

# Channel MAC : A Novel Medium Access Control Paradigm for Wireless Ad Hoc Networks

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**Abstract**—The IEEE 802.11 has been the dominant MAC protocols used in wireless ad hoc networks. It has been shown theoretically [1],[2] that significant performance improvements as compared to 802.11 can be achieved in random access wireless networks. In this paper we propose a new paradigm of medium access control, improving the performance of wireless ad hoc networks. Simulation results obtained show a significant improvement of throughput compared to that of an 802.11 system.

**Index Terms**— Ad hoc networks, Wireless communications, Throughput improvement, Medium access control.

## I. INTRODUCTION

An ad hoc wireless network is a collection of wireless mobile nodes that self-configure to construct a network without the need for any established infrastructure or backbone. The mobile nodes themselves handle the necessary control and data acquisition tasks through the use of distributed control algorithms. Significant research effort has been invested in designing protocols suited for ad hoc networks, with various objectives such as minimising energy consumption, throughput improvement, scalability, efficient self-configuration, fairness or minimising delay. In this paper, we propose a new MAC protocol paradigm which although implicitly designed to address a number of these issues, primarily concentrate on throughput improvement.

The implementation of MAC protocols for ad hoc networks has been dominated by the 802.11 standard, which has been initially implemented in the context of single-hop Wireless Local Area Networks (WLANS). Although often used in practical implementations of MANETs, 802.11 presents several drawbacks, one of them being its poor throughput performance for large networks. Indeed, Gupta et al. (2000) introduced a random network model for studying the throughput of wireless networks with fixed topologies and showed that the throughput per source-destination pair is  $\Theta(\frac{1}{\sqrt{n \log n}})$ , where  $n$  is the number of nodes [1]. Tse et al. (2001) later showed that when nodes

are mobile it is possible to have a constant throughput scaling per source-destination pair [2], independent of the number of nodes. However, the performance of ad hoc networks with MAC protocols such as IEEE 802.11 fall well short of what is predicted by these theoretical models. The reason for this performance difference has been attributed to various factors including the inability of current MAC protocols to simultaneously take into account various effects such as fading channel conditions due to mobility, challenges to self-configuration due to decentralized channel access and unfairness in access to the common channel [3],[4].

Throughput performance degradation of the 802.11 MAC protocol in the presence of fading channels has been studied in details in [5]. In this paper, authors quantitatively estimated the degradation of the network throughput due to fading. Figure 1 shows the degradation of network throughput vs probability of “bad” channel for different network sizes ( $n$  is the number of nodes in the network). This performance degradation can be explained by the fact that the MAC layer does not get the instantaneous notification of channel variations. Therefore, when the channel goes into a “bad” state, the nodes continue subsequently sending packets, even though these packets are discarded due to the low received power. This results in a waste of bandwidth which could have been used by other nodes. In [5], the authors proposed to improve the performance of the 802.11 scheme by utilising the channel state information (CSI). The resulting MAC only transmits packets when the channel is such that the received signal will be above a pre-determined threshold which ensures proper detection of the data. Although the performance of this proposed scheme was greatly improved when compared to that on the usual 802.11, it was not approaching the theoretical prediction of Gupta et al. Similarly, a mechanism for deciding which node, out of a set of nodes, should be allowed to transmit at a given time, has been presented in [6]. The basic idea exploits the multi-user diversity principle at the

MAC layer and relies on the fact that users competing for the channel access experience peaks in their channels at different times and can therefore be discriminated accordingly. In [6], it was shown that if at each slot, access to the medium is given in a centralised fashion to the user with the best channel condition, the throughput performance of the overall system is improved.

In [7] Qin and Berry considered a medium access control protocol where each user possesses knowledge of its own channel gain. They introduced a channel-aware ALOHA where users can still exploit multi-user gains in a decentralized way. A series of related work were published in [8],[9],[10]. It has to be pointed out that these proposed schemes, although exploiting diversity as a way to determine who has priority for transmission, are still working within a slotted system and therefore, in the absence of a central entity which would determine who will transmit based on the “best” channel, collisions will still occur because all nodes with good channel conditions will compete for resources at the beginning of the slot.

