Optimizing Carrier Sensing in 802.11 Multihop Wireless Networks

D. Valerio[*], F. Vacirca[*†], L. De Cicco[‡], S.Mascolo[‡], T.Ziegler[*]
[*] ftw. Forschungszentrum Telekommunikation Wien
[†] Infocom Dept. University of Rome ”La Sapienza” [‡] DEE - Politecnico di Bari

Abstract— **This paper focuses on the analysis of carrier sensing mechanisms adopted by the 802.11 medium access control. Through an analytical study, a mechanism to dynamically set the Carrier Sensing Range is presented. The mechanism improves the spatial reuse by avoiding the interference of neighbor nodes. Simulation results show that setting the Carrier Sensing Range according to the proposed model optimizes the network goodput. Additional simulations without Virtual Carrier Sensing enabled confirm the analytical results and show the inefficiency of typical Carrier Sensing Range values.**

I. INTRODUCTION

Wireless mesh networks are quickly emerging as a solution for broadband wireless connectivity. Many vendors sell mesh products based on the 802.11b technology (e.g. [1]). This standard, originally designed for Wireless Local Area Networks, has become the de facto standard for multi-hop networks. In the last years a big effort has been dedicated to the optimization of the 802.11 protocol in multihop scenarios. Several papers focused on the optimization of the MAC protocol for improving the spatial reusability. In [2] the authors investigate the effectiveness of RTS/CTS handshake mechanism to reduce the interference between nodes. In [3] and [4] the authors evaluate the spatial reuse of 802.11 links in multihop scenarios when the RTS/CTS handshake is enabled. Instead [5] and [6] investigate the effectiveness of the Physical Carrier Sensing. Other schemes for the optimization of the 802.11 spatial reuse have been proposed based on a power control mechanism (e.g. [7] and [8]) or using directional antennae [9]. Differently from previous papers, we propose an adaptive setting mechanism of the Carrier Sensing Range to increase the performance of MAC 802.11b and the spatial reuse of long chain topologies without the overhead of a VCS-based solution or the cost of the directional antennae.

II. CARRIER SENSING

In the 802.11 networks [12] the access to the medium is based on carrier sense multiple access with collision avoidance (CSMA/CA). Two carrier sensing mechanisms are defined in the standard: Physical Carrier Sensing (PCS) and Virtual Carrier Sensing (VCS). The channel is marked busy if either PCS or VCS mechanisms indicate that the channel is busy. The PCS is performed at the physical layer by the Clear Channel Assessment (CCA) function which monitors the channel to determine when the medium is free. The CCA compares the Received Signal Strength Indicator (RSSI) to a programmable threshold and updates the channel status information asynchronously with respect to slot boundaries.

The 802.11 standard defines three CCA operation modes: 1) when the energy exceeds the Energy Detection Threshold (EDT) it reports that the medium is busy; 2) the medium is considered busy if a valid DSSS signal is detected, even if it is below EDT; 3) the medium is marked busy if a DSSS signal is detected and the energy is above the threshold. According to the selected CCA mode, the CCA reports the state of the medium to the PLCP (Physical Layer Convergence Protocol). The PLCP then passes this information to the MAC layer.

The definition of EDT is strictly related to the concept of the Carrier Sensing Range (CSR, the range around the transmitter within which a STA is considered interferer). A lower value of EDT results in larger CSR. The latter should be set to cover all the stations whose transmissions lead to a violation of the Signal to Interference and Noise Ratio (SINR) specification at the receiver. Using the TwoRayGround propagation model and being d_{tr} the distance between the transmitter and the receiver, the received power is given by:

$$P_{tr} = P_t G_t G_r \frac{h_t^2 h_r^2}{d_{tr}^4}$$

where P_{tr} is the received power in the receiver from the transmitter, P_t is the transmitted power, G_r and G_t are the gains of the receiver and transmitter antennae, h_r and h_t are the heights of the receiver and transmitter antennae. Considering the same transmitted power and the same hardware at every station, the SINR (γ) at the receiver is given by:

$$\gamma = \frac{P_{tr}}{P_{ir} + P_n} \simeq \frac{P_{tr}}{P_{ir}} = \frac{P_t G_t G_r \frac{h_t^2 h_r^2}{d_{tr}^4}}{P_i G_i G_r \frac{h_i^2 h_r^2}{d_{ir}^4}} = \frac{d_{ir}^4}{d_{tr}^4}$$

where d_{tr} is the distance between transmitter and receiver and d_{ir} is the distance between the interfering node and the receiver. Thus the interference range of the receiver depends on the distance d_{tr} and on the minimum required SINR (γ_{th} as defined in the specification): $d_{ir_{MAX}} = \sqrt[4]{\gamma_{th}} \cdot d_{tr}$.

