

# **Performance Analysis of a Distributed Queuing MAC Protocol for Ad-Hoc Networks with Different Mobility Conditions**

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## **Abstract:**

This paper analyses the performance of the DQCA AD HOC MAC protocol for scenarios where the communication nodes have different mobility conditions, corresponding to different applications such as sensor networks, inter-vehicular and pedestrian applications. It has been demonstrated that under low mobility conditions, the protocol performance is near-optimum. This performance is slightly reduced due to the cluster setup time when the relative movement speed of the nodes is increased. The variability of this performance behaviour is described in detail. Anyway, the protocol efficiency is remarkably high in all situations and, as a consequence, the protocol could be feasible for a wide range of applications.

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Wireless Ad hoc networks, self-constructing networks, MAC protocols, mobility, master-slave architectures, self-configurable clustering algorithms.

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## I. INTRODUCTION

In the last years, an incipient growth of the so-called wireless ad hoc networking technologies has arisen. Mobile Ad Hoc Networks (MANETs) are those in which there is no previous infrastructure. In this kind of systems, there is a lack of central management station, and hence terminals must develop control functions in a distributed manner.

Mobile users are usually geographically dispersed, and due either to their relative movement or to the radio channel effects such as propagation loss, fading or shadowing, all of them should not be in the same transmission range. In these circumstances, some nodes must assume relaying functions, deploying what is called a multi-hop packet radio network.

In a first step, MANETs were intended only for military applications where mobile access to a wired network is either ineffective or impossible, such as the deployment of troops within the enemy field. Nevertheless, many potential commercial applications have recently arisen. Relevant applications are, for example, sensor networks in industrial environments, inter-vehicular communication devoted to evolve to the concept of intelligent driving and to improve

the safety on the road, or whatever possible application in which the setup of an infrastructure is not available.

In this kind of scenario, the development of efficient radio resource management strategies, routing protocols and distributed medium access control protocols (MAC) suppose a remarkable challenge.

One of the possible approach solutions consist of developing self-configurable clustering algorithms. The fact of self-organizing the network into clusters, emulating regular cellular systems, offers mainly three advantages:

1. The cluster structure allows radio channel reuse and hence it can lead to an increase of the network capacity as discussed in [1].
2. There is a reduction of the topological information update when a node changes from one cluster to another. Only the nodes of the two affected clusters must update their topological information, but not all the nodes in the network.
3. The existence of the so-called Cluster Heads, acting as relaying nodes, reduces considerably the routing control information.

Lots of clustering algorithms have been proposed so far [2-5]. In [2] a cluster algorithm is presented where the resources are split into two parts; one devoted to control information and the other one to the transmission of data. The control part is divided into three slots and its use is based on two busy tones which allow to completely avoid inter cluster interference, i.e. interference caused by a neighbour node belonging to a different cluster. In [3] the Access-Based Clustering Protocol (ABCP) is presented, which presents a multiple access scheme developed for control information broadcast. Clustering decisions are based on the result of channel access, reducing hence the control overhead. In [4], a novel framework is presented in which the probability of path availability can be bounded when organizing mobile terminals into clusters.

In [5], not only a clustering technique is outlined, but also a distributed MAC algorithm is presented. The MAC protocol is called DQCA AD HOC. The outstanding results achieved

with this protocol in representative mobile ad hoc networking scenarios have lead to the development of the further analysis exposed in the present paper.

The intention of this paper is to evaluate the performance of DQCA AD HOC when applying it in different scenarios characterized each one with a different mobility conditions suitable to represent different MANETs applications.

In the remainder of the paper, we first present a very brief overview of the DQCA AD HOC MAC protocol presented in [5]. In Section III we define the study-case scenario and set the parameters' values. Section IV presents and discusses the simulation results. Section V is devoted to the conclusions.

## II. DQCA AD HOC OVERVIEW

In this section we briefly outline the DQCA AD HOC protocol for the sake of the understanding of this paper. However, further details on the protocol can be found in [5].

DQCA AD HOC is based on the previous ideas exposed in [6] where it is defined the DQCA MAC protocol for centralized wireless networks.

DQCA AD HOC is a dynamic self-configuring cluster algorithm defined in order to overcome the lack of central stations capable of managing and controlling the communication within the network. Therefore, the network is organised in clusters in which the MAC protocol can follow almost the same algorithm rules defined for DQCA.

When a node has data to transmit, it must listen to the radio channel. If the channel is idle for a certain period of time, the node sets itself to be a master node and acts as the cluster head for a cluster. A master node sends a periodical synchronisation signal. Since all nodes must be regularly listening to the channel waiting for incoming signals, nodes closer to the master will listen to the master signal and set themselves as slave nodes.