The gain in throughput observed in these CSI based MAC protocols is explained by two reasons: firstly, only a reduced number of nodes (those with good channel conditions) will be competing for the available bandwidth for a given time slot which will reduce the number of collisions, and secondly, the allowed transmissions will always be successful due to the high signal quality which will reduce the number of retransmission requests, as well as the amount of bandwidth “wasted” on unsuccessful transmissions. However, in a decentralised system, collisions can still occur unless a direct sequence spreading technique is used [9] or collision avoidance mechanisms have to be implemented, resulting in an increased number of control packets and therefore drop in throughput performance.

In this paper, we propose a new MAC paradigm which exploits the random nature of the channel fading characteristics to determine in a decentralised and distributed manner which node will access the channel at any given time. We will show that this mechanism not only ensures that nodes only transmit packets when it is guaranteed that these packets will be properly received, but also makes the collision avoidance mechanism of the 802.11 redundant and operates in a non slotted system. Simulation results show that by using the new MAC paradigm, transmitters can achieve higher throughput.

In summary the major contributions in this paper are:

- 1) The introduction of the Channel MAC protocol based on complete channel information at receiver, resulting in improved throughput.
- 2) The demonstration of the Channel MAC protocol as an efficient decentralized multiple access control based on faded channel status.

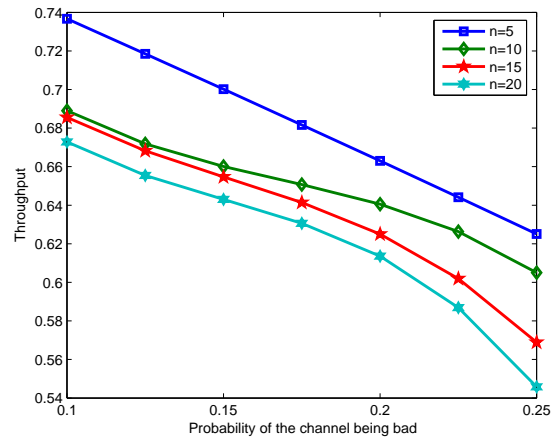


Fig. 1. Throughput degradation in IEEE 802.11 DCF mode depending on probability of bad channel

The paper is structured as follows. The motivation and the functionality of proposed MAC paradigm are described in section II. Section III presents a numerical analysis based on simulation, and discusses the implications of the results in details. Finally, section IV concludes this work with future objectives.

## II. PROPOSED MAC SCHEME

In all the above works, scheduling is accomplished either in a centralized way or at each node with the knowledge of other communication channels in the node’s neighbourhood. We use the concept of multiuser diversity, where the channel of each user will provide the scheduling scheme eliminating the scheduling-complexity at nodes. Based on channel predictions, each station can pre-arrange the instances at which it will send data-packets. Each station selects a channel gain threshold ( $P_{th}$ ) for transmission. When the channel gain goes above the  $P_{th}$  threshold the corresponding station potentially starts transmission. However, before sending data a node will sense whether the channel is busy (due to transmission of data between different source-destination pair) or not. If the medium is idle, i.e no other node is currently transmitting, the node starts transmission and continues it until the channel gain goes below the  $P_{th}$  threshold (i.e the channel goes into a fade). If any other channel becomes good during transmission, the corresponding node will sense the channel being busy and will not transmit. Thus, this MAC scheme can be viewed as opportunistic transmission similar to [11] for cellular system exploiting the “good” channel conditions. We denote this MAC paradigm: *Channel MAC*.

Given that each transmitter-receiver pair has an independent fading channel, the probability of two or more channels crossing the transmission threshold on a positive slope exactly at the

same time is assumed to be negligible. Although this probability may become significant for large node densities, we have observed that this assumption is valid for most relevant network scenarios. Furthermore, we assume an insignificant propagation delay, which results in a negligible collision probability due to sensing delays. Our discussion considers a fully connected ad hoc network ignoring the impact of hidden and exposed terminal problems. Mechanisms similar to RTS/CTS scheme to alleviate these issues are left as future work.

