# Mobility and wireless MAC Protocols in MANETs

***Abstract*— The emergence of lightweight wireless mobile devices, like laptops, PDAs, and sensors makes mobile ad hoc networks (MANETs) an exciting and important research area in recent years. The MANET community have been concentrating on some problems related to the network layer, especially on the routing protocols. But regarding the MAC level, little has been done. No novel protocol has been proposed but traditional wireless MAC protocols have been largely adopted. Our contribution in this paper is the deep investigation of the mobility impacts on MAC protocols in MANETs, using the GloMoSim simulation tool. We think we are the first who consider nodes' mobility when analyzing MAC protocols in MANETs.**

***Index Terms*— Mobile wireless ad hoc networks, MAC protocols, simulation, GloMoSim**

## I. Introduction and motivations

Nowadays, with the rapid proliferation of wireless devices, such as mobile laptop computers, PDAs, wireless telephones, and wireless sensors, the potentials and importance of nomadic computing and particulary mobile ad hoc networking have become apparent. A mobile ad hoc network (MANET) is formed by a group of mobile wireless nodes that form on the fly a self-organized network without the assistance of any fixed network infrastructure. In this novel environment, nodes must cooperate by forwarding packets so that nodes beyond radio ranges can communicate one with another. Consequently, packets follow multi-hop paths, and traverse several wireless links towards their final destination. There are a number of potential MANETs applications, such battlefield operations, emergency rescues, mobile conferences, home and community networking, and sensor dust. Generally speaking, MANETs potential applications include all mobile computing applications we can imagine that cannot support dependence on any fixed infrastructure.

Mobile wireless hosts used in MANETs have to ensure the roles ensured by the powerful fixed infrastructure in traditional networks. This is a challenging task, since these devices have limited resources (CPU, storage, energy, etc..). Moreover, the network's environment has some features that make the problem more complicated, such as the frequent topology changes caused by nodes' mobility, and the unreliability as well as the bandwidth limitation of wireless channels.

Few works have been devoted to MAC layer protocols, compared with the other layers. Distributed Wireless MAC protocols have been adopted for MANETs, for which little modifications have been brought. In this paper we drive a simulation-based comparative study, to investigate mobility impact on the most relevant wireless MAC protocols adopted for MANETs.

The remainder of this paper is organized as follows: in the next section we will present the related work, followed in section three by an overview of the MAC protocols involved in this study. The simulation environment will be presented in section 4, followed by the simulation results in the next section. finally, the last section concludes the paper.

## II. Related work

Almost all researches with respect to MANETs focused on problems related to the network and the upper layers. Earlier studies aimed to propose new routing protocols for MANETs [1], where recent studies have been tending to improve these protocols by considering new constraints, such as power consumption [2], [3], [4], and security [4], [5], [6], [7]. Other proposals have dealt with the upper layers issues, including the transport layer [8], [9], as well as the application layer, such as data management [10], [11], localization and partition prediction [12], [13], and replication [14], [15]. However, relatively few works have been devoted to MAC protocols. Distributed wireless MAC protocols have been adopted for MANETs, all these protocols are surveyed in [16].
Barret et al [17] have driven a simulation comparison study of three MAC protocols, CSMA, IEEE 802.11, and MACA. The purpose was to investigate the effects of the network topology, packet load, and nodes placement on the protocols' performance, regarding the packet delivery (the reliability), the latency, the fairness, and the throughput. The results showed that CSMA has the best performance for average load scenarios, whereas MACA was largely dominated by IEEE 802.11 and CSMA overall. However, the nodes have been being stationary in all scenarios, thus the mobility factor has

been ignored in this study. To the best of our knowledge, no neutral comparative study connecting the efficiency of these protocols and the mobility has been published yet. The contribution of this paper is the conduction of such a study.

## III. MAC PROTOCOLS OVERVIEW

MAC protocols can be classified according to several criterions, such as synchronicity, communication initiator, and contention [18]. In synchronous MAC protocols, all nodes are synchronized to a common clock, and the schedule of transmissions is established basing on this common resource. Relying on a such clock makes the protocol centralized, which is inadequate for MANETs. Asynchronous protocols on the other hand do not rely on any time referencing resource and the medium access is achieved in a distributed way. One could categorizes MAC protocols with regard to the communication initiation, we distinguish hence two classes: transmitter initiated and receiver initiated, the latter approach minimizes the number of steps to acquire a channel compared with the former, but would require a prior knowledge of the traffic pattern. The suitability of these classes depends on the applications to be run in the network. The last classification proposed in [18] considers the competition. Contention based protocols are fully distributed, and nodes content the channel access. In these protocols random slots are generally used to ensure fairness. On the other hand, non-contention protocols are generally based either on time division (like TDMA [18], [16]) or frequency division (such as FDMA [18], [16]), token based protocols that rely on a master node for the token distribution also belong to this class. All these protocols needs the infrastructure mode to be available, thus they are centralized. Although these protocols are deterministic and largely adopted than contention based protocols for infrastructured wireless networks, such like cellular networks and WLANs with access points, they are inappropriate for MANETs, since they could not meet the most important MANETs feature (infrastructureless).