DQCA AD HOC has been designed to work over the legacy IEEE802.11 PHY layer, and then, the spectrum resources are shared following a TDMA scheme. Each cluster maintains a frame structure, which is independent from the ones in the neighbour clusters. This frame is divided into three fixed-duration slots devoted to:

1. Access requests' transmissions to the radio channel (this slot is also split into three mini-slots),
2. Data transmission,
3. Feedback information transmission sent by master nodes.

Master nodes must broadcast the control information needed to update and maintain the value of two distributed logical queues. These two queues are the *Data Transmission*

*Queue* (DTQ) devoted to manage the access to the radio channel, and the *Collision Resolution Queue* (CRQ) devoted to resolve the collisions occurred in the access slot.

The MAC protocol then works as follows: When a node has data to transmit, it must check if the distributed queue CRQ is empty, in order to avoid new access requests while there are collisions waiting to be resolved. If it is the case, it must check if the distributed queue DTQ is also empty. If it is the case, the node will send its data packets in the immediate next frame, carrying out what is called a free access. If DTQ is not empty, the node sends an access request to the channel during one of the mini-slots (randomly chosen) of the first slot of the DQCA AD HOC frame. If this request is successful, the node starts queuing at DTQ, where the node will have to update and maintain its position stored as  $pTQ$ . When it gets to the first position of the queue, i.e.,  $pTQ = 1$ , it can start a transmission in the next frame. In case of collision, collided nodes must enter the CRQ. In this queue, each node has to update and maintain its position stored as  $pRQ$ , until it solves the collision and enters the DTQ for data transmission. Summarising:

- a) **DTQ** contains the nodes waiting to transmit data, and
- b) **CRQ** contains the nodes waiting to solve their access request collisions.

Following this simple algorithm, it is possible to state that:

- The protocol behaves as a random access protocol when low traffic loads are offered to the network and switches smoothly and automatically to a reservation protocol when the offered payload is increased, hence, obtaining the best of both kind of MAC protocols.
- In a single-hop scenario, collisions during data transmissions are totally avoided, and therefore, the protocol behaves as a near-optimum MAC protocol, obtaining the most of the radio channel capacity. In multi-hop scenarios, the performance is slightly reduced due to inter cluster collisions.

Having in mind that there is a common radio channel for the whole network, and hence, all nodes operate in the same frequency independently of the cluster in which they lie, and regarding the master-slave cluster scheme, the protocol performance is directly affected by the inter cluster interference, i.e., interferences between neighbouring nodes belonging to different clusters.

Once the cluster structure is set, it is adapted dynamically depending on the changes on the topology of the network. Relative movement among mobile terminals is the main cause of changes in the network topology. For this reason, it

has been considered of relevance the analysis of the protocol presented in the next section, where the performance of the protocol is evaluated for different mobility conditions.

In the next sections we will analyse the performance of the protocol for different mobility conditions, depending on the application taken into consideration.

### III. SIMULATION SCENARIO

#### A. Mobility model

We define the speed of a mobile terminal by means of the movement vector defined as:

$$v_{(m/s)} = |v|e^{j\theta} \quad (1)$$

where  $|v|$  is the module of the speed in m/s and  $\theta$  is the phase in radians. The value for  $|v|$  follows a uniform distribution between  $v_{min}$  and  $v_{max}$  defining the mean speed ( $v_{mean}$ ) as:

$$v_{mean(m/s)} = (v_{max} + v_{min}) / 2 \quad (2)$$

$\theta$  follows also a uniform distribution between 0 and  $2\pi$ . When a node gets to the bounds of the scenario under study, the phase is increased automatically into  $\pi$  radians.

Mobile nodes start their movement with a random speed (module and phase) and keep on with the same speed for a defined period  $T_v$  seconds. Periodically, every  $T_v$  seconds, each node changes its module with probability  $P_v$  and its phase with probability  $P_\theta$ . Changes in module and phase are made following the same uniform distribution.

In the scenario considered in this paper, the value for  $T_v$  has been fixed to 500ms and the values for both  $P_v$  and  $P_\theta$  have been set to 0.5.

#### B. Different application mobility conditions

The performance of the MAC protocol has been analysed for three different mobility conditions (MC) that are defined by the bounds of the uniform distribution, according to the mobility model defined in the prior section.

These three mobility conditions correspond to different kinds of applications such as:

- **Low** mobility: for pedestrian or sensor applications.
- **Medium** mobility: for mixed applications.
- **High** mobility: for inter-vehicular applications.

Table 1 shows the speed ranges for each mobility pattern.

