Efficiency of Physical Carrier Sensing in Wireless Access Networks

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Abstract

We propose an analytical approach for evaluating the impact of physical carrier sensing in simple wireless access networks. We describe the system through a time-continuous Markov Chain, and we gather from its solution performance measures in terms of throughput and collision probability. We derive qualitative dimensioning criteria for the carrier sensing itself under different network conditions.

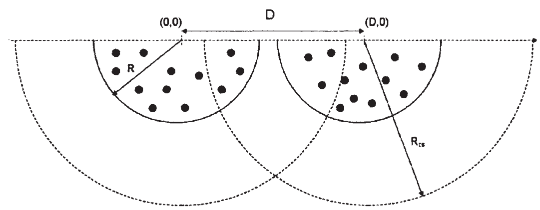

Figure 1: *Wireless Network Topology.*

1 Backgorund and System Model

The capability of reusing the shared resources in wireless systems is strictly related to the tuning of the specific access mechanism. Commonly deployed WLANs resort to the IEEE 802.11 standard, which adopts physical Carrier Sensing (CS) at the access level to limit the impact of interference.

The tuning of the CS is critical in determining the network efficiency. In fact, intuitively, collisions reduce as the CS range is increased, since the number of terminals accessing the channel decreases, thus lowering the overall network interference. On the other hand, enlarging the CS range can dramatically affect the channel reuse, since it limits the number of concurrent transmissions within the network.

Some works have recently appeared on the carrier sensing design issue. Zhu *et al.* [1] study the optimal carrier sensing setting for specific ad hoc network configurations and find out that an optimal value of the carrier sensing threshold does exist with respect to the network throughput. References [2] and [3] share the same ideas of [1]; the former considers the MAC layer overhead in the computation of network throughput, the latter analyzes through simulation the impact of carrier sensing on the performance of pure ad hoc networks. Fuemmeler *et al.* [4] prove that the product of transmitted power and carrier sensing sensitivity threshold must be kept constant in order to maximize the aggregate throughput of general ad hoc networkas. References [5, 6, 7] focus on IEEE 802.11 Distributed Coordination Function (DCF) and study, mainly through simulations, the combined effect of physical carrier sensing and multi-rate transmissions.

Generally speaking, all the works mentioned above analyze the carrier sensing in ad hoc networks either resorting to simulations, or to static geometrical models of the channel reuse. Up to now analytical evaluations of the CS setting and the relative achieved reuse accounting for the dynamics of the traffic both in time and space are still missing; the only attempt in this direction is reference [8], which proposes a spatio-temporal model of the physical CS representing the packet transmissions attempts as a three-dimensional Poisson-point process in space and time, with the simplifying assumption of an infinite number of interfering sources.

In this extended abstract, we describe an analytical model of a simple wireless access network based on a time-continuous Markov Chain, and we show how to evaluate the throughput versus channel traffic curve as a function of CS setting and other network topology parameters.

The reference network architecture we use to introduce the model is composed of two wireless Access Points (APs) set at fixed distance D (Figure 1). We assume that the propagation time between any couple of transmitters is small compared to the packet transmission time to the point that the effectiveness of the CS in avoiding access collisions is complete. Transmissions are generated according to a Poisson-point process with intensity λ. Once a transmission is generated, the position of the transmitting terminal is chosen in the network. The terminal senses the channel and, if the channel is sensed busy (i.e., the perceived power level is above the carrier sensing threshold), the transmission is cancelled and the terminal vanishes. Otherwise, the transmission starts and, after a period of time exponentially distributed with parameter μ, ceases and the terminal vanishes, whether the transmission has been correctly received or not.

Given a transmitter in position i and a receiver in position j, the received power level at j out of a transmission from i is given by: $P_r(d_{ij}) = P_t d_{ij}^{-\eta} 10^{\frac{\epsilon}{10}}$, where d_{ij} is the distance between position i and position j, P_t the transmitted power, η the attenuation factor, and $10^{\frac{\epsilon}{10}}$ accounts for the loss due to slow shadowing, being ϵ a normal variate with zero mean and σ^2 variance. Furthermore, if we denote by $P_I(d_{kj})$ the interfering power received from a concurrent transmitter located at position k, a transmission from i to j is successful if the *Signal To Interference and Noise Ratio* (SINR) is not below a

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given threshold γ for all the duration of the transmission, i.e.,

$$\frac{P_r(d_{ij})}{N + \sum_{k \in Int} P_r(d_{kj})} \geq \gamma, \quad (1)$$

where N represents the thermal noise contribution and Int the set of current interferers.

