffic is the dropping probability that affects the speech quality. Voice permission probability (Pv) has great impact on speech quality, so it has to be defined carefully. In general, if the permission probability is too low, the terminal waits too long between successive transmissions and eventually drop packets as the waiting time exceeds the system limit. If it is too high, excessive collisions occur, and the resultant congestion results in high packet dropping probabilities [3].

2.2 Data Traffic Representation over PRMA

Unlike voice and video traffic, data traffic is bursty in nature. The actual proportion of bandwidth utilized is typically very small. Real time delivery is not of primary importance, but strict error control and recovery

procedures are required. Data packets arrival at each user can be modeled by a Poisson process, and data arrivals at different users are independent of each other. With PRMA protocol, the data user who has packets to transmit, attempts transmission when he encounters an idle slot and his permission probability is below the specified value. As data packets can tolerate variable delay but no loss, so data user persists on transmitting the available packets in my frame at a reasonable time delay[3].
The data rate per user and the average delay are the important parameters to be defined on dealing with data traffic. PRMA can provide a high multiplex gain (support a large number of users) for bursty data packet traffic. For congested traffic condition, PRMA can also provide high throughput and fairness with the adoption of maximum packet transmission limit. The results in [4] imply that PRMA is an ideal protocol for data transmission.

2.3 Video Traffic Representation over PRMA

A video source is represented by the transmission of a number of video frames per second. Each frame consists of a number of pixels. The pixel is defined as the smallest unit that can be encoded decoded without any future information.
Video services need higher data rate than either voice or ordinary data. Due to the bit rate limitations of the wireless medium, various methods of band compression coding are used to reduce the transmission rate of video communications. One of these coding techniques is the interframe coding method, where the information of the previous frame is used as the predicted value, and only the difference from the previous frame is transmitted. This difference is small when the scene is the same as the previous frame but increases drastically when the scene changes. Video codec can generate either variable bit rate (VBR) or constant bit rate (CBR) streams.
For video transmission over PRMA protocol, the accessing technique is proposed to be as follows:
a) If the permission probability of the video user is legal, he contends for a number of free slots equal to the number of packets in its buffer.
b) If the free slots in the TDMA frame is equal to the number of packets in the buffer, all buffered packets will be transmitted, otherwise a number of packets that is equal to the number of free slots will be accommodate and the rest will be delayed to the next frame.
c) If the time spent in the buffer exceeds the bounded delay, the delayed packets will be lost [3].
On dealing with video traffic, severe requirements are imposed on packet loss probability and delay. During the period of TDMA frame, a number of video packets is generated according to the traffic model assumed. The packets generated as a group during the TDMA frame contends for access. If succeeded, the packets occupy the available free slots. If the number of generated packets is greater than the number of available slots, the un-accommodated packets are kept in the buffer to contend in the next frame as long as the maximum delay is not violated [3].

3. Variants of PRMA

Recently modified versions of the PRMA protocol have been the subject of extensive research. Some of them are discussed in this section.

3.1 C-PRMA

C-PRMA (Centralized Packet Reservation Multiple Access) [5] is a packet-switching multiple-access protocol especially devised for a microcellular environment. Within each cell, two separate time-slotted channels are used for communication. The uplink channel conveys the information
from the MS's to the BS, while the downlink channel is used to communicate in the opposite direction. The downlink channel is exclusively used by the BS, so that no multiple access problems exist. On the contrary, the transmissions of different MS's in the uplink channel must be coordinated. For this purpose, the BS transmits slot-by-slot *commands*, which allow managing a random-access polling scheme among the MS's.
The polling commands, generated by a scheduling algorithm specify whether a slot of the uplink channel is *available* or *reserved* and identify the MS enabled to transmit. The random access is used for reservation transmission in available slots, while the polling mechanism provides the transmission coordination, in the reserved slots, among the active MS's. This is a proper approach in the microcellular environment because the small propagation delay allows a very efficient command/response communication mode, and the BS, being the interface between the radio channel and fixed network, already performs other centralized functions.
The major goal of the scheduling algorithm is to achieve efficient traffic integration (through a dynamic slot allocation) for services with different bandwidth and delay constraints. Furthermore, the flexibility in the slot assignment allows recovering corrupted packets by using retransmission techniques.
In order to efficiently operate the scheduling algorithm, each
of the MS's must signal when it enters the *active* state, i.e., when it is ready to transmit packets. This signaling procedure is performed by sending a *reservation request* in an available slot on the uplink channel. Note that all available slots can be used for reservation request transmissions. The MS remains in the *contending state* until its reservation request is successfully received by the

