A distance-aware model of 802.11 MAC layer

Chadi Barakat[1], Gion Reto Cantieni[2]

[1] INRIA Sophia Antipolis - France, email: cbarakat@sophia.inria.fr
[2] EPFL - Switzerland, email: gionreto.cantieni@epfl.ch

1 Introduction: Motivation and overview of the model

Nowadays, the IEEE 802.11 WLAN technology offers the mostly used wireless access to the Internet. This technology specifies both the Medium Access Control (MAC) and the Physical layer (PHY) [1]. The PHY layer applies the correct modulation scheme given the channel conditions, whereas the MAC layer decides in a distributed manner how the available bandwidth is shared among all stations (STA).

Different analytical models and simulation studies have been elaborated the last years to evaluate the performance of 802.11 MAC layer [3–5]. These studies mainly aim at computing the saturation throughput of the MAC layer given the number of STAs. One of the most promising models has been the so-called Bianchi model [5]. It provides closed-form expressions for the saturation throughput and for the probability that a packet transmission fails due to contention. The model is based on a simple and elegant discrete-time Markov chain that describes the dynamics of the contention window of 802.11 MAC layer. It analyzes the case of saturated STAs, i.e. STAs that always have packets to send, accounts for the cases of ad-hoc and infrastructure modes, and works well when RTS/CTS is enabled or not.

The modeling of the 802.11 MAC layer is an important issue for the evolution of this technology. One of the major shortcomings in existing models is that distances between STAs and between STAs and the access point (AP) are not considered. The distance is a key factor to consider in wireless given the well known fast attenuation of the power with the distance. The existing models for 802.11 MAC layer assume that all STAs have approximately the same power at the receiving STA, so when two or more STAs emit a packet in the same slot time, all their packets are lost, which may not be the case if one STA is close to the receiving STA and the other STAs are far from it. The close STA will receive a better performance in this latter scenario since its packets will arrive at the receiving STA with a higher power compared to the other emitting STAs, so they might be correctly decoded while the other packets might be lost. This fact can be modeled by considering the spatial positions of the STAs in addition to the dynamics of 802.11 MAC layer. In [6] the spatial positions of STAs are considered for the purpose of computing the capacity of wireless networks, but only an ideal model for the MAC layer issued from information theory is used.

Our work reuses the model for 802.11 MAC layer from [5] and extends it in such a way that the interference caused by the other emitting STAs than the STA under study is considered (not only the fact that they are transmitting in the same slot time as in [5]). Our aim is to compute, for a given topology, the saturation throughput of any STA as well as the total saturation throughput of the medium. Both throughputs will be a function of the positions of the STAs with respect to each other as well as with respect to the AP. This extension will be done by changing the loss probability in the Bianchi model. In the Bianchi model, an STA loses a packet if at least one other STA transmits in the same slot time. In our case, an STA loses a packet if the signal to noise ratio when its packet arrives at its destination is high enough for it to be correctly decoded. The impact of the other STAs transmitting at the same time on the loss probability will appear in the computation of the interfering signal they will cause at the receiving STA. STAs that are not transmitting in the same slot time will not contribute to this interfering signal. The impact of distances will appear in the computation of the power of all signals (main and interference) at the receiving STA.

Note that since we will be basing our computation of the packet loss probability on the signal to noise ratio, our model will finally account for many other factors than the spatial distribution of STAs. Among others, the model will account for: the background noise, the interference caused by other systems than 802.11 STAs, the transmission powers of the STAs and the AP, the multipath fading, the modulation scheme used, the error detection and correction technique at the PHY layer. In fact, our work will build upon the Bianchi work a general model for IEEE 802.11 that covers both the PHY and MAC layers. Such a general model is of considerable importance for the performance evaluation and the tuning of the IEEE 802.11 technology (e.g. optimization of the error detection and correction techniques, optimization of the transmission power). Another application is the optimal placement of APs in a building that maximizes the total throughput of the medium while ensuring some fairness among STAs.

