# Simulating the 802.11a PHY Model: How to Make It Accurate

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## ABSTRACT

In simulating wireless networks, modeling of the physical layer behavior is an important yet difficult task. The implementation of physical layer capture, preamble detection, and carrier sense threshold plays an important role in successful frame reception in the presence of interference. We show in our testbed study that the operations of the frame reception and the capture effect in real IEEE 802.11a systems differ from those of popular research simulators. We present our modifications of the IEEE 802.11a PHY models to the current simulators. We implement our modifications to the QualNet simulator and show that the aggregated TCP throughput can increase up to 430% with the modified PHY model compared to the current simulation model.

## 1. INTRODUCTION

There have been extensive research efforts on analyzing the physical layer issues such as interference in wireless communications. The impact of interference on frame reception and throughput, however still needs further investigation. When we analyze the throughput of flows in wireless networks, the crucial problem is modeling the reception process at the physical (PHY) layer in the presence of interference. An IEEE 802.11 system can perform carrier sensing by using preamble detection and energy detection. Physical layer capture also affects interference and collision, and hence the link capacity. From the previous measurement studies on IEEE 802.11 capture [3, 2], we learned that the capture effect works differently depending on the 802.11 chipsets. Although the testbed study help us to learn the different capture operations of the different chipsets, the testbed experiments are difficult to test all possible scenarios, topologies, and so on.

In this poster presentation, we first present the detailed model of IEEE 802.11a PHY reception and capture process. The current simulators' frame reception is only based on the received signal strength. However, the real 802.11 systems can start the frame reception only when the Signal-to-Interference Ratio (SIR) is high enough to detect the preamble. Second, different 802.11a chipsets exhibit different reception behaviors, depending on the implemented capture logic. We identify the two distinct capture models. Third, the current simulators set the carrier sense threshold equal to the receiver sensitivity; the standard however states that it should be 20 dB higher than the receiver sensitivity. Through the testbed experiments, we discover and modify parts of the simulators that do not correctly reflect the behaviors of real 802.11a systems. Fourth, through the QualNet simulation, we show that different models of 802.11a reception process yield substantially different network performances.

## 2. 802.11A PHY OPERATION

An 802.11a frame begins with PLCP (Physical Layer Convergence Protocol) preamble that consists of OFDM training symbols. Upon receiving a transmitted PLCP preamble, the receiver (i) detects and measures the signal energy and (ii) synchronizes its timing with the training symbols: we call this the *preamble detection* process. If the preamble detection is successful, the receiver recognizes it as the start of a valid 802.11 frame transmission and it goes into a *receiving* state. In this case, the PHY also ensures that it holds the carrier sense (CS) busy for the duration of the transmitted frame as indicated in the PLCP header. If the receiver detects the signal energy but the preamble portion was missed, the receiver holds the CS busy for any signal 20dB above the minimum receive sensitivity (RXSens).

After the PLCP header, the MAC data follows and a CRC is piggybacked for frame error checksum. The receiver generates a MAC CRC error if the MAC frame is corrupted.

### 2.1 Capture Effect in 802.11a PHY

In this section, we categorize the capture cases and describe how the 802.11 PHY processes frame capture in each case.

#### 2.1.1 *Case 1: The Second Frame Arrives* within *the First Frame's Preamble Time*

Suppose the first frame arrives at a receiver and subsequently, the second frame arrives while the receiver is still receiving the first frame's preamble. In this case, the receiver has not yet completely locked onto the first frame. If the second frame's signal power is strong enough for the receiver to detect an energy increase above a certain threshold, which we call *capture threshold*, the receiver drops the first frame's preamble and tries to detect the second frame's