The thermal noise determines an area around the receiver where each transmission is correctly received if no interference is present[1]. The average radius of this area, called thermal noise range, is given by: $R = \left(\frac{P_t}{N\gamma}\right)^{\frac{1}{\eta}}$. In our case, a terminal is allowed to access the channel if, at access time t, the following condition holds:

$$\sum_{k \in Int} P_r(d_{kj}) \leq P_{CS}, \quad (2)$$

where P_{CS} is the carrier sensing threshold. In the case when only a single interferer can be active at a time, i.e., $|Int| = 1$, the carrier sensing power threshold induces a blocked circular area around such interfering terminal with radius $R_{CS} = \left(\frac{P_t}{P_{CS}}\right)^{\frac{1}{\eta}}$.

2 System Throughput: A Markovian Analysis

The system described above becomes analytically tractable if we assume a discrete set of n feasible locations for the transmitters. In this case, we introduce the multi-dimensional time-continuous Markov Chain: $(X(t), Y(t), V_a(t), V_b(t))$, $(0 \leq X, Y \leq n)$, where integers X and Y are labels identifying the positions of terminals attached to AP a and b respectively, $X = 0$ and $Y = 0$ representing those cases where no terminal is transmitting towards AP a and b, respectively. V_a and V_b are two binary variables defining the status of the transmission (0 if not collided, 1 if collided). In the following, we will refer to terminals a and b to indicate terminals transmitting towards AP a and b respectively. For example, state $(1_a, 1_b, 1, 1)$ represents the case where a terminal in position 1_a is transmitting towards AP a, a terminal in position 1_b is transmitting towards AP b and both are experiencing a collision.

The state space of the Markov chain is composed of all the possible combinations of the four variables X, Y, V_a, V_b, and can be synthetically represented as in Figure 2(a). Here the values of X and Y are extended to include all the cases of the four combinations of (V_a, V_b), i.e., states in which $1 \leq x \leq n$ denote the positions of terminal a where its ongoing transmission is not (yet) collided, states in which $1' \leq x \leq n'$ denote the positions of terminal a when its ongoing transmission has collided. Similar meaning is assumed by variable y. We use throughout the paper the formalism $i' = i + n$ to define the indices of collided states, both in X and Y.

The state space in Figure 2(a) can be split into nine distinct subsets of states whose logical meaning is reported in Figure 2(b). In details:

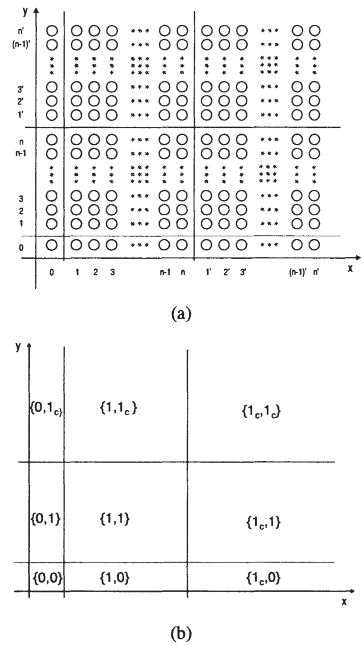

Figure 2: *Simplified Time Continuous Markov Chain representing the system in Figure (a), meaning of the different zones of the chain in Figure (b).*

- zone $\{0, 0\}$ is composed by the single state $(0, 0)$ where no terminal is active;
- zones $\{1, 0\}$ and $\{0, 1\}$ are composed by states where only one terminal is active (a and b, respectively) and the ongoing transmission has not suffered any collisions yet;
- zones $\{1_c, 0\}$ and $\{0, 1_c\}$ are composed by states where only one terminal is active (a and b, respectively) and the ongoing transmission has already suffered some collisions;
- zone $\{1, 1\}$ is composed by states where both terminals a and b are active and both ongoing transmissions have not suffered any collisions;
- zones $\{1_c, 1\}$ and $\{1, 1_c\}$ are composed by states where both terminals are active and only one of the ongoing transmissions (a and b, respectively) has already suffered some collisions;
- zone $\{1_c, 1_c\}$ is composed by states where both terminals a and b are active and both ongoing transmissions have already suffered some collisions.