BS. When this event occurs, the MS starts transmitting data packets in the reserved slots, assigned by the BS, and keeps on transmitting as long as it remains active.

The core functions of C-PRMA are performed by the scheduling algorithm that dynamically assigns reserved slots

in the uplink channel to active MS's. The information needed at the BS to enable the operation of the scheduling algorithm is provided by the MS's. The parameters that specify the service class (i.e., voice, data, packet rate, etc.) and service quality (i.e., priority level, maximum tolerable packet delay, etc.) are negotiated between MS's and the BS at the call-setup phase. Each reservation, in addition to a request to transmit, also contains the indication of the delay already suffered by the first packet of the burst. The latter information is used by the scheduling algorithm. Furthermore, in addition to the reservation information transmitted on the uplink channel, the C-PRMA implementation requires the transmission of "commands" at each slot from the BS to MS's. To accommodate the transmission of this additional information, the slots on the downlink channel are taken long enough to contain a data packet and a command. The same slot length is assumed in the uplink channel. In fact, in such a slot, an acknowledgment for the data packet correctly received by the MS on the downlink channel must be transmitted in addition to data packet or reservation information. The immediate acknowledgment is needed at the BS if a quick recovery of error packets is necessary to meet a given quality of service for real-time traffic. Notice that the acknowledgment for an uplink data packet transmission is not needed in the downlink channel, as the BS can account for not correctly received packets by repeating the polling command to request the transmission of the failed packet.

3.2 D-PRMA

D-PRMA (Dynamic Packet Reservation Multiple Access) is a medium access control protocol for wireless multimedia applications [6]. It allows the integration of both constant bit rate (CBR) and variable bit rate (VBR) traffic through a single access control mechanism that permits users to specify their bandwidth requirements. Users are allowed to repeatedly update this information in order to reflect any changes in their data rates. A base station analyzes the mobiles' requests, determines which can be accommodated, and conveys the resulting bandwidth assignments to the users. The ability of a mobile to initially reserve a portion of the channel capacity and to then dynamically alter this reservation is a primary feature of the system. In DPRMA, an attempt is made to match the capacity assigned to the user with the user generation rate. Furthermore, this capacity can be allocated using fractional or multiple slot assignments.

The primary difference between CPRMA and DPRMA is the manner in which reservations are made and resources are allocated for VBR sources. The slots within a DPRMA frame are divided among the users based on the amount of bandwidth that each user requires. Users may reserve a number of slots within a frame or even slots in alternating frames, as long as that capacity is currently available. In addition, changes to a user's allocation request can be easily accommodated. The base station in the cellular environment has the responsibility of dividing the bandwidth up among the active users. In order to accomplish this task, each mobile must be able to convey its requirements to the base station. In the DPRMA scheme this is performed by setting aside several Reservation Request (RR) bits within the header of each uplink time slot. It is the user's responsibility to determine the appropriate rate reservation required and set its rate bits accordingly.

When a user has a new burst of information to transmit it must first attempt to obtain a reservation. It sets the appropriate RR bits to indicate its rate request, contends for an empty slot, and monitors the downlink channel to determine its success or failure status from the base station. This is indicated via several Reservation Acknowledge (RA) bits in the header of the downlink messages. When a successful transmission has occurred, the base station immediately attempts to accommodate as much of the rate requested as is possible. If the total request cannot be fully accommodated, then a partial allocation is made. The base station keeps a record of any partial allocations so that the remaining request can be accommodated whenever the bandwidth later becomes available.