Using a static value of EDT limits the carrier sensing capabilities since the interference range depends on d_{tr} that varies dynamically. According to these considerations, EDT should be set to:

$$EDT = P_i G_i G_t \frac{h_i^2 h_t^2}{d_{ti_{MAX}}^4}$$

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where P_i is the power of the interfering node; G_i and G_t are antenna's gains of interfering and transmitter nodes, h_i and h_t are the heights of the interfering and transmitter antennae and $d_{ti_{MAX}}$ is the maximum distance between the transmitter and interfering nodes which causes interference. The latter can be evaluated by adding $d_{ir_{MAX}}$ to the distance between the transmitter and the receiver. Thus:

$$EDT = P_i G_i G_t \frac{h_i^2 h_t^2}{(\sqrt[4]{\gamma_{th}}+1)^4 \cdot {d_{tr}}^4}$$

Considering a symmetric medium:

$$EDT_t = \frac{P_r}{(\sqrt[4]{\gamma_{th}}+1)^4} \tag{1}$$

where EDT_t is the optimal EDT on the transmitter and P_r is the received power. Note that the latter is the same at both nodes due to the symmetry assumption.

As an example we show in Figure 1 the case with five nodes (A,B,C,D and E) placed on a straight line.

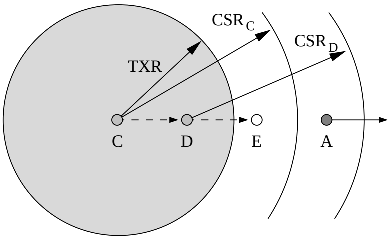

Fig. 1. DPCS example.

The ratio between the EDT in C and D and the received power transmitted from A depends on the number of hops between A and C and A and D:

$$\frac{EDT_C}{P_{AC}} = \frac{3^4}{(\sqrt[4]{\gamma_{th}}+1)^4} \quad \frac{EDT_D}{P_{AD}} = \frac{2^4}{(\sqrt[4]{\gamma_{th}}+1)^4}$$

which are equal to 1.36 and 0.27 when γ_{th} is 10dB as in the 802.11b specifications. This example shows that EDT_C is greater than P_{AC} and that EDT_D is lower than P_{AD}, indicating that during a communication between A and B, C can transmit to D while D is interdicted to transmit to E, respecting the IEEE 802.11 standard SINR specification.

III. RESULTS

In order to analyze the performance of the DPCS scheme, we compare the behaviour of three EDT settings:

- **CSR=2.2TXR**: The setting of 802.11b WLAN cards provided with the Lucent Orinoco Wavelan chipset [10] as implemented in the 802.11 module for ns-2.
- **CSR=TXR**: The standard setting used by the widespread Intersil [11] chipset.
- **DPCS**: The EDT as computed using equation (1),

where TXR is the transmission range of the corresponding hardware.

Before showing numerical results we discuss the behaviour of the three settings in some particular scenarios. In the following examples during a communication between stations A and B, another station, C, senses the channel in order to start a transmission to D. All the nodes are alligned on a straight line l meters away from each other.

A. Overestimation

Consider the scenario in Figure 2 where A is distant $2l$ from D and $3l$ from C.

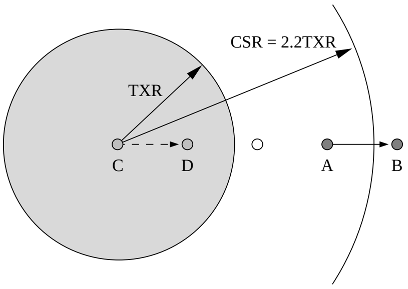

Fig. 2. Overestimation example.

In this case the CSR=TXR rule and the DPCS rule would allow the contemporaneous transmission of A to B and C to D. In the CSR=2.2TXR case the transmission is interdict to C bacause CSR is too large. Computing the SINR with the TwoRayGround model, we obtain: $P_{CD}/P_{AD} = d_{AD}^4/d_{CD}^4 = (2l)^4/l^4 = 16 = 12.04dB$, where P_{CD} and P_{AD} are the received power of the signal received in D from C and A respectively. In this case the obtained SINR is greater than 10dB meaning that the power transmitted by A does not interfere with the transmission from C to D and the latter is able to decode frames. In spite of the computed SINR, the CSR=2.2TXR rule does not allow the transmission as it overestimates the carrier sensing range.

B. Underestimation

The second case shown in Figure 3 depicts the situation where A and C have the same distance from D. In this case the SINR at node D is basically 0 dB because the interference power at the receiver (D) is equal to the useful power transmitted by C. Observing Figure 3 it is possible to notice that the CSR=TXR setting would allow A and C to transmit simultaneously, leading to packet collision and to a steep goodput decrease. In this case the CSR=TXR setting is not able to work correctly without the RTS/CTS handshake mechanism (VCS), whereas DPCS and CSR=2.2TXR modes interdict the simultaneous communication.

