# Performance Evaluation of Point-to-Point Scheduling Strategies for the ADHOC MAC Protocol

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*Abstract*— **The complexity of resource management in a wireless environment lies in the shared nature of the medium. The capacity of any wireless network is determined by the capability of the medium access control mechanism to handle the access process and to achieve high resource reuse. The ADHOC MAC protocol allows the exchange of connectivity information among wireless terminals which can be usefully exploited to devise effective broadcast and point-to-point services for wireless ad hoc networks. In this paper we propose a dynamic strategy for reserving point-to-point resources and we evaluate its performance through detailed simulation. Furthermore we address the issue of differentiating users in the access phase and we show how to extend the ADHOC MAC to provide a QoS framework**

**Key words:** ad hoc networks, MAC protocols, point-to-point communications.

## 1. INTRODUCTION

The fast growth that mobile communications have been experiencing in the last years and the increasing demand for new and flexible services have posed a great scientific and technical effort in order to provide prompt, reliable and efficient network architectures and protocols.

In the case of mobile ad hoc networks this effort is even more noticeable due to the complexity of the dynamic environment of these networks. The complexity of resource management in a wireless environment lies in the shared nature of the medium. Further on, the radio resources are often limited in comparison with the number of users which access them, thus the capacity of any wireless network is highly determined by the capability of the medium access control mechanism to handle the access process and to achieve high resource reuse [1].

ADHOC MAC [2] is a medium access control protocol recently introduced within the European Commission funded CarTalk2000 project [3] for providing connectivity in ad hoc inter-vehicles networks [4].

ADHOC MAC works on a slot synchronous physical layer and implements a completely distributed access technique capable of dynamically establishing a reliable single-hop Basic broadcast CHannel (BCH) for each active terminal, i.e., each transmission within a BCH is correctly received by all the terminals within the transmission range of the transmitter. Each BCH carries signaling information that provides a prompt and reliable distribution of layer-two connectivity information to all the terminals.

This information provides a valuable basis for the efficient implementation of point-to-point data services, exploiting parallel transmissions, and also supplies a prompt means to manage different QoS requirements for these services.

In [5] and [6] the performance of ADHOC MAC broadcast services in a static scenario and with users' mobility has been studied respectively, while in [7] we evaluated the efficiency of the protocol in a scenario where broadcast and point-to-point communications coexist. An adaptive bandwidth allocation strategy was proposed to share the resources between broadcast and point-to-point communications in a dynamic situation with the aim of guaranteeing access requirements for BCH whereas capacity for extra data communications is optimized.

In this paper we focus on the point-to-point service by proposing an access strategy based on resource reservation. Further on, we show how to integrate in ADHOC MAC a simple mechanism to handle user/traffic differentiation, thus providing a solid starting point to devise effective QoS algorithms. The remaining of the paper is organized as follows. In Section 2 we briefly summarize the basis of the ADHOC MAC protocol. The proposed access scheme for the point-to-point connections is described in Section 3. In Section 4, the protocol is evaluated through simulation. Finally, in Section 5 some conclusions are provided.

## 2. THE ADHOC MAC PROTOCOL

### 2.1. Basic operation

ADHOC MAC operates with a time slotted structure, where slots are grouped into virtual frames (*VF*) of length *N*, and no frame alignment is needed. For a correct operation, the ADHOC MAC needs that each active terminal has assigned a Basic CHannel (BCH), corresponding to a slot in the *VF*, which is a reliable single hop broadcast channel not suffering from the hidden-terminal problem. This is obtained in a distributed way by the RR-ALOHA protocol [8], where, as in R-ALOHA, contention is used to get access to an available slot in the frame and, upon success, the same slot is reserved in the following frames and no longer accessed by other terminals until it is released. Since the ad hoc environment is not fully broadcast, the information needed for the RR-ALOHA correct operation is provided to all terminals by means of the BCHs.

