Simulation-Based Performance Analysis of 802.11a Wireless LAN

Mohammad Hossein Manshaei and Thierry Turletti
INRIA, 2004 Route des Lucioles, BP-93,
06902 Sophia-Antipolis Cedex, France
Tel: +33 492387610, Fax: +33 492387978
e-mail: hossein.manshaei@sophia.inria.fr, thierry.turletti@sophia.inria.fr

***Abstract*—In this paper, a simulation study is presented to evaluate the performance of 802.11a wireless LAN protocol. We have simulated 802.11a in a simple network topology taking into account both physical and MAC layers characteristics. Based on simulation results we show that some transmission modes are not efficient to use without extra power control mechanisms. Our simulations confirm that FEC can increase significantly the range of coverage. Then a mechanism to select the best rate is addressed. Two algorithms, RBAR and Predicted-RBAR (P-RBAR), are evaluated for 802.11a. As for 802.11b, simulations show that P-RBAR can provide maximum available throughput while RBAR achieves lower throughput in high rates.**

***Index Terms*— Wireless LAN, ns-2 Simulation, IEEE 802.11a, Multirate, FEC, RBAR.**

I. Introduction

The 802.11b IEEE standard is the most widely used Wireless LAN (WLAN) standard today, deployed almost everywhere [1]. WLANs usually operate as the license free ISM frequency band at 2.4GHz and the maximal theoretical rate for this standard is 11 Mbps using Direct Sequence Spread Spectrum (DSSS) modulation. Since the end of 2001, higher data rate products based on 802.11a [2] have appeared on the market. New 802.11a WLAN stations transmit at 5.2 GHz using Orthogonal Frequency Division Multiplexing (OFDM) modulation. Up to 8 different transmission modes are available with various rates from 6Mbps to 54 Mbps, 3 different Forward Error Correction (FEC) rates and 4 types of modulations (BPSK, QPSK, 16-QAM, 64-QAM).

While a lot of performance studies have been done for 802.11b, very few analysis of 802.11a are available so far. A goodput performance evaluation of 802.11a is provided in [3]. In [4] and [5], system performance, data rate and fragmentation adaptation for 802.11a are studied under similar analytical models. However, these three papers only consider the physical layer of 802.11a and today, we are not aware of any evaluation of these modes that take into account the MAC layer and its overhead. The first part of this paper describes a simulation-based performance analysis of 802.11a that considers both physical layer and MAC layer characteristics.

In addition, mode selection in physical layer could be performed manually or automatically in each station. This selection depends on sender and receiver current states. Basically, if channel condition is suitable, a station can increase its sending rate by selecting a new mode. A few rate selection mechanisms have been proposed in the research community such as Auto Rate Fallback (ARF) [6] and Receiver-Based Auto Rate (RBAR) [7]. These mechanisms try to select the best mode with the help of Signal to Noise Ratio (SNR) computed at the receiver side. The only simulation study available for 802.11a selection rate was done for ARF using the OPNET simulator [6]. However, according to simulations done in [7], ARF fails to perform as well as fixed rates because it periodically tries to send data packets at the next highest rate when it receives ten consecutive ACKs. So in the presence of low SNR, packets are lost with high probability. Since RBAR does not have this flaw, we have selected this mechanism and we present in the second part of this paper a first performance evaluation of a modified version of this mechanism for 802.11a environments.

In Section II, our simulation environment is presented. Section III evaluates the different transmission modes of 802.11a. Section IV analyses the performance of RBAR and P-RBAR mechanisms for 802.11a. Then conclusion and future work are presented in the last section.

II. 802.11a ns-2 Simulation Environment

Our simulations are based on the simulation environment described in [7] which uses the ns-2.1b3 network simulator, with extensions from the CMU Monarch project [8]. The Rice Monarch Project has made extensions to the ns-2 network simulator that enable it to simulate mobile nodes communicating by wireless network interfaces, including the ability to simulate multi-hop wireless ad hoc networks.

Holland [7] has modified this simulator in order to consider the effect of wireless physical layer in modeling mobile networks. Physical layer parameters like path loss, fading, interference and noise computation are usually not taken into account in WLAN simulations in spite of their important effects in simulation results [9]. For example, Rayleigh fading channel and log-distance path loss model are used for error model and estimation of received signal respectively. Also, Friis free space propagation model [7] has been employed in this simulation. Further details of this simulation environment are available in [7] and the ns group is currently working to import these new functionalities to the next release of ns [10].