After this discussion, it would be obvious that suitable MANETs MAC protocol should be asynchronous and contention based. The most relevant wireless MAC protocols adopted for MANETs are CSMA [19], MACA [20], IEEE 802.11b [21]. In the following we briefly overview these protocols, detailed presentations could be found in the appropriate papers.

### *A. CSMA*

A commonly known group of MAC protocols is based on the Carrier Sense Multiple Access (CSMA) paradigm [19]. The idea behind this paradigm is to check the medium at the originator (source) by the so called *carrier* (channel) *sensing*. That is a node senses the common channel for ongoing transmissions, if the channel is idle then it begins its transmission, otherwise it sets a *random* timer before attempting to transmit again (backoff). CSMA does not address the handling of *collisions* on the channel. The protocol suffers from the hidden terminal problem, i.e when three nodes A, B, and C are located in such a way that B is between A and C and belongs to the power range of both, but A and C are out of the power range of each other, C is said hidden for A, because when sensing the channel, C could not capture A's transmission, which can result in a collision at B (C transmits when A is transmitting to B). Another drawback of CSMA is the unreliability, since in this protocol a receiver does not acknowledge packets reception. One can consider the advantageous side of this, which is the overhead diminution.

### *B. MACA*

To avoid the hidden terminal problems, Karn [20] has proposed MACA (Medium Access Collusion Avoidance), which introduces a reservation system achieved with exchange of an RTS/CTS (Request To Send/Clear To Send) pair of control packets. MACA eliminates the phase of censing the channel, Karn argues this by the fact that this approach does not ensure reliable access and can causes collisions (the hidden terminal problem). When a node wishes to transmit a data packet (in a frame), it sends a RTS packet to reserve the channel, the receiver replay with a CTS allowing the transmitter to send its data packet. All nodes that overhear this packet postpone their transmissions at least for the time required for the CTS transmission, and all nodes which meet the CTS postpone their transmissions at least for the duration of the data packet transmission. Like CSMA, MACA does not employ any acknowledging mechanism. Many variants of MACA have been proposed [16], the most important one is MACA-BI that we will overview hereafter.

## IV. MACA-BI

MACA-BI or MACA By Invitation [22], is the only receiver initiating protocol we consider in this work. This protocol replaces the RTS/CTS mechanism, which includes three steps, by a two steps communication handshake mechanism, where the RTR is removed and the CTS is replaced by RTS (Ready To Receive). The receiver invites the transmitter to transmit a given number of packets by sending it a RTR, when receiving the RTR the sender sends its packet in the second step. This mechanism requires that each node would know or at least accurately estimate the outgoing traffic of its neighbors.

## V. IEEE 802.11

IEEE 802.11 [21] is a standard MAC protocol for traditional wireless networks (but not for MANETs) applicable for both infrastructured and infrastructureless modes. It defines two access methods, namely DCF (Distributed Coordination Function) and PCF (Point Coordination Function), this latter is solely operational in the infrastructured mode, hence it could not be used in MANETs. On the other hand, DCF is operational in the two modes, it is based on CSMA/CA to which it adds a positive acknowledgment mechanism, i.e the receiver acknowledges the data packets upon it receives them. IEEE 802.11 also uses RTS/CTS mechanism to avoid collisions and mitigate the hidden terminal problem. However, this RTS/CTS differs from that of MACA with respect to the postponing period, in IEEE 802.11 the whole exchange (RTS/CTS/DATA/ACK) is considered as an atomic operation and any node which receives the RTS postpones its transmission for a duration long enough to allow the transmission of all these packets. This RTS/CTS mechanism causes the problem of exposed terminal [18] which results in channels misuse. To explain this problem we consider the previous example of three nodes: A, B and C, assume also that there is another node D neighbor to C and out of A's and B's power ranges. When B overhears a RTS sent from C to D it postpones any transmission to A for the whole 4 steps exchange, but these two transmissions (B to A and C to D) do not cause any problem when performed simultaneously. However with MACA's RTS/CTS mechanism, B postpones merely for the CTS transmission, since it will not receive the CTS (because it is out of D's power range) it will communicate normally and simultaneously with A.
Table I summarizes the features of the presented protocols.