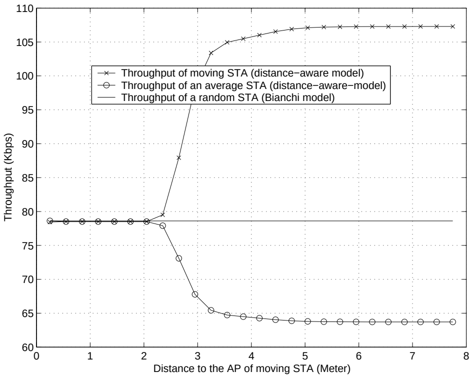

Figure 1. Throughput in the fixed topology case.

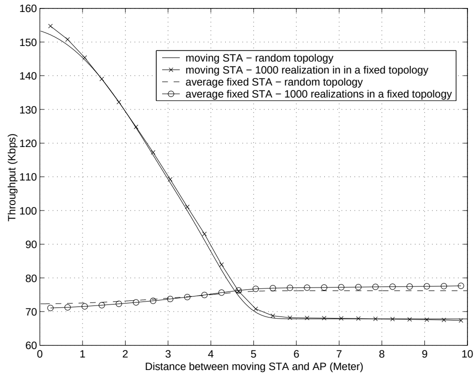

Figure 2. Throughput in the random topology case.

In the next section we present some numerical results obtained with our model for the particular case of infrastructure mode and RTS/CTS disabled. For more details on the study of this particular case, we point the reader to [2].

2 Throughput vs. Distance to the AP: Some numerical results

Without loss of generality we assume in [2]: (i) the traffic only flows from STAs to the AP and all STAs are saturated, (ii) all STAs use the Distributed Coordination Function (DCF) of 802.11 and disable the RTS/CTS functionality, (iii) all STAs can hear each other, so the hidden terminal problem does not exist, (iv) a packet is lost if at least one of its bits is corrupted (no Forward Error Correction is implemented), and (v) the power drops as the inverse of the distance square. As for the positions of STAs, we consider two topologies. First, the positions of all STAs are known. The only randomness in this case lies in the dynamics of the MAC layer. Second, STAs are uniformly distributed in the plane. Next are some numerical results obtained with our approach (see [2] for more details).

Consider the fixed topology case. We place 5 STAs at 1 m from the AP, and the other 5 STAs are placed on a circle centered at the AP whose radius is changed from 0 to 8 m. We compute the saturation throughput of one fixed STA and that of one moving STA. The throughputs (in kbps) are shown in Fig. 1. We also plot in the same figure the throughput obtained by an STA if the Bianchi model was used. The results are very interesting. When the STAs are all close to the AP (less than 2m), they all have the same throughput and it is equal to the one given by the Bianchi model. When the moving STAs are far from the AP (more than 5m), their power level at the AP starts to be very low compared to that of the close STAs, so they lose their packets when they contend for the medium with the close STAs. The close STAs get then a high throughput and the moving STAs get a low throughput approximately equal to the bandwidth not used by the close STAs. The Bianchi model is no longer good in this case.

We now consider the random topology case, where STAs are uniformly distributed in a disk of radius 10 m centered at the AP. We pick one STA, move it from 0 to 10 meter, and compute its throughput averaged over all possible locations of the other 9 STAs. We also compute the average throughput of any other STA. The results are shown in Fig. 2. When the moving STA is close to the AP, it gets higher throughput than the average throughput of the other STAs and than the throughput given by the Bianchi model (Fig. 1). However, this throughput decreases when the STA moves farther from the AP until it drops below the average throughput of the other STAs. The minimum throughput of the moving STA is again obtained at a distance of 5 m. Note that Fig. 2 also shows the average throughput over 1000 realizations of the 9 STAs. We use the fixed topology method to find the throughput per realization, and we average over all realizations. The purpose is to validate our analysis in the random topology case.

References

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