Transition intensities $q_{(xy),(zw)}$, between states (x, y) and (z, w) of the chain (where it is always $(x, y) \neq (z, w)$) can be easily determined according to Eq. (2) and Eq. (1), once positions of the nodes and shadowing samples are known. The explicit formalization of such parameters is not reported here

[1]The shape of this area depends on the shadowing effect on the signal propagation

due to space limitations, however, Figure 2 shows how the Markov chain can be obtained, given a sample physical topology with just two positions in the network (Fig. 2.a). The two positions are feasible as for the physical carrier sensing algorithm, however, if two transmitters located at the two positions are both active in the system, the SINR of position B is below the quality threshold. In Fig. 2.b, this is represented by transitions from states $(A, 0)$ and $(0, B)$, where the two transmission are active alone in the system, to state (A, B'), where both are active but the one in b has suffered a collision.

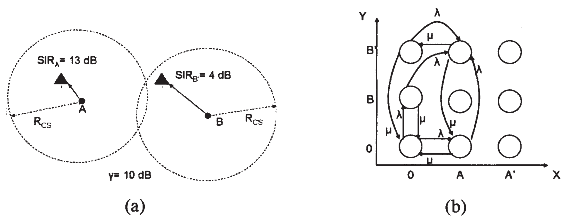

Figure 3: *Sample topology (Figure (a)) and corresponding Markov chain (Figure (b)).*

The throughput of the generic AP, say AP a, can be evaluated from the chain as:

$$S_a = \lambda_{Sa} D_a,$$

where λ_{Sa} is the frequency of transmissions ending up with success and D_a is the average duration of such transmissions. Frequency λ_{Sa} can be evaluated as:

$$\lambda_{Sa} = \mu \sum_{(x,y)\in\mathcal{A}} \pi_{(x,y)},$$

where $\mathcal{A} = \{1, 0\} \bigcup \{1, 1\} \bigcup \{1, 1_c\}$ is the set of states where a non-collided communication is active toward AP a, and $[\pi_{(xy)}]$ is the stationary distribution of the chain, which can be retrieved with standard solution methods. In the full paper we also show how to calculate D_a.

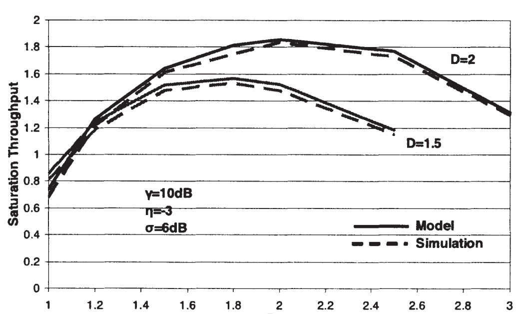

Figure 4: *Network saturation throughput (with $G = 1000$) versus the carrier sensing range R_{CS} when varying the normalized distance between the two APs; m =20.*

The proposed model provides a powerful tool to assess network throughput, which can be used to support network planning decisions, where the spatial density of the traffic can be made discrete and predicted *a priori*. Furthermore, performance measures of general networks can be obtained by averaging on several solutions (say m) of the model, where at each solution the fixed locations are randomly drawn in the network.

Figure 4 reports the network saturation throughput, i.e., the throughput at $G = 1000$, versus the CS range (R_{CS}) for different values of the distance between the two APs. As clear form the figure, an optimal value of the carrier sensing radius (and threshold) does exist for both the network configuration considered. Such value comes from a trade off between the need of protecting from collisions which calls for high carrier sensing radius (low carrier sensing thresholds), and the need of reusing the channel. The calculated throughput is also compared against a simulation of the same 2-APs scenario, where entering terminals are drawn randomly throughout the network.

3 Concluding Remarks

In this extended abstract, we have proposed an a Markovian model able to predict the throughput performance of a pure physical carrier sensing access mechanism in simple wireless access network. In the full version of the paper, we also show that the model can be extended to account for hidden node collisions, and propagation impairment due to fast fading.

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