## VI. SIMULATION ENVIRONMENT

Using GloMoSim [23], that we extended by implementing MACA-BI protocol and many other computations, we have simulated a network of 50 nodes moving within a $2000m \times 800m$ area, during 15 minutes. Each node has a $200m$ power range, and moves according to the random way-point pattern [24]. To generate traffic, 12 nodes act as CBR sources and 12 other nodes as destinations, we have chosen nodes such that each source and destination are as far as possible from each other, the purpose behind this choice is to ensure that packets follow multi-hop routes.
Mobility has already been considered to evaluate MANETs routing protocols. In the earlier studies, this parameter was represented by nodes speed, or by the pause time when using the random way-point model. These representations, however, do not accurately reflects the topology changes. Nodes might move either in a high speed or a low pause time, but toward the same direction without causing any topology change. On the contrary, nodes might have a low speed or a high pause time, but they move away from each other, resulting in important topology changes. This illustrates the weakness of this mobility representation.
A more rigorous mobility definition that better expresses the network topology change has been proposed by Johansson et al [25], and has been used in the recent studies, such as [24]. This definition is based on relative nodes' movements, and represents the mobility by a parameter called mobility factor (mob) that depends on both the nodes speed and the movement pattern (directions). It is given by the following formula:

$$Mob = \sum_{i=1}^{n} \frac{M_i}{n}$$

$$M_x = \sum_{t=0}^{T-\Delta t} \frac{|A_x(t) - A_x(t+\Delta t)|}{T}$$

$$A_x(t) = \sum_{i=1}^{n} \frac{dist(n_x, n_i)}{n-1}$$

where:
$dist(n_x, n_y)$: the distance between nodes x and y
$n$: the nodes number
$A_x(t)$: the average distance between node x and all the other nodes, at time t
$M_x$: the average relative mobility of node x regarding all other nodes, during the simulation time
$T$: simulation time
$\Delta t$: time period used in computation.
In our implementation, this parameter (mobility factor) is computed during the simulation. After each $\Delta t$, $A_x(t)$ is calculated, i.e it is calculated for: t=0, t= $\Delta t$, t= $2\Delta t$, $\cdots$, t=T.
In [24] it has been shown that this mobility definition reflects better the links changes. In our simulation we represent mobility by this metric that we have added its computation to GloMoSim. In different relative mobility

| Protocols | CSMA | IEEE 802.11 | MACA | MACA-BI |
|---|---|---|---|---|
| **Initiator** | transmiter | transmiter | transmiter | receiver |
| **carrier sensing** | yes | yes | no | no |
| **ACKs** | no | yes | no | no |
| **RTS/CTS** | no | yes | yes | -no RTS<br>-CTS replaced by RTR |
| **steps** | sensing channel → transmitting data | RTS → CTS → data →ACK | RTS → CTS → data | RTR → data |
| **possible collisions** | between data packets | -between control packets<br>-between control and data packets | idem to IEEE 802.11 | idem to IEEE 802.11 |

TABLE I

MAC PROTOCOLS FEATURES

values (ranging from 1m/s to 5m/s), the protocols performances are evaluated and compared in terms of: The average power consumption, the number of collisions, the average packet delay (at the MAC layer buffers), and the data reception rate (reliability).

## VII. SIMULATION RESULTS

All along this simulation, we vary the (relative) mobility from 1m/s to 5m/s, and we investigate its impact on the performances of the MAC protocols with respect to the metrics sited above.

### A. Power consumption

As shown in figure 1, CSMA and IEEE 802.11 outperform clearly the other protocols, and they are unaffected by the mobility. CSMA consumes slightly less power than IEEE 802.11, since it uses neither RTS/CTS nor ACKs. MACA and MACA-BI are hugely affected by the mobility, their power consumptions increase dramatically with mobility. We argue this result by the fact that MACA and MAC-BI do not use the carrier sensing, i.e nodes initiate the communication and transmit the RTS or RTR (if they are not in any backoff period) without checking the channel. This might result in many collisions when the mobility rises as it will be shown later, retransmissions of RTS or RTR are therefore performed which increases the power consumption.

We also remark that MACA-BI consumes more energy than MACA. This because the former is based on invitations, with the mobility rise, the number of RTRs sent to nodes out of the inviter power range believed still being in the neighborhood and getting traffic to transmit increases, the invitor performs retransmissions of the RTR when no data are sent. This useless invitations causes important power consumption.