Table 1 Mobile Terminal Mobility Conditions

Mobility Condition	Speed Range	Mean Speed
Low	1-3 m/s	2 m/s
Medium	5-15 m/s	10 m/s
High	10-50 m/s	25 m/s

#### C. Definitions

It has been considered a scenario where  $N=30$  nodes move within a 2D-square of 300x300 meters, following the previously defined mobility model. The transmit power has been set to 20 dBm. The selected propagation model is the one defined in [7], which sets a radio coverage range of approximately 150 meters. Nodes generate fixed length data packets following a Poisson arrival distribution. The total offered load to the network ( $TP$ ) is considered as the aggregate of the individual load offered by every node  $i$  ( $TL_i$ ).

$$TP = \sum_{i=1}^N TL_i \quad (3)$$

In this situation, the maximum capacity  $C$  of the protocol in a single-hop scenario, which means that all nodes are within the same transmission range, can be defined as:

$$C = \frac{t\_data}{t\_frame} * r_b \quad (4)$$

where  $t\_data$  is the allocated time for data transmissions,  $t\_frame$  is the total duration of the DQCA AD HOC frame, and  $r_b$  is the transmission bit rate. In the remainder of the paper, we will consider that the total traffic load is low when  $TP < C/2$ , and that the traffic load is high when  $TP > C/2$ . In the study,  $r_b$  has been defined to be 11 Mbps. setting hence the low-high traffic load threshold at 5.5Mbps.

The performance of the protocol will be analysed in terms of throughput and packet delay, and both are defined as follows:

$$throughput(Mbps) = \frac{bits\_transmitted}{real\_time\_simulation} / 10^6 \quad (5)$$

$$delay(s) = t_{deliver} - t_{generation} \quad (6)$$

Where  $bits\_transmitted$  denote the total number of correctly transmitted bits,  $real\_time\_simulation$  is the total studied time,  $t_{deliver}$  is the instant in which a packet is delivered to either the intended destination or the master node

(cluster heads assume relaying functions), and  $t_{generation}$  is the time in which the packet was generated by the source node.

#### IV. SIMULATION RESULTS

Computer simulations have been carried out in order to evaluate the protocol performance.

Figure 1 shows that when the offered traffic load is low, the mobility conditions of the terminals do not affect the performance of DQCA AD HOC in terms of throughput. However, the higher the offered load the more deteriorated the protocol performance in case of medium and high mobility.

For a better understanding of this behaviour, it is convenient to evaluate other parameters of the network. Figure 2 represents the percentage of transmissions carried out with a free access among all the mobile terminals. When the offered load is low, the protocol behaves as a random access control protocol, and hence the mobility of the network has no effects on the performance of DQCA AD HOC. As the offered load increases, the cluster configuration substitutes the random access mechanism as master nodes control accesses to the radio channel. In this case, the mobility of the terminals becomes the most important parameter. The faster the nodes move, the more frequently the network has to be reconfigured. This reconfiguration requires a minimum set up time, and during this interval it is impossible to make data transmissions. This fact results in a loss of efficiency.

This behaviour is also shown in Figure 3 from a different point of view. The average percentage of time in which nodes work in each mode of operation (idle, slave or master) is depicted.

Let's consider a scenario in which the total offered traffic load is low. In this case, the probability of two neighbouring nodes having data to be transmitted at the same time can be considered as negligible. Then, when a node has to transmit data, it is set to master mode to do so. When its transmission is finished, the node is set back to idle mode.

Therefore, it can be assured that the average time in which a node is in a master mode is equal to the frame duration of the protocol.

In this case, if we denote  $ATM$  the average time during which a node is in master mode, and we remind that the total duration of the DQCA AD HOC frame has been previously defined as  $t_{frame}$ , we can state that:

$$ATM = t_{frame} \quad (7)$$

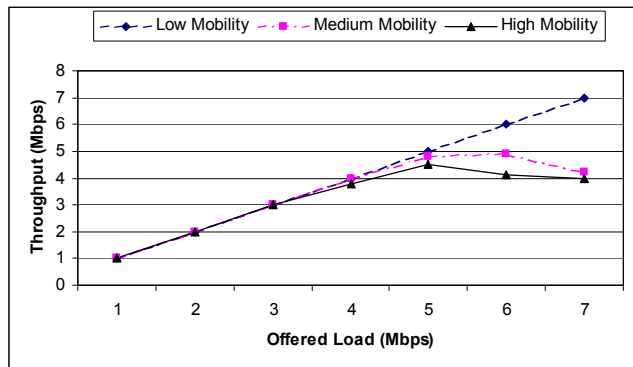


Figure 1 Throughput as a function of TL and MC

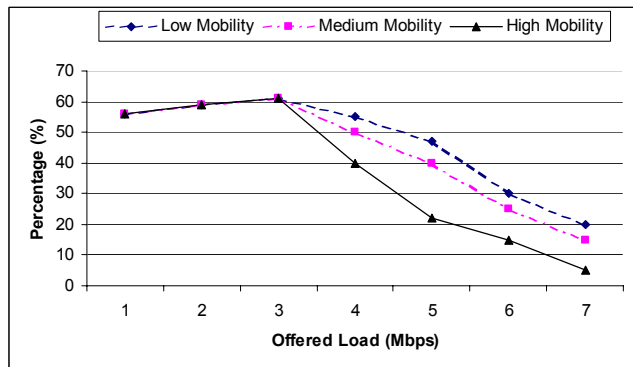


Figure 2 Percentage of free access transmissions as a function of TL and MC

Let us call  $t_{ic}$  the minimum time interval in which we consider that the topology changes enough as to require a reconfiguration of the cluster topology (we can call it 'topology coherence time'), and let us consider the mobility grades defined in Section III, it is intuitive that:

$$t_{ic} > t_{frame} \quad (8)$$

In this case, the mobility of the terminals does not affect at all the protocol performance.

On the other hand, when high traffic loads are offered to the network, neither (6) nor (7) are true. In this case, when mobility grade is increased,  $t_{ic}$  is reduced, and therefore topological changes in the network are likely to arise whilst a cluster set is defined. These topological changes trigger the reconfiguration of the network, and hence, cause the loss of efficiency depicted in Figure 1.

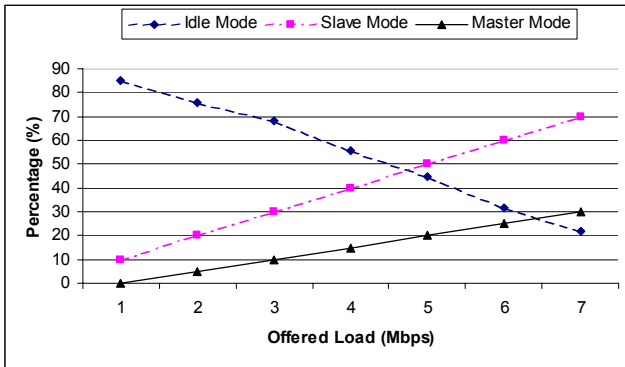


Figure 3 Mean percentage of time in each mode (master, slave and no mode)

For a better understanding of this problem, we expose a possible practical situation in which high mobility conditions can lead to inefficiencies in the access to the shared medium. It is worth to mention that this condition is not the only cause for the loss of efficiency when high mobility is considered, but it is a representative situation in which inefficiencies can occur due to the changes in the topology of the network.

Consider a scenario where a node A (see Figure 4) is in master mode, and another node B is in slave mode, connected to A. Node B is moving towards out of the transmission range of master node A. After a successful access request, node B is queuing at DTQ waiting for its turn to transmit data and is not at the first position of the queue, i.e.,  $pTQ > 1$ . When node B value for  $pTQ$  is set to 1, i.e., it has get the first position of the data transmission queue, it is granted to send a data packet during the next frame. Nevertheless, node B is not within the node A transmission range any more, due to its movement.

This situation has two undesirable effects:

- Node B's packet delay will suffer an important increase, since it will need to restart the transmission of the current packet under process.
- Within the cluster cell corresponding to node A, there will be an empty frame when maybe another node could correctly have transmitted.

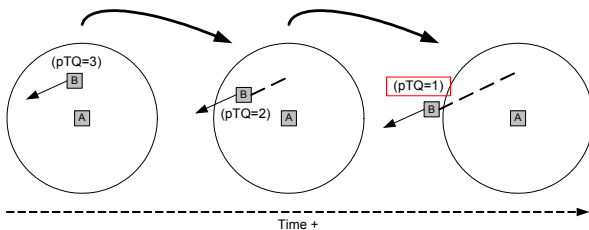


Figure 4 Example

Then, a reduction on the system performance arises.

The results discussed in this section show that the performance of DQCA AD HOC is affected by the mobility level of the terminals jointly with the total offered traffic load. When traffic load is low, the mobility of the nodes does not affect the performance of the protocol since it behaves as a random access protocol. When the traffic load is increased, the protocol performance depends on the mobility of the terminals. When the mobility is low, the performance is unaltered, whilst when the mobility is high, the protocol performance is reduced due to the automated network reconfigurations.

## V. CONCLUSIONS

In this paper we have analysed the effects of terminal mobility in a mobile ad hoc network deploying DQCA AD HOC as the MAC protocol. We have seen that when low traffic loads are considered, the protocol almost behaves as a random access protocol, and hence, it is unaffected by the mobility level of the terminals. On the other hand, when higher traffic loads are considered, the network has to be reconfigured often. In this case, high speeds of the nodes produce frequent changes in the network topology. As this reconfiguration requires of a certain setup time, it results in a loss of the overall efficiency of the system.

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