If a full allocation is possible, the base station must determine which of the remaining unclaimed slots will be assigned. The base station first identifies which slots are currently unallocated and determines how many such slots exist. Next, the base station examines each of these slots in sequential order to determine if the slot will be assigned to accommodate the new request. Throughout the process, the base station maintains a record of how many slots, S_n the user still needs in order to have its request satisfied. Every time a slot is successfully assigned, S_n is decremented. In addition, the base station keeps track of the number of available slots, S_c, that have not yet been considered for assignment. Each time a new slot is considered, S_c, is decremented. As the base station sequentially considers each available slot, it assigns each one with probability P_a, where

$$P_a = S_n / S_c$$

Once a user has secured a reservation, it must monitor the downlink channel to determine in which slots it is allowed to transmit. This is indicated via several Slot Reservation (SR) bits that are incorporated into the downlink message header. Any changes to a user's reservation requirements are communicated by the user to the base station via the RR bits. An increase in reservation is accommodated if the resources are available.

When a rate decrease is requested by a user, the base station first determines which slots are currently assigned to that user. The base station then considers each of these slots one at a time in sequential order for deallocation purposes. The number of slots yet to be released, S_d and the number of slots yet to be considered for release, S_r are constantly updated throughout this process. Each slot is released with probability

$$P_d = S_d / S_r$$

After the slots have been deallocated, the base station determines if there are any users waiting for additional slots to be assigned. The backlog of such users is handled in a first-come first-serve basis, and as many users as possible are accommodated.

3.3 DD-PRMA

Designing an efficient MAC protocol to support the real-time services in distributed wireless networks is difficult. This is mainly because 1) no fixed central entities like base terminals can be used by the MAC layer in these networks to coordinate communications, the centralized scheme used difficultly; 2) high dynamics of network topology caused by terminal mobility since any terminal may join and leave an MANET in an unpredictable manner; 3) real-time applications often have some requirements on quality of service (QoS) such as time delay bound.

DD-PRMA (Dynamic Distributed PRMA) [7] emphasizes on voice application in distributed wireless networks which combines 802.11 DCF and PRMA's advantage. In DDPRMA protocol, the access mechanism of voice and data is different.

Access Procedure for Voice Packets

The medium access procedure for voice terminals can be separated into three states. One corresponds to the Contending state, where the terminals contend to access the medium for reservation, and the other corresponds to the Reservation State, where voice terminals transmit their packets periodically without any contention. Initially, each terminal will stay in the Idle State. The access procedure which is modified to apply the distributed wireless networks is based on PRMA protocol. In order to maintain the correct access sequence, each terminal needs a sequence ID (SID) table, which record the time slot reserved by the voice terminals.

If a terminal with voice packets intends to access the channel at time t, first it will inquire about the SID table to find if there is any slot reserved.

If not, the terminal will send RF frame to the destination terminal to reserve the channel and it will enter into contending state. The RF frame is a broadcast frame that each terminal could receive it. It indicates a time frame is beginning if reserving channel successfully. If no collision occurs, the terminal will receive CTS packet after a time interval (SIPS). It means this terminal reserve the channel successfully; the terminal will enter into reservation State. Then it will send voice packet periodically. From now, the channel is divided into frames with a fixed and equal size along the time axis.

A frame is divided into N slots which used to transmit voice or data packets. The terminal will transmit the voice packets periodically. The SID table's content will be refreshed when the terminal receive the CTS packet from any other terminals.

If by inquiring SID table, the terminal find one or more slots is reserved, the voice terminal will send RTS packet to the destination to reserve the slot and it will enter into contending state. In order to reduce the probability that two or more terminals wanting to reserve the same slot in the frame, the terminal will select the first slot which has not been reserved in probability P_v.