In the BCH, each terminal broadcasts information on the status of the channel it perceives. The BCH contains a control field, the Frame Information (FI) field, which is an N-elements vector specifying the status of the *N* slots preceding the transmission of the terminal itself. The slot status can be either

BUSY or FREE: it is BUSY if a packet has been correctly received or transmitted by the terminal, otherwise it is FREE. In the case of a BUSY slot the FI also contains the identity of the transmitting terminal. Based on received FIs, each terminal marks a slot, say slot k, either as RESERVED, if slot *k-N* is coded as BUSY in one FIs received in the slots from *k-N* to *k-*1 at least, or as AVAILABLE, otherwise. If a slot is AVAILABLE, it can be used for new access attempts.

Upon accessing an AVAILABLE slot, terminal *j* will recognize after *N* slots (a frame) its transmission either successful, if the slot is coded as "BUSY by terminal *j*" in all the received FIs, or failed, otherwise.

In Fig. 1, an example of FIs transmitted by a set of terminals is given. We define one-hop cluster (OH) as a group of mobile terminals all in the same cover range. The union of all OH-clusters with a common subset is denoted as two-hop (TH) cluster. The terminals belonging to the same OH-cluster see the same status (AVAILABLE or RESERVED) for all the slots; terminals belonging to different OH-clusters of the same TH-cluster mark as RESERVED all the slots used in the TH-cluster, whereas terminals belonging to disjoint OH-clusters usually see a different channel status. As a result, slots can be reused in disjoint OH-clusters, but can not be reused in the same TH-cluster and, therefore, the hidden-terminal problem can not occur [4].

## 2.2. Point to point mode

The BCH provides a reliable single hop broadcast channel which can be used both for signaling and for data traffic purposes. On top of this, point-to-point data communications among terminals can be effectively established by exploiting the distributed signaling provided by the FIs. To this end, each entry of the FI encloses a Point-To-Point (PTP) flag, which is handled as follows:

- A terminal sets the PTP flag of a given slot in the FI, if the packet received in the slot is a broadcast one or if it is destined to the terminal itself.

In order to set up a point-to-point communication, all the AVAILABLE slots can be used. Further on, even some RESERVED slots can be used according to the following rule:

- A RESERVED slot can be accessed:
    - (i) if the PTP flag is signaled off in all the received FIs
    - (ii) and the FI received from the destination terminal signals the slot as FREE.

The whole set of slots that a terminal can select for PTP connections to a given destination will be referred as AVAILABLE PTP slots for that destination. The conditions above allow point-to-point transmissions to share the same slot when there is no collision at the receivers. This can be seen referring to the four cases shown in Fig. 2. The cases *a* and *b* in the figure consider two transmitting terminals, say 1 and 2, belonging to different not disjoint clusters. Assuming that terminal 1 has already activated a PTP channel with terminal 3, terminal 2 can transmit using the same slot if these two conditions above are satisfied. In case *a*, terminal 2 can use the same slot as terminal 1 even if it is signaled as RESERVED. In fact, the only PTP flag ON is the one in the FI transmitted by terminal 3 and not received by terminal 2 (satisfying condition (i)), and the FI generated by terminal 4 marks the slot as FREE (satisfying condition (ii) ).

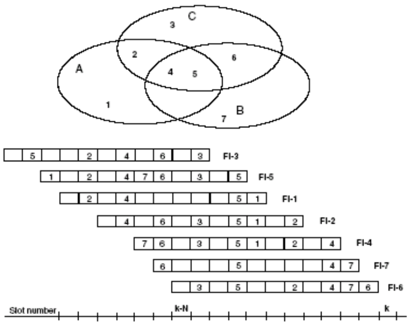

*Figure 1: Example of the FI information propagated by the terminals 1-7 in the one-hop clusters A, B, and C represented by ellipses.*

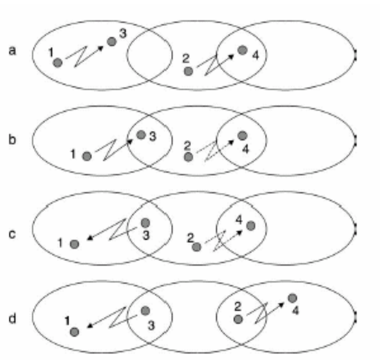

*Figure 2: Examples of parallel transmissions. Transmission from terminal 1 is established first. Allowed transmissions by terminal 2 are indicated by solid arrows.*

In case *b* the FI generated by terminal 3 and received by terminal 2 prevents terminal 2 from transmitting (not satisfying condition (i)). In this case parallel transmissions would, in fact, interfere at terminal 3.