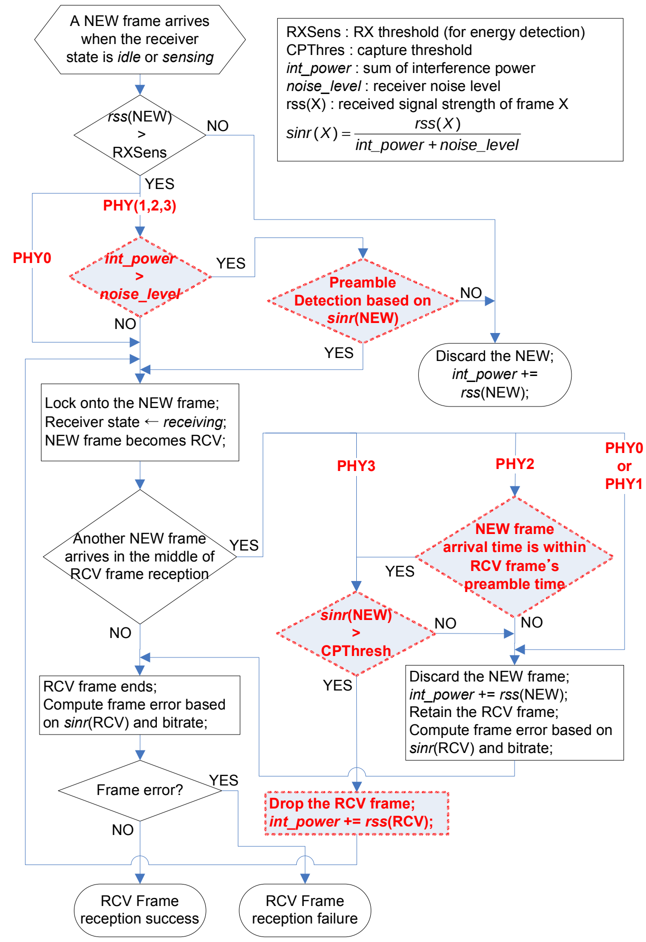



**Figure 1: Revised simulator model flow chart.**

preamble. We call it as SFC (Second Frame Capture). If the second frame's SINR (with the first frame signal as interference power) is high enough to receive second frame's preamble, PLCP header and MAC data without error, the second frame is successfully captured. If the energy increase due to the second frame's preamble is too small to detect or is below the capture threshold, the receiver retains its lock onto the first frame's preamble and tries to synchronize with it. We call it as FFC (First Frame Capture).

### 2.1.2 *Case 2: The Second Frame Arrives* after *the First Frame's Preamble Time*

In the second case, the second frame arrives after the first frame's preamble time. The receiver has already synchronized its timing with the first frame and is in the *receiving* state. In order to capture the second frame, message-in-message (MIM) mode should be implemented in 802.11 PHY [1]. In the MIM mode, if the energy increase due to the second frame is above the capture threshold, the receiver drops the first frame and begins to synchronize its timing with the second frame preamble, i.e., SFC. If the MIM mode is not implemented or if the energy increase is below the capture threshold, the receiver retains its reception of the first frame, i.e., FFC. The implementation of MIM mode is chipset-dependent. In our measurement study [3], we showed that the second frame that arrives later

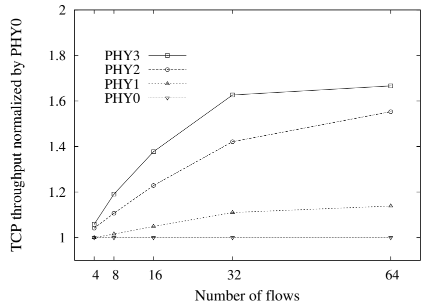



**Figure 2: Average aggregate TCP throughput normalized by PHY0.**

than the first frame preamble time can be captured with Atheros chipsets that are believed to implement the MIM mode. However, when we tested with the Prism chipset wireless cards, the second frame capture does not happen when the second frame arrives after the first frame preamble time even when the second frame is much stronger than the first frame.