Figure 2 explains in detail the principles of Channel MAC. In Figure 2, we observe that as soon as *Channel 1* goes above the threshold, transmission for node 1 starts. Transmission is terminated as soon as the channel gain goes below the threshold. Next, *Channel 2* goes above the threshold and starts transmission. During the transmission at node 3, *Channel 2* and *Channel 1* become active (good) but both node 1 and node 2 will sense the channel busy at those instances and defer from data transmitting.

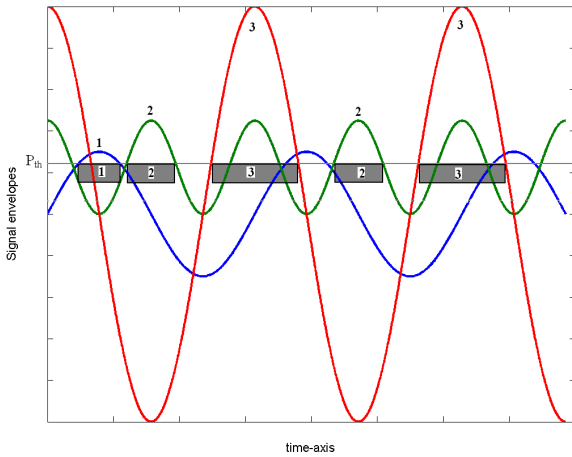


Fig. 2. Data transmission using Channel MAC

### III. SYSTEM MODEL

Let us define a neighbourhood of  $2n$  nodes, where  $\mathcal{N}_T \in (1, 2, \dots, n)$  are the transmitters and  $\mathcal{N}_R \in (1, 2, \dots, n)$  are the receivers. For symmetry let us assume that each transmitter  $i \in \mathcal{N}_T$  is communicating with receiver  $i \in \mathcal{N}_R$ . If only the  $i^{\text{th}}$  transmitter transmit at a given moment, the received signal at receiver  $i \in \mathcal{N}_R$  is given by:

$$y_i(t) = \sqrt{H_i}x_i(t) + z(t)$$

where  $x_i(t)$  is the transmitted signal,  $H_i$  is the time-varying channel gain, and  $z(t)$  is the additive white Gaussian noise. It is assumed that transmitter power is kept at a constant value

throughout each transmission. If transmitter  $i$  uses transmission power  $P_{ti}$ , the received power at the receiver is given by  $P_{ri} = H_i P_{ti}$ . Furthermore, channel gain is assumed to be fixed during each transmission period. Channel gains between each transmitter-receiver pair during each transmission period are i.i.d random variables with probability density  $f_H(h)$ .

Node  $i$  will transmit only when the channel gain is above a certain threshold  $H_T$ . For simplicity we assume that when  $H_i \leq H_T$ , it takes the constant value  $H_T$  and when  $H_i > H_T$ , it takes a random value such that  $H_i$  is distributed with density function  $f_H(h)$ .

From the above description it can be observed that the channel between each transmitter-receiver pair is modelled as a block-fading channel with non-uniform fade durations. In this paper we assume that channel gains are Rayleigh distributed; hence  $f_H(h) = \frac{\exp^{-h/h_0}}{h_0}$ , where  $h_0$  is the average fading level. Furthermore, using the Rayleigh distribution we can calculate the average transmission interval (i.e. average duration where  $H_i > H_T$ ) to be  $\frac{h_0}{\sqrt{2\pi}f_m H_T}$ , where  $f_m$  a parameter that depends on the mobility between the transmitter-receiver pair.

