SND-MAC: An Efficient Media Access Control Method for Integrated Services in High Speed Wireless Networks

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Abstract

With the development of the wireless communication technology, a wide range of services such as the voice, video, and data communication should be provided to users. To support integrated services, efficient Medium Access Control (MAC) methods should be developed. In this paper, a new MAC, reservation-scheme and contention-scheme combined, termed the Sequence Number based Dynamic MAC (SND-MAC), is proposed to efficiently realize the integrated service in wireless communication networks. The SND-MAC can fit for the integrated service overload in the network adaptively to keep the performance always good. The reservation scheme used in the Heavy Overload Mode (HOM) of the SND-MAC is different from traditional ones in the sense that wireless terminals need not send reserve requests which will cause collisions to the control center. The method can greatly improve the channel utility. Under the HOM of the SND-MAC, there are no collisions during the communication. No slots will be wasted and the frame can be fully utilized. Moreover, no hidden terminal problems will happen. The SND-MAC will improve the system performance significantly, especially in the case where the integrated communication overload in the wireless network is heavy. It allows the voice, video and data terminals to share the wireless channel efficiently, and makes it possible to realize integrated services based on wireless networks efficiently. The SND-MAC can also be applied to wired networks with the control center, such as HFC (Hybrid of Fiber and Cable) networks.

1. Introduction and Background

In recent years, wireless communication technology has advanced rapidly, especially on how to realize real-time multimedia communications based on wireless communication networks. Multimedia applications integrated into wireless networks (we discuss centralized wireless communication networks here) have driven recent research to develop wireless architectures to satisfy the demand of such advancements. Particularly, designing an efficient MAC protocol for wireless networks is a key issue. Much work [1-15] has been completed on the MAC layer of wireless communication networks recently. The contention-based scheme (CSMA/CA, etc) is widely used in the existing MAC methods. For example, the time non-sensitive data communication is always based on contention scheme. Even in the Centralized Wireless Network (CWN), using the MAC methods to realize the integrated service, the contention scheme is used more or less. For example, the most commonly used REQ/ACK reservation scheme, in which the terminal that wants to reserve the channel will send a REQ message to the control center such as Base Stations. The control center will reply with an ACK message to assign the terminal a channel. REQ messages from terminals will be transmitted based on the contention scheme. In the Packet Reservation Multiple Access (PRMA)[1,4], the first voice packet of a talk-spurt is transmitted based on a contention mechanism although other packets of a talk-spurt are transmitted under the reservation technique. As we know, under the light overload situation, the contention scheme can work well. However, when the overload is heavy, the throughput of the system will become worse. The more the active terminals, the worse the network performance due to the high probability of collisions of the packets. When using carrier sensing technologies, the hidden terminal problem in the wireless environments will further increase the probability of collisions. Although the Busy Tone method was suggested to avoid the hidden terminal problem, an additional channel is needed to transmit the channel busy message. This will reduce the channel utility which is important for the wireless network. In a word, for the heavy overload wireless network, the contention scheme

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will degrade the performance, especially for real-time communications.

For the traditional reservation methods, when a terminal succeeds in reserving sub-channels for real-time communications, reserved sub-channels will be occupied by the terminal all the time even when it has no data to send. Only after the reservation is finished, reserved sub-channels can be re-used by other terminals. The following case will often happen in the traditional reservation scheme such that some terminals reserve sub-channels but not fully use them while other terminals have a sub-channel shortage. Such a reserved-but-wasted problem will degrade the channel utility, especially under the heavy real-time communication overload. On the other hand, for the real-time communication such as the voice communication, there are no voice data needed to be sent out for much of the time during the talk due to the silence. We can see that the traditional reservation method is not efficient, especially under the heavy overload situation.

In this paper, a new MAC, reservation-scheme and contention-scheme combined, termed the Sequence Number based Dynamic MAC (SND-MAC), is proposed to efficiently realize the integrated service in wireless communication networks. The SND-MAC can fit for the integrated service overload in the network adaptively to obtain good performance all the time. The novel reservation scheme used in the Heavy Overload Mode (HOM) of the SND-MAC is different from the traditional ones in the sense that wireless terminals need not send reserve requests which will cause collisions to the control center. The method can greatly improve the channel utility. Under the HOM of the SND-MAC, there are no collisions during the communication. No slots will be wasted and the frame can be fully utilized. Moreover, no hidden terminal problems will exist. The SND-MAC will improve the system performance significantly, especially in the case where the integrated communication overload in the wireless network is heavy. It allows the voice, video and data terminals to share the wireless channel efficiently, and makes it possible to realize integrated services based on wireless networks efficiently.