If the sender receives the CTS packet sent by the receiver successfully, it has got the reservation of this slot and transmits its voice packet immediately. Thus the terminal will enter into reservation state. A successful reservation of a packet must also meet the follow three conditions:

1) the slot is available
2) the terminal has the permission to transmit
3) no other contending voice terminals

It will transmit its BF frame and voice packets periodically in the same slot of every frame until it doesn't have the voice packets. The recording of time slot reserved of BF frame is consistent with the SID table. So the new terminal which enters into the networks could know which slot has been reserved in a time frame timely. If there are more than two terminals are selecting the same slot, reserving will failed, the voice terminal will still try to select the next first non-reserved slot in frame also in probability P_v. If the wait time is long than the D_{max} which is the maximum delay time for voice packets, the terminal will discard the voice packet.

Access Procedure for Data Packets

When there is no voice packet transmitting in networks, the basic access method for data packets is based on DCF. A terminal with a data packet waiting for transmitting should sense the medium until an idle duration DIFS is detected. Then the terminal will attempt to transmit after a random delay applied by a backoff counter. The backoff counter decrements one by one after each slot time. And when the backoff counter reaches zero the terminal transmits its packet immediately and waits for reception of an acknowledgement (ACK) from the destination after a time interval called short interframe space (SIPS). However, if during any slot time the channel is sensed busy (due to transmission of other terminals) down-counting is stopped and after sensing the idleness of the

channel for a period of DIFS the backoff process will be resumed.
If no ACK is received by the transmitting terminal, due to assumption of ideal channel conditions, packet collision has occurred and retransmission is carried out according to the binary exponential backoff rules.
As soon as a data terminal has a packet in its buffer, it will attempt to transmit on the first available unreserved slot which is not contending by other voice terminals in probability P_d.
A successful transmission of a packet must also meet the follow three conditions:
1) The slot is available 2) the terminal has the permission to transmit and no other contending voice terminals 3) and no other data terminals permission.
However, a successful transmission does not provide the data terminal with an additional reservation. Data terminals must contend for each packet transmission.

3.4 CS-PRMA

Carrier Sense Packet Reservation Multiple Access (CS-PRMA) [8] protocol is proposed for Wireless Local Area Networks (WLAN). The protocol can be viewed as a combination of CSMA with adaptive permission probability for contentions and TDMA for reserved transmissions. The key point of the CS-PRMA is to use very short busy signal in front of a shortened voice packet to declare that the available slot is now occupied. If a terminal in the contention state has not received the busy signal at the minislot, it may send busy signal and its shortened packet from the next minislot, with a greater permission probability than at the first minislot. The successful transmission of the first packet of, a talkspurt will reserve the slot to the terminal for the transmission of ordinary packets in the whole talkspurt. As the original PRMA, the CS-PRMA system has the properties of soft capacity, soft hand-over, and distributed slot assignment and selection. The basic feature that characterizes CS-PRMA with respect to basic PRMA is its very high channel efficiency.
This protocol is suitable for an environment with low propagation delay, as in indoor and microcellular systems.