In this paper, we present modifications to this simulation environment to support 802.11a. We have modified ns-2 PHY and MAC layer parameters from 802.11b to 802.11a standard specification [2]. These parameters include MAC and PHY header formats, data rates and use of FEC. For 802.11a, FEC Viterbi decoding is assumed in the receiver side. We have used the upper bond probability of error that is given in [11] under the assumption of binary convolutional coding and hard-decision Viterbi decoding. Specifically, for packet of length L this probability is:

$$P_e(L) \leq 1 - (1 - P_u)^{8L} \tag{1}$$

where the union bound P_u of the first-event error probability is given by

$$P_u = \sum_{d=d_{free}}^{\infty} a_d \cdot P_d \tag{2}$$

d_{free} is the free distance of the convolutional code, a_d is the total number of error events of weight d[1] and P_d is the probability that an incorrect path at distance d from the correct path is chosen by the Viterbi decoder. When hard decision decoding is applied, P_d is given by

$$P_d = \begin{cases} \sum_{k=(d+1)/2}^{d} \binom{d}{k} \cdot \rho^k \cdot (1-\rho)^{d-k} & if\, d\, is\, odd \\ \frac{1}{2} \cdot \binom{d}{d/2} \cdot \rho^{d/2} \cdot (1-\rho)^{d/2} + \sum_{k=d/2+1}^{d} \binom{d}{k} \cdot \rho^k \cdot (1-\rho)^{d-k} & otherwise \end{cases} \tag{3}$$

where ρ is the bit error probability for the modulation selected in PHY layer. In order to obtain more realistic results, Cisco Aironet 1200 Series parameters are used in our simulation [13].

Note that in the following simulations, CTS (Clear to Send) packets, RTS (Request to Send) packets and all data headers are sent with BPSK modulation with FEC rate equal 1/2 and 6 Mbps data rate and also that ACK packets are sent with the same rate than corresponding data packets. Note also that all throughput shown in the following figures exclude MAC and PHY headers.

In the remainder of the paper we define goodput as throughput after removing FEC at the application level.

[1] We have used the a_d coefficients provided in [12].

III. Evaluation of 802.11a Transmission Modes

Figure 1 shows the network topology used for the following simulations. Two wireless stations are communicating on a single channel. Station A is fixed and station B moves toward station A. Station B held fixed each 5 meters for a 60s transmission of data and we ensure that station B has always data to send to station A (with selecting proper rate) over a single CBR connection. 8000 CBR packets of size 2304 bytes (including FEC and payload) are sent in each step.

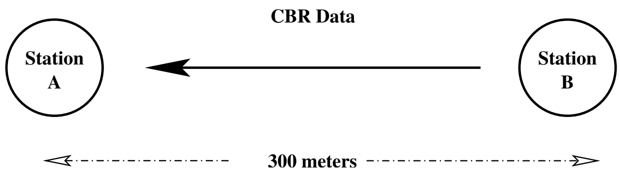

Fig. 1. Network configuration

Figure 2 shows the mean throughput of a single CBR connection for each mode according to the distance. One interesting point in this graph is the behaviour of mode 2. Similar to analytical goodput evaluation presented in [3] PHY mode 3 achieves always better mean throughput (about 2 Mbps and with more coverage) than PHY mode 2. According to probability of bit error rate for QPSK and BPSK in [14], QPSK modulation has higher probability of bit error rate compared to BPSK, but the combination of rate 3/4 convolution code with BPSK achieves lower performance compared to rate 1/2 convolution code with QPSK. So mode 2 is not a good selection when mode 3 is available. However, using a suitable power control mechanism it can achieve better performance [3].

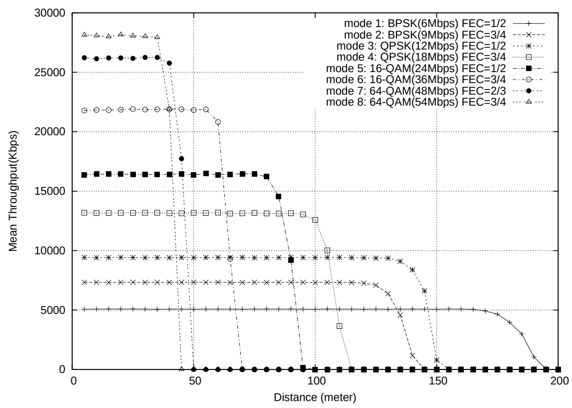

Fig. 2. Mean throughput at PHY layer for single CBR connection

Forward error correction is performed by adding bits to each transmitted character or code block, using a predetermined algorithm. Figure 3 shows the mean throughput once the redundancy data has been removed at the application level.