In cases *c* and *d* the two transmitting terminals belong to the same cluster. In case *d*, terminal 3 can use a RESERVED slot since both conditions (i) and (ii) are satisfied (in fact, this is the exposed-terminal case [9]) whereas in case *c* condition (ii) is not satisfied and a collision would occur at terminal 4.

If several access attempts occur concurrently, collisions can still occur. In order to check if the point-to-point transmission has been successful, the transmitting terminal has to check if the slot is coded as BUSY by the transmitter in the FI of the destination terminal; otherwise the transmission is failed.

# 3. A BOOK IN ADVANCE SCHEME FOR POINT-TO-POINT CONNECTIONS

The distributed signaling provided by the FIs allows to efficiently establish point-to-point communications between different pairs of neighbors. In order to maximally exploit this capability, a joint management of the different connections in each terminal must be performed. A terminal has to schedule its new accesses and the already established connections so that it can satisfy the different demanded requirements. Hereafter, we propose the Book In Advance Scheme (BIAS) for the access to the PTP resources.

At the beginning of each virtual frame, a terminal must decide the number of slots to be allocated in the frame to give service to its current connections within the set of AVAILABLE PTP slots. If the access is carried out through RR-ALOHA as explained in the previous section, the terminal decides in which slots is going to transmit among the free ones and then directly access to them in the next Virtual Frame. Collisions can happen in the access since terminals choose randomly among the free slots leading to a reduction in the performance of the medium access.

On the other hand, the BCH capabilities can be used to signal the request before the access, in such a way that collisions can be theoretically avoided. To this end, a new status, ACCESSING, must be included in addition to BUSY and FREE in the FI. Before transmitting its FI, a terminal marks in it all the new requests as ACCESSING, also containing its identity as in the BUSY status, and including in addition the identity of the destination.

Under these conditions, a terminal can receive several requests for a given PTP resource within its virtual frame, and not all of them have to be destined to the terminal itself. Upon all the received requests, it has to decide what to send in its FI. The decision must be consistent with the rest of neighbors. In a first approximation, it can choose the first received request and ignore the remaining. It has to include in the FI of that slot the status ACCESSING, the identity of the transmitter, and, if it is the destination, the PTP flag ON. Another possibility could be based on random numbers included with the requests. The terminal could choose the one with the highest or lowest random number, for example.

After a frame, the transmitter must check the result of the requests. A reservation has been successful if:

(iii) The slot is coded as ACCESSING by the transmitter in the FI of the destination terminal with the PTP flag ON

(iv) and the PTP flag for that slot is not ON in the FI of any other terminal.

In any other case, the reservation has failed and must be re-attempted: if the slot is not coded as ACCESSING by the transmitter means that the receiver has chosen a different request, whereas if more nodes signal the PTP flag ON, they are waiting for receiving and, if established, this transmission would cause a collision.

An example it is shown in Fig. 3. The situation reported in this figure is equivalent to case *c* in Fig. 2. In this case, if 1 and 2 decide to access concurrently, with RR-ALOHA a collision would occur in terminal 3. With the reservation scheme, terminal 3 receives the requests of both terminal 1 and terminal 2. If terminal 2 wins, the collision avoidance is obvious, since terminal 1 do not receive the *ACK* (the slot coded as ACCESSING by the transmitter with the PTP flag ON). If terminal 1 wins, terminal 3 will send the *ACK*. In that case, terminal 2 receives the *ACK* from terminal 4 to itself and the *ACK* from terminal 3 to terminal 1. Since it receives 2 *ACKs*, it does not reserve the slot and terminal 3 will receive correctly from terminal 1.