## 3. SIMULATOR MODIFICATIONS

We modify QualNet (version 3.9.5) by augmenting two components in the RX process: the SINR-based preamble detection and the capture algorithm. To effectively show the impact of each component in the revised simulator model, we first define four PHY models as follows.

- **PHY0**: The current QualNet model (FFC only).
- **PHY1**: PHY0 + SINR based preamble detection.
- **PHY2**: PHY1 + SFC (second frame capture) *within* first (RCV) frame's preamble time.
- **PHY3**: PHY2 + SFC *after* first (RCV) frame's preamble time (MIM mode is supported).

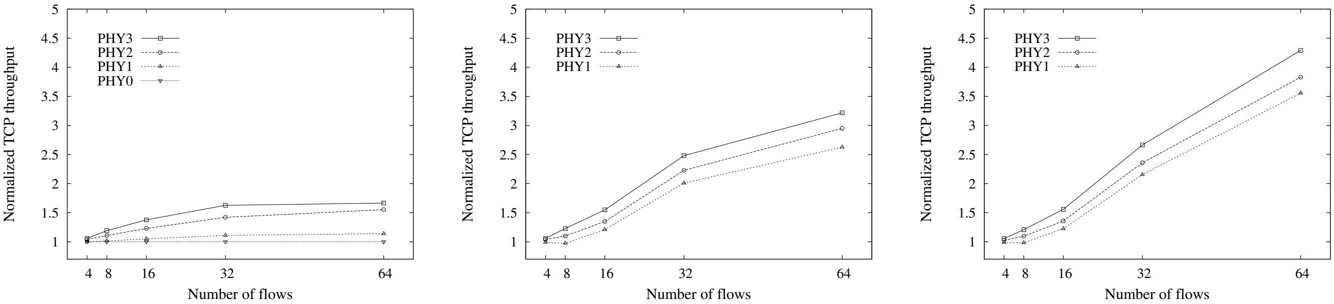
The flow chart for the revised simulator model is presented in Figure 1. Our revision is highlighted by the dotted boxes and the solid boxes illustrate the current Qualnet RX model. In the flow chart, we denote the frame that newly arrives at the receiver as a NEW frame. If the NEW frame's preamble is successfully detected and the receiver locks onto the frame, the frame is called a RCV frame.

### 3.1 SINR-based Preamble Detection

We first revise the RX model to check $sinr(NEW)$ as well as $rss(NEW)$ before going into the *receiving* state. Based on [3], (i) we determine the success of preamble detection based on a probability function linearly increasing from zero to one as the SINR increase from 4dB to 10dB and (ii) we compare the interference power with the noise level and apply the preamble detection logic only if the interference power is greater than the noise level. If $rss(NEW)$ is greater than the RXSens and the preamble detection is successful, the receiver goes into the *receiving* state and the NEW frame becomes the RCV frame.

### 3.2 Capture Models

If another NEW frame arrives during the reception of the RCV frame, we apply different capture algorithms based on the different PHY models. The PHY0 and PHY1 models follow the current QualNet implementation: always discard




(a) CSThres=RXSens (QualNet) (b) CSThres=RXSens+10dB (Atheros) (c) CSThres=RXSens+20dB (standard)

**Figure 3: Aggregate TCP throughput of indoor propagation model with different CSThres settings. Normalized by PHY0(CSThres=RXSens).**

the NEW frame and treat its signal as interference power for the RCV frame. In the PHY2 model, if the NEW frame arrives after the RCV frame's preamble time, the NEW frame is discarded. If the NEW frame arrives within the RCV frame's preamble time and $sinr(NEW)$ is greater than the CPThres, the NEW frame is captured, the RCV frame is dropped, and $rss(RCV)$ is added to the interference power. When we calculate $sinr(NEW)$, $rss(RCV)$ is also considered as the interference power for the NEW frame. The PHY3 model compares $sinr(NEW)$ to the CPThres regardless of the arrival timing between the two frames.[1]

# 4. SIMULATION RESULTS

For simulation, we use the log-distance radio propagation model with the path-loss exponent ($n$) set to 4, which mimics the indoor radio environment. With 16dBm TX power and -88dB RX sensitivity, the maximum transmission range at 6Mbps is $48.5m$. To remove the effect of routing, we intentionally arrange the sender and the receiver of each flow to be only one hop away. Each sender transmits a large file using an FTP application, which leverages TCP. We use Auto Rate Fallback (ARF) for the rate adaptation mechanism.