As the transmission interval differs from transmission to transmission, we intend to use variable size packets in our system model. Figure 3 shows the system model that we have used for a single transmitter-receiver pair in Channel MAC. The bad channel condition denotes the duration at which channel gain is less than the threshold used in a node.  $H_{ij}$  corresponds to the channel gain of  $i^{\text{th}}$  transmitter-receiver pair during the time interval  $\theta_j$ .

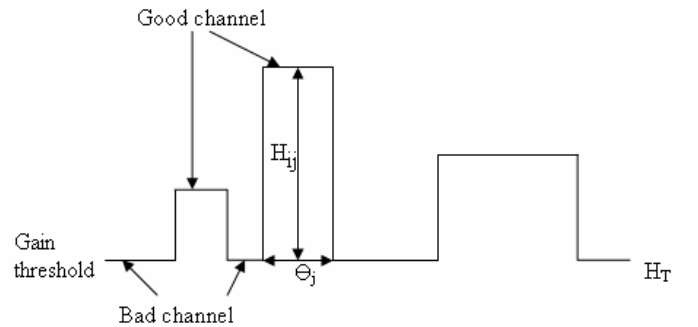


Fig. 3. Channel model of the system

To understand the throughput performance of Channel MAC protocol let us consider the following lemma.

**Lemma 1:** With multiple transmitter-receiver pairs and saturated load-condition (i.e. at any given time all nodes have a packet to send), the throughput of the system is lower-bounded by the throughput of a single transmitter-receiver pair. For a single transmitter-receiver pair the throughput equals the summation of all non-fade durations (i.e. where  $H_i > H_T$ ) in a

particular time-span of the corresponding channel. Mathematically,

$$\text{Throughput}_{\text{one channel}} = \frac{\sum_j \theta_j}{T} \quad (1)$$

where  $\theta_j$  is the  $j^{\text{th}}$  non-fade duration and  $T$  is the time-span over which the performance is measured. The lemma follows directly from the operation of the Channel MAC protocol.

#### IV. ANALYSIS OF CHANNEL MAC THROUGHPUT PERFORMANCE

It is sometimes desirable to estimate quantities whose exact values are difficult to calculate. In these cases, Monte Carlo simulations can be used to provide an estimate. This section presents the detailed Monte Carlo based throughput estimation of Channel MAC.

In the simulation we generate a number of independent channel gain profiles according to the system model described in section III. For this study we have assumed the channel gain characteristics (i.e the times where channel gain is greater than the threshold) are Rayleigh distributed. We define the parameter “probability of good channel”,  $p$ , as the probability that the channel gain  $H_i$ , is above a certain threshold,  $H_T$ . Assuming that the channel gain characteristics are Rayleigh distributed, the probability that the channel gain is above a certain threshold  $H_T$  is given by:

$$p = \exp\left(-\frac{H_T^2}{h_0^2}\right) \quad (2)$$

where  $h_0$  is the average value of fading.

In the simulation, for a given  $p$  value we derive the channel gain threshold,  $H_T$ , using equation (2). Then we generate a channel model, covering a time period  $T$ , in the form of a set of time intervals,  $\Theta = \{\theta_1, \theta_2, \dots, \theta_i, \dots\}$ , where the channel gain is above the threshold  $H_T$ . These  $\Theta$  time periods are the transmission intervals of a node when the probability of good channel is  $p$ . Throughput of this single node is given by equation (1). For  $n$  nodes,  $n$  sets of independent  $\Theta$  time intervals, were generated. Recall that in Channel MAC, a node will only transmit when the channel is idle. Therefore, when more than one node predicts the channel to be above the threshold during a certain time interval, only the first node that crosses the threshold on a positive slope will be able transmit. Hence, when there are overlapping transmission intervals from different nodes, only the first transmission interval in the overlapping group contributes to the throughput. We repeat the above steps a number of times and get the average of all the simulation runs as the final throughput. We assume same  $p$  for all the stations in multiple node simulations. We have verified the sample size

was sufficient to validate the correctness of the result using randomness of the input variables and statistical error bounds.