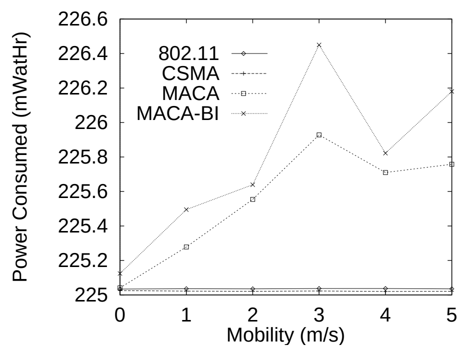


Fig. 1. Power consumption vs. mobility

### B. Collisions

As illustrated in figures 2, both MACA and MACA-BI are largely outperformed by the two other protocols and are affected by the mobility rise. This is due to the unemployment of the carrier sensing mechanism, in other words, it is due to transmissions of control packets (RTS/CT for MACA and RTR for MACA-BI) without checking the channel, which results in many collisions when the mobility increases. CSMA and IEEE802.11 cause too less collisions and are not affected by the mobility rise, this good performance is achieved by the usage of the carrier sensing. Moreover, the channel reservation mechanism (RTS/CTS) gives IEEE 802.11 a little advantage (less collision) over CSMA.

### C. Data reception rate

Figure 3 presents the data reception rate, i.e the number of the received packets per the number of packets sent. IEEE 802.11 is the only protocol uninfluenced by the mobility, it has rates very close to 1 in all mobilities. This reliability is mainly due to the ACKs usage. On the other hand MACA and MACA-BI have good reliability for low mobility, but they are, especially MACA-BI,

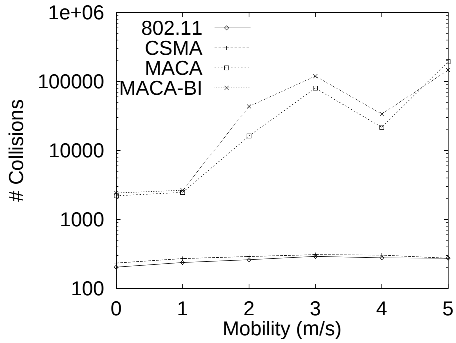


Fig. 2. Collisions number vs. mobility

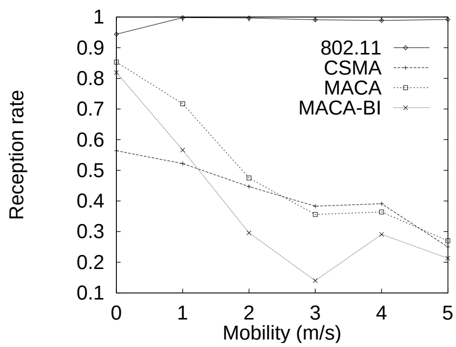


Fig. 3. Data reception rate vs. mobility

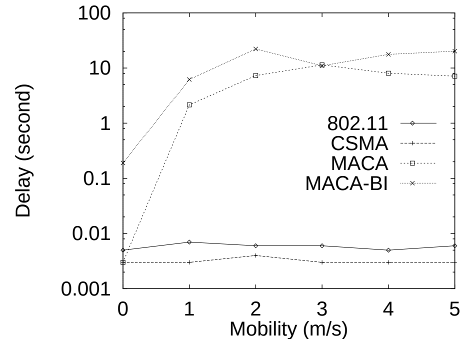


Fig. 4. Average MAC delay vs. mobility

clearly affected by the increasing of mobility, where CSMA causes important loses even for low mobility.

### *D. Average packet delay*

We realize from figure 4 that IEEE 802.11 and CSMA have short delays for all mobilities, unlike MACA and MACA-BI which have very important delays and are dramatically affected by the mobility increasing. We explain this by the collisions observed before, which are important for these latter protocols than the others. CSMA causes shorter delays compared to IEEE 802.11, we argue this ad follows: unlike IEEE 802.11, CSMA does not use any reservation mechanism (RTS/CTS), which eliminates the delay required for reserving the channel. But note that this average delay was computed for the well received packets, lost packets (whose number was important for CSMA) were not taken into account.

## VIII. Conclusion

The MANET community have been concentrating on some fundamental problems related to the network layer, especially on the routing protocols. However, relatively few works have been devoted to the MAC protocols.
In this paper we have conducted a GloMoSim based simulation study to investigate the mobility impact on the most relevant wireless MAC protocols adopted for MANETs, namely CSMA, MACA, MACA-BI and IEEE 802.11, whose efficiency has been measured in terms of energy consumption, collisions, reliability, as well as latency, in different mobilities. The mobility factor has been presented using a metric based on the related movement (proposed in [25]) instead of the absolute speeds or pause times, it has been shown in [25], [24] that this expression accurately reflects the topological changes.
IEEE 802.11 is the only protocol that has been unaffected by the mobility, it has been the best on the whole. Except the reliability (reception rate), CSMA has shown satisfactory performance very close to that of IEEE 802.11, moreover it has caused shorter delays than IEEE 802.11, since it eliminates the reservation (RTS/CTS) phase. But unfortunately, its reception rate has been dramatic and largely affected by the mobility rise. MACA on the other hand has provided good performance for a stationer network (mobility=0m/s), but it has been hugely influenced by the mobility.

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