3.5 CDMA/PRMA

Joint Code Division Multiple Access Packet Reservation Multiple Access (CDMA/PRMA) [9] protocol was introduced as a candidate for an uplink protocol for third generation mobile communication. Whereas in Packet CDMA the time axis is unslotted and packets are granted random access to the channel, in Joint CDMA/PRMA the time axis is slotted, with the slots grouped into frames (as in PRMA) and the access of packets to the channel is controlled such that the channel load is kept as near as possible to an optimum in terms of maximum throughput. This will result in increased throughput and hence increased spectral efficiency compared to a random access DSCDMA system. **A** channel access function, which relates the number of users in a given slot to the permission probability in the same slot of the subsequent frame, controls the access to the channel.
Capacity is defined as the supported system load (in terms of number of simultaneous conversations) for a given maximum packet loss ratio. Both packets dropped by the MAC layer (as in conventional PRMA) and packets corrupted on the channel due to Multiple Access Interference (MAI) will contribute to this packet loss.
Terminals can send three types of information, namely “periodic”**,** “random”, and “continuous”. Speech packets are always periodic, but data packets can be random (isolated packets), periodic or continuous, depending on the source nature. Each downlink (base to mobile station) packet is preceded by feedback based on the result of the most recent uplink (mobile to base station) transmission. If the base is able to decode the header of one or more arriving packet(s), the feedback identifies the packet sending terminal(s), indicates which of the corresponding packets were received successfully, and transmits the new permission probability that is valid for the corresponding slot in the next frame.
The transmission time scale is organized in frames, each containing a fixed number of time slots. The frame rate is identical to the arrival rate of voice packets. In contrast to conventional PRMA, terminals do not classify slots as either “reserved” or “available”, as the channel access for contending terminals is governed by time-varying permission probabilities.
A terminal that generates periodic data (e.g. speech data) switches from contention to reservation mode as soon as a successful packet reception is acknowledged by the base station. It will stay in reservation mode until the last packet of the current spurt is transmitted. The base station counts all the packets sent from periodic terminals in each slot such that it can compute the permission probability for the same slot in the next frame with the channel access function and then transmits it in the feedback.

3.6 CDMA/NC-PRMA

The joint CDMA/PRMA protocol is essentially an extension of the conventional PRMA protocol operating in a DS/CDMA environment. During a time-slot period, a certain group of terminals have their quotas to transmit using the direct sequence (DS) spread-spectrum scheme. The time axis is divided into slots, which are grouped into frames, as in PRMA. The frame rate is identical to the packet arrival rate of voice terminals so that a voice terminal may periodically transmit a packet during a frame interval. On the uplink carrier, a number of information channels, separated by different spreading codes, are dynamically assigned to terminals for information transmissions. As for downlink transmission, each downlink packet is preceded by a feedback message in response to the results of the most recent uplink transmissions. If the BS is able to decode the header of one or more arriving packets, the feedback message identifies the packet-sending terminals, indicating which of the corresponding packets were received successfully, and transmits the available permission probability of the corresponding slot in the next frame.

In the original PRMA, each contending terminal conducts a Bernoulli experiment with a predetermined permission probability as the parameter. If the outcome is positive, the terminal is granted to transmit. The essence of the joint CDMA/PRMA protocol is the use of the CDMA scheme in connection with the PRMA protocol with a dynamic permission probability in response to the variation of the number of reservation users. The BS, obtaining information from the packet headers sent from the reserving terminals in a current slot, calculates the available permission probability of the corresponding slot in the next frame via a channel access function. Thus, the contending terminals can contend for a reservation according to this permission probability.

The main idea of NC-PRMA [10] is the use of a time–frequency signaling scheme by which the BS can learn the service requests from all dispersed terminals. Thus, the BS can have a centralized control over the slot allocation policy. Moreover, the signal strengths of signatures from specific users may indicate the current transmitted power levels in the corresponding information slots. The NC-PRMA access scheme is suitable for wireless multimedia communications. The reasons are summarized twofold:

One is due to its excellent design of the time–frequency signaling mechanism that offers an easy way for terminals to inform their bandwidth demand to the BS without collision and the other is the operation of centralized control over a slot allocation policy. Thus, using NC-PRMA as the underlying TDMA architecture, joint CDMA/NC-PRMA protocol is a centralized and frame-based protocol, which enables us to design two slot-assignment schemes to further reduce the MAI variation.

3.7 Explicit CDMA/PRMA

An explicit code-division multiple access/ packet-reservation multiple access (CDMA/PRMA) [11] protocol is proposed in response to the disadvantage of the conventional CDMA/PRMA protocol, the permission probability of which estimated from the channel access function limits the access efficiency when the overall system load remains low.