Network throughput of Channel MAC for different probabilities of good channel ( $p$ ) is presented in Figure 4. Performance of IEEE 802.11 under fading channel conditions are also shown in this figure [5].

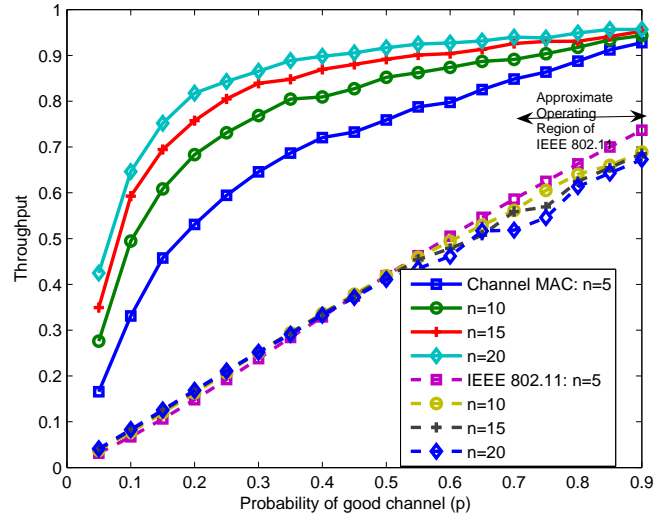


Fig. 4. Throughput vs.  $p$  for different number of stations

It can be noted that Channel MAC outperforms 802.11 for all  $p$  values. Furthermore, with higher number of nodes, Channel MAC achieves higher throughput at lower  $p$  values, increasing the potential operating range. For example for  $n = 5$ , throughput of the system is greater than 0.8 for  $p > 0.6$ , while for  $n = 20$ , same level of throughput can be achieved for  $p > 0.2$ . For larger node numbers (for example  $n = 20$ ) Channel MAC throughput tend to saturate for  $p$  values greater than 0.5, resulting a wide range of operating parameters that can be used to achieve very high throughput. This makes it possible to further optimise the performance of channel MAC based on either performance parameters such as power and rate allocations.

It is very interesting to note that, in Channel MAC, increasing the number of nodes improves the throughput as opposed to IEEE 802.11. The significance of this observation is that with increasing number of nodes the total throughput of the network will continue to increase, contrary to the performance of most other medium access control protocols. This is due to the fact, with increasing number of nodes, at any given time the probability of finding a transmitter-receiver with a good channel increases, increasing the transmission opportunities; and hence throughput. Note here that with increasing number of nodes, throughput of each individual node will decrease despite the increase in total network throughput. Furthermore, we have assumed that there are no collisions between nodes in Channel

MAC. Although the probability of collision in Channel MAC is small, it will increase with increasing number of nodes. The full effects of collisions on the throughput performance will be studied in the future.

## V. CONCLUSION

In this paper we propose a new channel based MAC paradigm to improve throughput. The simulation results presented show that Channel MAC can achieve higher throughput than IEEE 802.11 in distributed wireless networks. With a simple simulation study we have shown that the proposed Channel MAC scheme achieves higher throughput as compared to 802.11 MAC protocol. From the results it can be observed that the throughput in channel MAC scheme increases with increasing number of nodes, due to the multi user diversity of the system.

Some of the important features of the Channel MAC scheme are:

- Achieve higher throughput by exploiting random fading nature of wireless channels;
- Minimize packet loss due to transmitting while the channel is in fades;
- Use of the randomness of fading channels to achieve distributed access control among nodes.

Drawbacks of this scheme are the bandwidth required to exchange channel information between transmitter-receiver pairs and the added processing power required to predict channel conditions. Bandwidth required to transmit channel information can be minimized by piggy-backing the information in Acknowledgement packets. We intend to fully address these issues in the future. Some of the issues that needs to be addressed to design a full MAC protocol using the Channel MAC concept are:

- Effective mechanism to predict channel conditions;
- Effective mechanism to exchange channel information;
- Mechanisms to eliminate or minimize hidden and exposed terminal problems.

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