The paper is organized as follows. Section 2 describes the SND-MAC in detail. Section 3 shows its applications in different kinds of wireless and wired networks. Section 4 gives conclusions and future directions of this research.

2. The Description of the SND-MAC

2.1. The Network Model and Assumptions

A network with a control center and some terminals (wired or wireless connected) is our research object. There are two different channels for communications in the network model. One is referred to as the upstream channel: from terminals to the control center and the other is referred to as the downstream channel: from the control center to terminals. The channel utility for the downstream channel is relatively high since data packets are sent by the control center only. We will focus on the upstream problem in the following part. With the SND-MAC, the downstream performance will be made even better.

Consider such a network with a control center and N (N is not very large) different terminals. The terminals are sequenced initially and every terminal has its own sequence number which is not an indication of the priority. The number should be continuous, from 1 to N. The sequence number for each terminal can be adjusted later. Good synchronizations and lower Bit Error Rate (BER) is assumed (the high BER case for wireless environments will be discussed later). The SND-MAC has two operation modes. One is Heavy Overload Mode (HOM) (for heavy communication overload case) and the other is the Light Overload Mode (LOM) (for light communication overload case).We discuss the HOM first.

2.2. The Description of the HOM

In this mode, since the communication overload is heavy, the contention-scheme MAC will degrade performance. Organized data transmission should be adopted to improve the channel utility. With the help of the sequence number for every terminal, the throughput of the system can be relatively higher.

2.2.1. The Format of the Frame Structure of the HOM

Time Division Duplex (TDD) is assumed for the SND-MAC (Frequency Division Duplex can also be used). The length of the upstream and downstream frames is fixed (as we should guarantee the Constant Bit Rate (CBR) for the voice communication). The upstream frame is composed of two parts. One is the *reservation part* and the other is the *upstream data part* which is composed of three sub-parts. The downstream frame is also composed of two parts. One is the *reservation reply part* and the other is the *downstream data part*. The frame structures are shown in Figure 1 and Figure 2.

The diagram of a reservation process is shown in Figure 3. At the start of the *nth* upstream frame, terminals that want to send data (voice, video or the time non-sensitive data, etc) should send reservation information in the *reservation part* of the upstream frame. The *reserve reply part* of the following downstream frame will bring the modified reservation information to all the terminals based on the *reservation part* of the *nth* upstream frame. From the *reservation reply part*, the terminal sending reservation information in the *nth* upstream frame will know which slots it should occupy to send the data in the *(n+1)th* upstream frame. That means the *reservation part* of the *nth* upstream frame is to reserve the *data part* of the *(n+1)th* upstream frame. The reservation is based on each frame (no reserved-but-wasted problem will exist) and the terminals should reserve the slots for all kinds of data transmission(voice, video or the time non-sensitive data, etc).

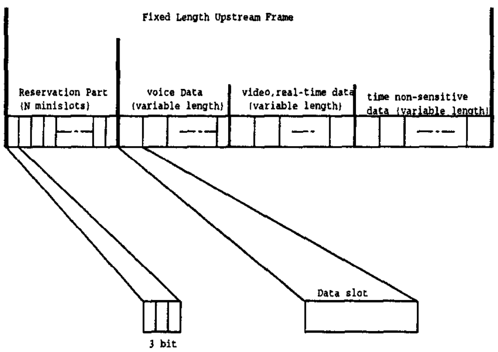

Figure 1. The Structure of the Upstream Frame

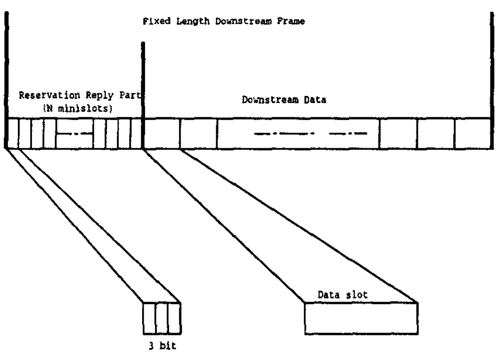

Figure 2. The Structure of the Downstream Frame

2.2.2. The Detailed Description of the HOM

The *reservation part* is composed of *N* minislots .Every minislot is *3 bits* long (The number of bits can be adjusted according to the system requirements) and each terminal reserves *1* minoslot. The terminal having the sequence number *m*, is assigned the *m*th minislot of the *reservation part.* The definition of the *3-bit* minislot is shown below (Suppose the video type terminal can request 0 slot at least, 5