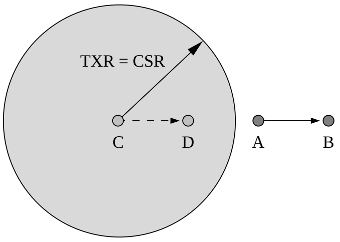

Fig. 3. Underestimation example.

C. Long chain topology

The effect of the incorrect EDT settings is underlined by the long chain topology, depicted in Figure 4. The topology consists of 10 hops. If we set a communication between A and M, after some milliseconds every node will be competing to use

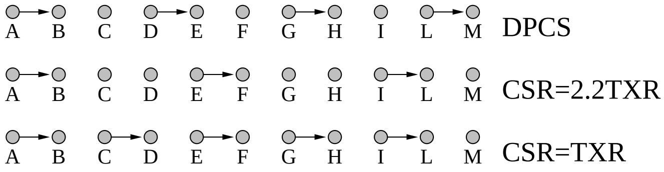

Fig. 4. Long chain topology: spatial reuse.

the channel. Using an inaccurate EDT value leads to the spatial underutilization (lower throughput) or spatial overutilization (higher throughput, many retransmissions, lower goodput). The figure depicts also the spatial reuse in the cases of CSR=2.2TXR, CSR=TXR and DPCS. It is worth noticing that the CSR=2.2TXR rule leads to underutilization of the links, whereas the CSR=TXR rule leads to an overutilization of the links. With DPCS, the reuse factor is 1:3, which is the optimal for the depicted scenario.

Drawing on the last example, we show simulation results based on the popular ns2 simulator with an additional wireless extension [13]. The simulation topology consists of n nodes displaced on a straight line and transmitting on the same physical channel. The communication takes place between the first node (the sender) and the last node (the receiver), hopping on the intermediate nodes. The distance between every node is l=500m and the number of nodes n varies between 3 and 14.

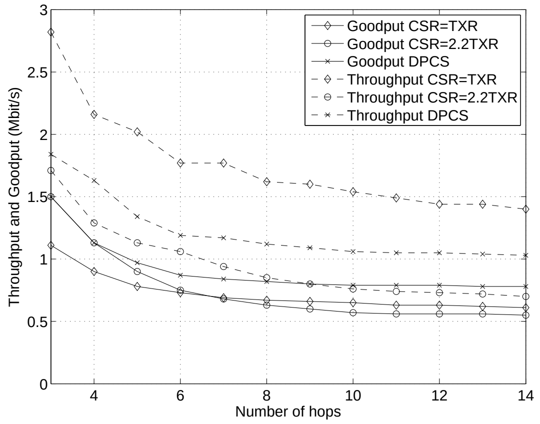

Fig. 5. Throughput and Goodput vs. number of hops.

Figure 5 depicts the throughput (dashed line) and the goodput (solid line) at the MAC layer, whereas Figure 6 depicts the retransmission probability.

It is possible to observe that the CSR=TXR model gives the highest throughput, because the EDT allows nodes to access the channel more frequently. However the frame retransmission ratio is very high indicating that the most of the transmitted packets collide and are not decoded at the receiver side. With the CSR=2.2TXR setting, the throughput as well as the number of retransmissions are the lowest one, while the DPCS setting is a trade-off between the two solutions. As far as regards the goodput obtained with the three different settings, it is worth noticing that, as the number of hops increases, DPCS gives an improvement of 41% and 27% in comparison to the other settings.

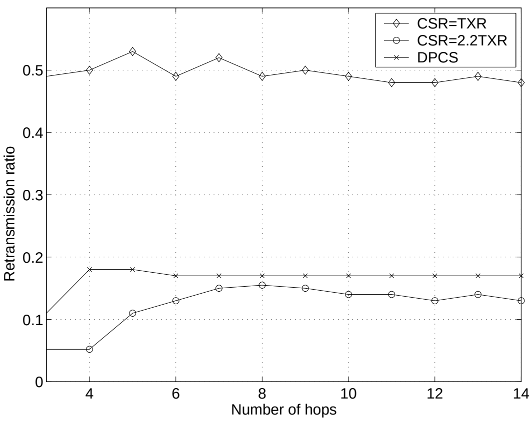

Fig. 6. Retransmission ratio vs. number of hops.

IV. CONCLUSIONS

This paper focuses on the performance of multihop 802.11b based mesh networks. It is shown that the performance of the whole system depends on several factors such as the spatial reuse of the links and the setting of physical carrier sensing parameters.

We found that the proposed dynamic mechanism (DPCS) to set the Carrier Sensing Threshold improves the performance of the system. The mechanism is based on the assumption of homogeneous hardware and adjusts the EDT according to the received power level estimation and the minimum SINR acceptable according to the 802.11b standard. It is shown that the mechanism improves the spatial link reuse factor while respecting the SINR constraints.

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