If the reservation has been successful, the transmitter terminal signals the slot as BUSY in its FI and it is able to transmit within the next virtual frame in a collision-free situation. Upon this, the slot will be maintained while it is necessary as with the RR-ALOHA access. This decision will be made in the next frame, during the scheduling process.

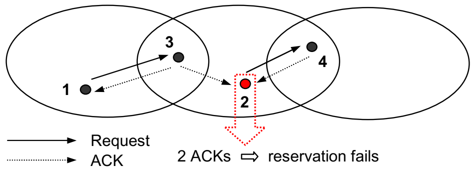

*Figure 3: Examples of the operation mode of the reservation scheme*

Obviously, the proposed reservation scheme gets rid of access collisions, since it resolves collisions in the reservation phase. On the other hand, the access delay can be augmented. In the next section we show the trade off between these two aspects.

### 3.1. Priority management

Upon the basis of this access scheme, information related to the priority can be also included in the BCH [2] in order to manage connections with different QoS requirements. Besides the status, the identity of the transmitter and receiver and the PTP flag, each entry of the FI can enclose a priority field. This field allows a high priority terminal to either gain the access in the request phase or even to preempt established lower priority transmissions modifying the RESERVED slots that can be accessed for a point-to-point connection according to these conditions:

- The PTP flag is signaled OFF or ON with lower priority in all the received FIs.
- The FI received from the destination terminal signals the slot as FREE or either BUSY or ACCESSING with lower priority.

In this case, the requests can be differentiated according to given priorities access. First, it has to choose with the same rule as without priorities within the set of requests of high priority and just if there are not high priority requests, choose among the low ones.

When pre-emption is carried out, a low priority receiver modifies its FI for that slot and the acknowledgment for the last received packet would be missed. In order to avoid this situation, an additional field with the *ID* of the former low-priority transmitter is included in the BCH to inform of this last acknowledgment.

A terminal which is not a destination of any connection can be receiving concurrently several transmissions with different priorities, so in that slot, it sees a collision. In order to provide the most accurate information to its neighbors, it updates its frame information for that slot as BUSY with the highest received priority according to the received FIs.

## 4. PERFORMANCE EVALUATION

We have built up an event driven simulator in C++ which implements all the functionalities of the ADHOC MAC. The topology in each simulation is configured with terminals randomly positioned within a square area with edge equal to 1 Km. Since we mainly focus on performance evaluation of the medium access control protocol, as first step of analysis, we simplify the physical layer assuming neither fading nor shadowing in the calculation of the received power. The connectivity among terminals is simply determined by the Euclidean distances and no power control procedures are implemented. As consequence, a transmission either broadcast or point-to-point can be erred due to collisions only.

In order to guarantee an outage probability for new terminals accessing the system, in [7] we propose an adaptive frame subdivision into two subframes, where the acquisition of a BCH, i.e., the access of a terminal to the system, is not limited by the amount of PTP traffic in the network: A frame with $N$ slots is divided into $N_{BCH}$ and $N_{PTP}$ slots for BCH and PTP communications. For this assumption, it is required a slot and frame time synchronization of each terminal in the network, that can be obtained with the Global Position System (GPS) or other solutions [10]. It must be guaranteed a trade-off between ensuring the access for new terminals whereas providing the maximum bandwidth for PTP data communications. In this paper, we assume a static frame subdivision that guarantees the access requirements for BCH. This simplifies the analysis, allowing to focus on point-to-point performance.

Terminals are generated at the beginning and remain active through all the simulation. Upon generation, each terminal tries to acquire a BCH, thus after a certain transient time, all of them have acquired their BCHs and a stationary scenario is arranged. This allows to evaluate the proposed PTP access scheme without interacting with failures in the BCH.