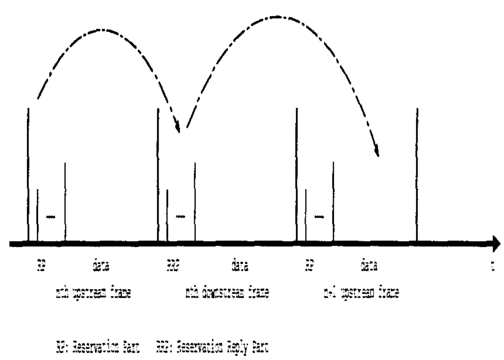

Figure 3. The Diagram of the Reservation Process

slots at most every time for each upstream frame):
000: No reservation (default value);
001: Normal Data Transmission;
010: Video (or real-time data) transmission, 1 slot required;
011: Video (or real-time data) transmission, 2 slot required;
100: Video (or real-time data) transmission, 3 slot required;
101: Video (or real-time data) transmission, 4 slot required;
110: Video (or real-time data) transmission, 5 slot required;
111: Voice transmission (default 1 slot);

The *data part* of the upstream frame is composed of three sub-parts (voice type, video type, and normal data type). The length of the slot in different parts can be different. For example, the slot in the normal data sub-part can be longer than that of the voice sub-part. Sub-parts are length-variable depending on how many termianls are active.

When the *reservation part* of an upstream frame arrives at the control center, the control center will modify every minislot of it based on the priorty of the service, the available length of the upstream frame, etc. For example, *001* (Normal data transmission reservation) may be modified to 000 (No reservation which means the control center refuses the reservation); 101 (video transmission reserve, 4 slots) may be modified to 010 (video transmission reserve, 1 slot). After the modification, in the *reservation reply part* of the downstream frame, which has the same format as the *reservation part,* the control center will send the modified *reservation part.* The *mth* minislot (3 bits long) of the *reservation reply part* is for the terminal with the sequence number *m.* Every terminal should receive the *reservation reply part* and after simple calculations, it is aware of which slot it should occupy in the coming upstream frame. The following example shows the process of the reservation (assume *N=8*).

Suppose at the start of a certain upstream frame, terminals *1, 3, 4* want to send the voice data. Terminals

2, 8 want to send the video data (all request *3* slots) and terminals *5,7* want to send the normal data. The *reservation part* of the current upstream frame will look like *111100111111001000001100*. When this *reservation part* arrives at the center, the center will modify it based on the system requirements. Suppose the control center refuses terminal *7* which attempts to send normal data, and re-assigns *2* slots for terminal *2* to send video type data. After the modification, the *reservation part* will look like *111011111111001000000100*. The center will send it back to all terminals in the *reservation reply part* of the following downstream frame. Every terminal will receive the *reservation reply part* and will calculate their reserved slots based on that. For the voice terminal, terminal *1* will occupy the first data slot in the voice sub-part. Terminal *3* will calaulate the number of slots occupied by the voice terminals before it based on the scan of the received *reservation reply part*. It is *1* in this example, and it will send the voice data in slot *(1 + 1)* in the voice sub-part. As to terminal *4*, the number of slots occupied by the voice terminals before it is *2*, and it will know to send the voice data in slot *(2 + 1)* in the voice sub-part. For the video terminal, first it will calculate the total number of slots occupied by the voice terminals in order to decide the start of the video sub-part. It is *3* here. After that, terminal 2 will calculate the number of slots occupied by the video terminals before it. It is *0*. Then terminal 2 will occupy the first two slots (The minislot of it is modified to be *011* by the control center) in the video sub-part. Terminal 8 will occupy the *3rd,4th and 5th* slot of the video sub-part after the same calculations. The process will also be executed by the normal data terminal *5* which will occupy the first slot in the normal data sub-part. Terminal *7* needn't calculate when it finds that its minislot has been modified to be *000*. The calculation is done independently and parallelly in every terminal.

It is pretty clear that no collision will occur at any time and no data slot will be wasted. Since the reservation is based on each frame, the reserved-but-wasted problem can not exist and the CBR , VBR (variable bit rate) services can be supported with high efficiency. The length of the sub-parts is variable depending on how many terminals actually reserve slots, which is efficient especially for the heavy communication overload case. The system throughput will be improved significantly.

The SND-MAC will first satisfy the voice communication, the video and real-time data next, and the normal data last. If many real-time terminals attempt to send the voice, video or real-time data and occupy most of the space of one upstream frame, since sub-frames are all length-variable, the length of the normal data sub-part will become very short. This is rational because the real-time service should have the higher priority than the normal data communication. However, the control center should balance the different services by modifying the *reservation part*.