## 4.1 PHY Model Performance Comparison

In Figure 2, we normalize the aggregate TCP throughputs of the four PHY models with reference to PHY0 as the number of sender-receiver pairs varies. The aggregate throughputs of the real chipset models (PHY2 and PHY3) are higher than that of the current model of the simulator (PHY0). The advantage of the capture logic implementation over non-capture models is substantial. Simply adding the SINR-based preamble detection logic (PHY1) can yield a notable gain over PHY0. The preamble detection logic prevents the PHY layer from going into *receiving* state upon receiving a useless frame and allows the PHY layer to transmit its own. In the indoor propagation model with ($n = 4$), a signal attenuates rapidly over distance. Hence, the sender's frame can be successfully captured at the receiver with a higher probability. Therefore, PHY3 achieves a noticeable throughput gain over PHY2.

## 4.2 Simulator Revision for Carrier Sense

We revised QualNet to use a separate parameter (CSThres), which is configurable in the configuration file. Note that when the CSThres is (much) higher than the RXSens, the success or failure of the preamble detection greatly affects the carrier sensing. To evaluate the impact of the revised carrier sensing model on the network performance, we run simulations with three difference CSThres settings: (i) the CSThres is equal to the RXSens (current QualNet setting), (ii) the CSThres is 20dB higher than the RXSens (802.11a standard setting), and (iii) the CSThres is 10dB higher than the RXSens (Atheros setting). The Atheros setting is based on our measurement from the Atheros-chipset-embedded testbed.

In Figure 3, we show the aggregate TCP throughput of indoor propagation model for each CSThres setting. The throughput improvement of PHY1$\sim$PHY3 over PHY0 increases as the number of flows increases and the CSThres increases. Not only does the standard setting result in substantial performance improvements (Figure 3(c)), but the Atheros setting (with the 10dB increase) also shows considerable improvements (Figure 3(b)). In particular, the PHY1's throughput gains in the Atheros setting (up to 263%) and in the standard setting (up to 356%) are much greater than that of the QualNet setting (up to 111%). Recall that the PHY1 model implements the SINR-based preamble detection logic on top of PHY0. The preamble detection logic prevents the PHY from going into the *receiving* state upon receiving a useless frame and spares the PHY to be able to (i) receive a more strong and useful frame or (ii) transmit its own frame.

The performance gain of PHY3 over PHY2 and that of PHY2 over PHY1 are also increased in the Atheros and standard settings. In those settings, senders transmit more aggressively due to the higher CSThres and the chance of SFC also increases: PHY3 and PHY2 perform better.

# 5. REFERENCES


[1] Jan Boer et al., Wireless LAN with Enhanced Capture Provision, US Patent 5987033, Nov. 16, 1999.

[2] A. Kochut, A. Vasan, A. Shankar, and A. Agrawala. Sniffing out the correct physical layer capture model in 802.11b. In *Proc. IEEE ICNP*, Berlin, Germany, Oct. 2004.

[3] J. Lee, W. Kim, S. J. Lee, D. Jo, J. Ryu, T. Kwon, and Y. Choi. An Experimental Study on the Capture Effect in 802.11a Networks. In *Proc. ACM WiNTECH*, Montreal, Canada, Sept. 2007.


[1] As for the CPThres, we use the measurement data of the Atheros wireless cards in [3], which reports that at least 10dB SINR is required for SFC.