In explicit CDMA/PRMA, the slot assigned to a contention success mobile terminal is no longer in the same time domain in which the contention packet is successfully demodulated. Before the base station decides to assign a slot to the contention success mobile terminal, it scans all time slots and picks out the time slot whose traffic load is smallest among all the time slots in one frame. The base station will attach this time slot mark just after contention success is acknowledged. The corresponding mobile terminal shall receive both positive acknowledgement and the attached time slot mark. It then buffers the traffic packets and transmits them in the corresponding assigned time slot. Such a mechanism guarantees the smoothness of the overall traffic load in one frame, and in return increases the system capacity. Since the base station specifies explicitly the reserved resources, this protocol is called explicit CDMA/PRMA.

The simulation results show that the explicit CDMA/PRMA protocol performs better when the simultaneous conversations load is low.

3.8 JPPS

Joint PRMA and packet scheduling (JPPS) [12] treats real-time traffic and non-real-time traffic separately. Once a real-time traffic flow (a continuous packet burst) is admitted to the system, its code channel(s) will be implicitly reserved until its last packet is transmitted, as in PRMA. Real-time traffic has delay priority over non-real-time. Packet scheduling techniques are then used to schedule all the real-time and non-real-time packets.

As in PRMA, once an RT traffic flow (a continuous packet burst) is admitted into the system, the code channel(s) which guarantee the QoS requirements of the traffic will be reserved for the terminal until its last packet is transmitted. Unless a "reserved" terminal is informed by the BS of the change of slot allocation, the terminal will automatically continue to use the previous slot allocation scheme. As such, in contrast to the scheduling based MAC protocols, the downlink signaling overhead can be mitigated. At the end of every frame, the BS examines the slot allocation status and reallocates the reserved terminals if necessary.

Taking the delay-insensitive nature of the NRT traffic into account, we schedule the NRT terminals to transmit with lower priority compared to RT traffic flows, in which the packets have to be discarded if exceeding the time-out value. After allocating all the RT traffic using the packet scheduling algorithm, the BS will select an NRT terminal to transmit if there are still available code channels. No reservation applies to NRT terminals. This procedure will continue until all the free code channels have been filled or no NRT packets are backlogged.

Although the NRT terminals need to wait longer when the traffic load is heavy, the RT terminals benefit, and in turn the overall performance of JPPS is considerably improved, when the traffic load is below a certain threshold.

3.9 PRMA with Random contention

PRMA with random contention [13] does not depend on a predetermined permission probability as in the original PRMA. In this method, terminals select the contention slot uniformly from the pool of remaining free slots in the current frame.

Contention scheme in PRMA is based on permission probability, terminal that has packets to transmit can contend on the slot only if it has a permission to contend, this type of contention is useful for avoiding collision. For maximum system capacity, permission probability should be small because increasing this permission probability leads to excessive number of collisions. Also reducing the permission probability beyond a certain value leads to a poor utilization for free slots.

PRMA with random contention reduces the number of simultaneous contention on a specific available slot. This random contention scheme is based on the fact that available slots are known in advance. Therefore, rather than allowing all ready active stations to contend on the first available slot, we limit this number of simultaneous contention by allowing for each active terminal to select its expected available slot randomly from the pool of remaining free slots in the current frame. The new scheme still has the maximum capacity that is reached by the permission contention scheme.

The main features of this approach are reducing average packet delay at high traffic rates and reducing number of wasted slots for low traffic rates.

4. Conclusion

This paper presents a classification of MAC protocols for wireless networks. PRMA can be viewed as a combination of TDMA and slotted ALOHA protocols. PRMA can also be seen as a kind of statistical multiplexing scheme. Statistical multiplexing gain comes from the fact that speech terminals are equipped with speech activity detectors and thus they transmit packets only during talkspurts. The characteristics of PRMA for different traffic types and different variations of PRMA protocol are also presented in this paper.

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