The modification of the *reserved part* of the upstream frame by the control center is very important. The strategy of the modifications can be different in different network environments. The following is some issues that should be considered during modifications: (1) the priority of the services (voice first, video second and normal data last);(2) the available length of the upstream frame since the total length that has been reserved for each upstream frame should not exceed the fixed frame length); (3) for the real-time service, an on going call has the higher priority than a new call.

In the HOM, there will be no collisions, nor wasted slots, but some reservation information overhead. It is obvious that the upstream channel utility for the HOM will be *close to one* if the reservation information overhead is trivial compared to the overall communication overload. We can draw the conclusion that if we can keep the sequence number structure for the terminals efficiently, the HOM of the SND-MAC can support the integrated communication pretty well under the heavy communication overload case.

2.3. The Description of the LOM

Suppose the number of terminals in the network is *N*. There are $3*N/8$ bytes in every upstream frame and every downstream frame for the reservation information. With such overhead, the performance in the network will be improved under the heavy overload. However, when the communication overload is light, most of the reservation bits will be zero. leaving the reservation field not fully used is inefficient. In this case, the SND-MAC should work in the Light Overload Mode (LOM). The terminals are to use the modified REQ/ACK to reserve the sub-channel for real-time communication and the contention-based scheme for normal data communication. Since the overload is light, the probability of collisions caused by packets in the upstream channel will be low. The overhead for the reservation information can be avoided, too. It is proved that in the light real-time communication overload, the REQ/ACK (or PRMA) method can work well. When the center finds that the *average* upstream overload is below a gate value, it will change the SND-MAC working mode to the LOM. Otherwise, the SND-MAC will work in the Heavy Overload Mode (HOM). The upstream frame structure and the downstream frame structure are shown in Figure 4 and Figure 5, respectively.

In the upstream frame, the length of two real-time sub-frames is fixed now. In the voice sub-frame, the REQ field has *M* minislots and the voice data field has a number of sub-channels. Because terminals have sequenced numbers, it is easy to divide them into *M* groups. The grouping method can be defined by users. As an example, one grouping method can be as follows: terminals from *1* to $\lfloor N/M \rfloor$

belong to group *1*, terminals from $\lfloor N/M \rfloor$ to $\lfloor 2*N/M \rfloor$ belong to group $2 \cdots$, terminals from $\lfloor N*(M-1)/M \rfloor$ to N belong to group M. Following is another grouping method: the terminal with sequence number x belong to group $x \bmod M$. Terminals of group s will send their REQ messages in the *sth* minislot in the REQ field (using Carrier Sensing technology). Because the number of terminals in each group is $\lfloor N/M \rfloor$, the probability of collisions will be further decreased. If REQ messages reach the center successfully, the center will assign sub-channels to the terminals and send back ACK messages. When a terminal receives the ACK message, it will know in which sub-channel it can send the data. For the normal data communication part, contention-scheme data transmission can be used. Different network environments can select different contention-schemes, for eaxample, slotted CSMA/CA with the Busy Tone can be modified a little to be used in most of the cases.

The performance analysis of the REQ/ACK method under LOM is given in many papers in detail and we will not discuss here. Since we use the grouping method to reduce collisions, the performance of LOM can be better.

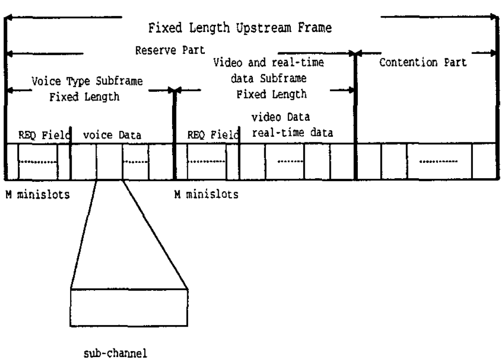

Figure 4. The Structure of the Upstream Frame in the LOM

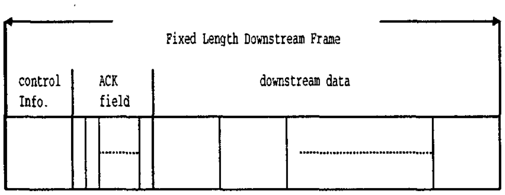

Figure 5. The Structure of the Downstream Frame in the LOM

3. The Applications of the SND-MAC

3.1. The CWN with Fixed Wireless Terminals

In the CWN with fixed wireless terminals, a control center normally covers a number of wireless fixed terminals. Terminals can not move randomly, for example, wireless transceivers for families. The SND-MAC can be easily applied. Sequence numbers can be preset for wireless terminals. When terminals are deleted or added, the center sends control information to terminals in its covered area to adjust sequence number. For the wireless network of fixed terminals, the communication speed can be very high using the SND-MAC. The QoS communications can be strongly supported, and the throughput of the system can be greatly improved.