Under these conditions, each terminal generates PTP communications according to a Poisson process with intensity $X$ (PTP connections/s). The source of each point-to-point communication is randomly chosen among the users with an active BCH, while the destination is randomly chosen among the source's neighbors. The duration of each point-to-point communication is exponentially distributed with mean $D$ (frames). Likewise, each connection generates 1 packet per frame (CBR). The parameters $X$ and $D$ define the point-to-point offered traffic by each terminal. We define a common framework of simulation by setting the length of a frame $F$ = 100 ms, the number of slots within a frame $N = 50$, with $N_{BCH} = 25$ and $N_{PTP} = 25$ and the coverage radius $R$ = 100 m. The number of terminals in the system is set to 200. The modification of the simulation parameters only impacts on the absolute values of the performance figures, whereas the comparative results obtained in this paper still hold.

When a terminal initiates the scheduling process and the slots allocation is performed, it does not only decide which slots trying to access but also the corresponding priority. Connections for priority services will be assigned to priority slots in order to increase the probability of accessing the shared medium. According to the priority classification, the time that individual packets have been waiting for being transmitted and the available resources, the terminal decides which reservations has to maintain and the new accesses to be attempted. Since the FI of the receiver provides the acknowledgement for each packet, a retransmission strategy (selective repeat ARQ) has been implemented. Packets are retransmitted until they are correctly received or they exceed the maximum tolerable delay in the transmitter (Discard Time).

Fig. 4 shows point-to-point throughput with RR-ALOHA access and with BIAS for three different values of $D$ (10, 50 and 250 frames) when varying the offered point-to-point traffic. The throughput reduction is due to packet discard in the transmitter. Performances degrade with the RR-ALOHA access, especially for short connections, where the fraction of resources dedicated to the access is more important. On the other hand, the impact of accesses has less influence when reservations are carried out. In fact, the impact of accesses can be seen in Fig. 5, which shows the probability of packet collision for RR-ALOHA access (with BIAS collisions are fully avoided). As the duration of the PTP connections decreases, the number of accesses for the same amount of offered traffic increases. This makes more probable that several access attempts occur concurrently, leading to collisions. Collision probability decreases after a certain point, since when the traffic is high, slots for a given destination can be already reserved for previous connections when a new one arrives at a terminal.

Furthermore Fig. 6 reports the probability of an unsuccessful access for both RR-ALOHA and BIAS. An access is defined as the first packet of a connection (RR-ALOHA) or a slot request in the FI (BIAS). With RR-ALOHA the failure probability quickly increases as the offered traffic grows until stabilizing around 0.9, since when there is an available slot, all the nodes waiting for resources access concurrently. When reservations are used, the receivers can choose among the requests, in such a way that when several accesses for the same slot occur at the same time, one of them can be established. Fig. 7 shows mean access delay for both strategies with $D$ = 50 frames. As it was expected, at low traffic conditions RR-ALOHA provides a faster access, since the reservation phase is avoided. On the other hand, when traffic increases BIAS clearly outperforms RR-ALOHA, since collisions slow down the access process.

In order to evaluate the capability of the protocol to manage traffic with different requirements, simulations also with $D$ = 50 frames where each terminal generates PTP connections with two levels of priority with the same probability have been carried out. When a high priority terminal does not find AVAILABLE PTP slots, it can access in slots labeled as ACCESSING or BUSY with lower priority. Fig. 8 shows throughput for both priorities when priorities are used just in the access and also to pre-empt already established connections. This illustrates the basic capability of the protocol to allocate services with different priorities in a distributed way, providing better performance for the high priority services. As clear from the figure, preempting low priority connections produces very slight increase in the high priority throughput, whereas it determines a remarkable drop in the low priority one. The amount of loss in the low priority throughput exceeds the gain in the high priority one at high traffic load, i.e., in order to accommodate one high priority connection, multiple low priority connections must be dropped. The ratio between the number of dropped connections and the number of preempting connections can be estimated with the reuse of the point to point service.