3.2. The CWN with Moving Terminals but Only One Control Center

In the CWN with moving terminals but only one control center, the Control Center covers a number of wireless terminals. The terminals can move, but should not move out of the coverage of the Center (for example, the centralized wireless local area network for a building). The SND-MAC can be used here efficiently. Every moving terminal can be assigned a sequence number. When terminals are deleted or added, the control center sends control information to terminals in its covered area to adjust the sequence number. For the CWN with moving terminals but only one control center, using the SND-MAC, the QoS communication can be realized efficiently. The throughput of the system can be greatly improved.

3.3. The HFC network

In the HFC network, the header of the HFC is the control center. There are also the upstream channel and the downstream channel for HFC networks. The SND-MAC can be easily used. Each terminal can be assigned a sequence number first. When some terminals are deleted or added, the header sends some control packets to the terminals to maintain the sequence number structure. Using the SND-MAC, real-time communications can be strongly supported in the HFC network and the throughput can be improved.

3.4. The Cellular Wireless Network

In the CWN with fixed wireless terminals, the CWN with moving terminals but only one control center and the HFC network, the SND-MAC can be efficiently applied since it is easy to keep the sequence number structure.

In the Cellular Wireless Network, for a given cell, there is a BS (Base Station) and a number of terminals. However, the terminals often move in or out of this cell referred to as the handoff problem. It is not easy to keep the sequence number structure. If the handoff is very frequent, which means terminals frequently move in or out of the cell, the SND-MAC will perform worse due to the cost to maintain the sequence number structure. If the handoff is not frequent, the SND-MAC can be used efficiently, especially in the case that every cell has heavier communication overload but infrequent handoff. The heavier the communication overload in one cell and the lower the frequency of the handoff, the better the SND-MAC performs than other methods. A simple method to maintain the sequence number structure in cellular networks is given below.

When one moving node enters a cell, the BS will assign a sequence number *N+1* to it (*N* is the largest sequence number of the current cell). At the same time, the number of total nodes will be broadcasted to all the nodes in the cell by the BS.

When one node exits a cell, the BS will delete its sequence number. The BS will send a control packet for "deleting one sequence number in the network" to every node in the cell. Every node will check if that number is greater than the sequence number of itself. If that number is less than the sequence number of itself, the node will decrease its sequence number by one. Otherwise, leave the sequence number of itself unchanged. At the same time, the total number of nodes will be broadcasted to all nodes in the cell by the BS.

3.5. The High BER Case

In the wireless environments, the BER is often high. We want to see how this affects the SND-MAC. There are two issues we should consider.

If the reservation information transmitted by the center in the downstream channel is incorrectly received by terminals, because each terminal calculates its slot independently, only the terminals incorrectly receiving the reservation information will calculate the slots incorrectly. Because of the wrong calculation, such slots will be wasted due to collisions. If m terminals receive the reservation field (for voice) incorrectly, then $2m$ slots (for voice) at most will be wasted. We should apply some methods to reduce the BER of the reservation field, such as using better channel coding scheme for reservation field, using more bits to represent the reservation, etc.

When the center attempts to adjust the sequence number, for example, deleting a sequence number from the network, if terminals receive the control information incorrectly, it will adjust its sequence number incorrectly. Then collisions will occur in the reservation field. The center will detect the collision, and the collision part will be reset to zero. By this way, the terminal of the error sequence number can not send its data when calculating (its reservation bit is zero). Although one other terminal will be affected (it cannot send data either due to the zero reservation bit), no slots in the upstream frame will be wasted in this case. In the meantime, the control center can be aware of which terminals have error sequence numbers and will notify them.

4. Conclusions and Future Work

We have designed a new MAC method to support integrated services based on wireless networks. This method can achieve good performance all the time by adaptively selecting its working mode. This will improve the efficiency of the network bandwidth significantly especially in the heavy overload case. Under the HOM, the collisions in the upstream channel can be avoided and no reserved-but-wasted problem or hidden terminal problem will exist. For every terminal, it can reserve data slots easily and efficiently without sending any request packet. The high BER case is discussed. The channel utility of the upstream is greatly improved which is very important for the real-time multimedia communication for wireless networks. The SND-MAC can speedup the QoS communication of the CWN. Furthermore,the SND-MAC can be used not only for the centralized wireless communication network, but also for the normal wired network with the control center. In a word, the SND-MAC will efficiently support the realization of the integrated services. It is worth while to put continuous efforts in this and related research areas, including a simpler implementation of the SND-MAC.

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