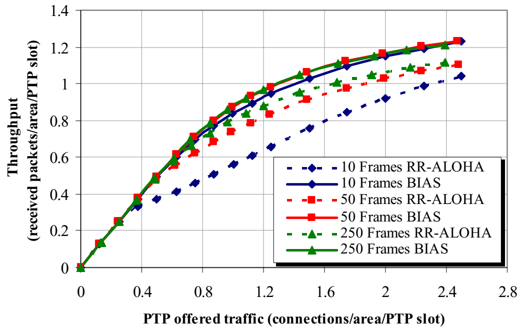

*Figure 4:Point-to-point throughput versus point-to-point offered traffic*

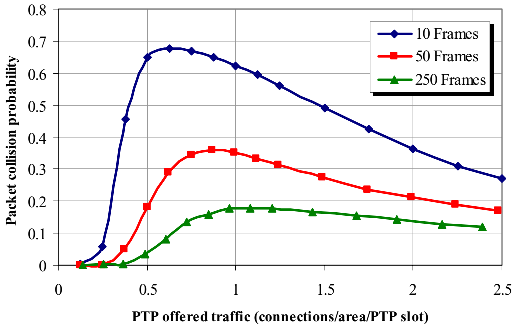

*Figure 5: Packet collision probability versus point-to-point offered traffic with RR-ALOHA access*

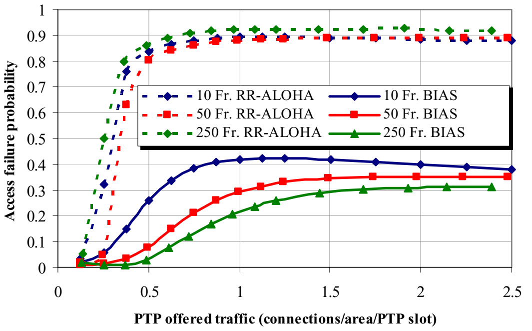

*Figure 6: Failure access probability versus point-to-point offered traffic*

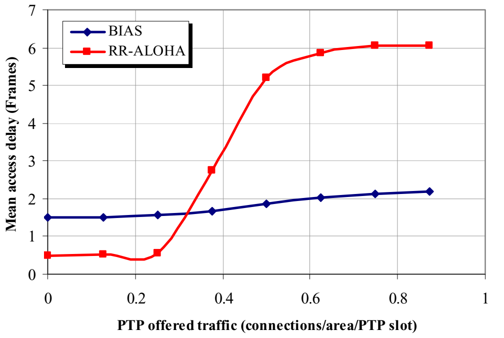

*Figure 7:Mean access delay versus point-to-point offered traffic (D=50 frames)*

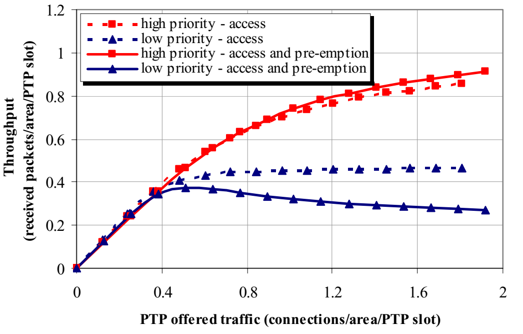

*Figure 7: Point-to-point throughput versus point-to-point offered traffic for different priorities with and without pre-emption*

## 5. CONCLUSIONS

Prompt access and capability of supporting traffic differentiation and QoS schemes are central issue which determine the performance of any mobile networks. To this purpose, an effective MAC scheme for ad hoc networks should be able to provide reliable communication services, both broadcast and point-to-point, and to implement solid resource management schemes in order to match different QoS demands.

In this work we have proposed BIAS, a reservation based mechanism to handle the access to PTP resources within the ADHOC MAC. Further on, we have shown how to implement simple but efficient traffic differentiation by exploiting the in band signaling provided by the ADHOC MAC protocol.

Simulations have proved the effectiveness of the proposed solutions and the flexibility of the ADHOC MAC framework with regard to the resource management and QoS issues.

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