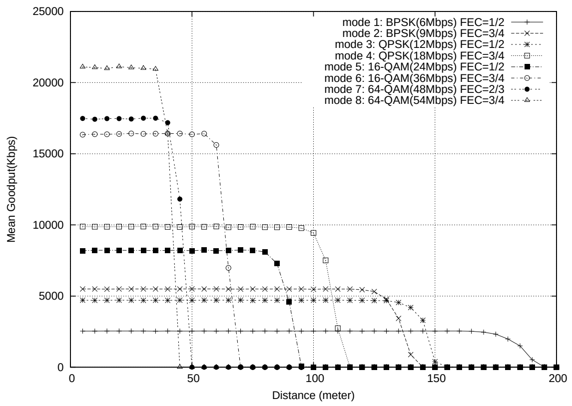

Fig. 3. Mean goodput for single CBR connection

Referring to Figure 3, mode 5 has lower performance (about 2 Mbps) in application level comparing to mode 4. Thus, it is better not to use mode 5 when mode 4 is available.

Another interesting point in Figures 2 and 3 is the difference between theoretical maximum rate and mean data rate obtained. For example in mode 8, when physical layer uses 64-QAM with 54 Mbps, mean throughput is only about 28 Mbps. The main reason is MAC overhead in wireless LAN. Indeed, sending CTS/RTS before sending data, decreases the mean throughput significantly in high rate, since CTS/RTS have to be sent with the lowest rate.

In order to evaluate performance of FEC in 802.11a, we have made another simulation using the same network configuration, but without using FEC[2] at PHY layer. The results are shown in Figure 4. Note that, in this particular case, the basic mode becomes BPSK at 12 Mbps for CTS and RTS. Clearly, the mean throughput is significantly increased, but the maximum range of transmission decreases compared to the default case when FEC is used, for example, it is 90 meters without FEC and 190 meters with FEC.

IV. Evaluation of RBAR for 802.11a

IEEE 802.11a can support the use of different high rates for multiuser at the same time. However the standard does not define any mechanism to select the best

[2]Note that FEC is mandatory in the standard [2].

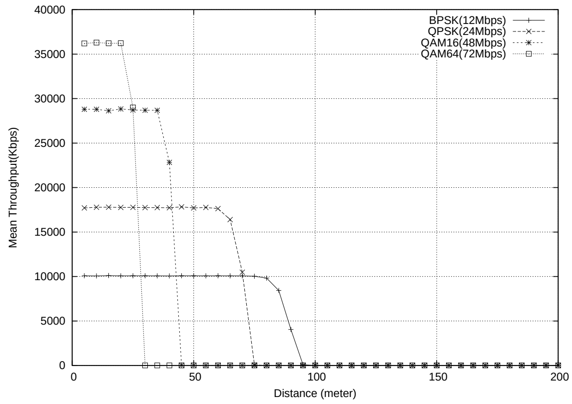

Fig. 4. Mean throughput (goodput) for single CBR connection without FEC

combination of rate and FEC according to the channel characteristics. As mentioned in the introduction, we have modified the RBAR algorithm to perform automatic data rate selection in 802.11a. Now we describe RBAR in detail:

The sender chooses a data rate based on some heuristic (such as the most recent rate that was successful for transmission to the receiver), and then stores the rate and the size of the data packet into the RTS. Other stations, overhearing the RTS, calculate the duration of the requested reservation using the rate and packet size carried in the RTS. They update their NAV (Network Allocation Vector) to reflect the reservation. While receiving the RTS, the receiver uses the information concerning the channel conditions to compute an estimation of the conditions for pending data packet transmission. It then selects the appropriate rate with a simple threshold mechanism, and transmits it along with the packet size in the CTS back to the sender. Other stations, overhearing the CTS, calculate the duration of the reservation similar to the procedure used by stations when they receive RTS and then update their NAV to reflect the reservation. Finally, the sender responds to the receipt of the CTS by transmitting the data packet at the rate selected by the receiver. RBAR algorithm implementation issues and performance obtained for 802.11b are available in [7].

To use RBAR for 802.11a we have modified the threshold values to select the best rate based on SNR since Viterbi decoding algorithm is now used at the receiver. These thresholds are calculated using probability of error for all the modes discussed in Section II. Table I shows these thresholds. In other words, with these SNR we have union bound of the first-event error probability less than 1e-5, 1e-10 or 1e-20.

TABLE I

SNR(dB) THRESHOLDS FOR DIFFERENT UNION BOUNDS OF THE FIRST-EVENT ERROR PROBABILITY WITH VITERBI DECODING

	P_u ≤1E-5	P_u ≤1E-10	P_u ≤1E-20
Mode 1	-2.31	0.79	3.69
Mode 2	1.74	4.89	8.06
Mode 3	0.68	3.80	6.97
Mode 4	4.75	7.90	11.07
Mode 5	7.08	10.49	13.81
Mode 6	11.39	14.72	17.97
Mode 7	15.95	19.82	23.40
Mode 8	17.29	20.79	24.13

In the following simulation we have used thresholds respecting to P_u ≤1E-5. As it is shown in Section III, mode 2 is not useful. This is confirmed in Table I. All thresholds corresponding to mode 3 are always less those corresponding to mode 2. Moreover, since simulations done in section III has shown that mode 5 is useless when mode 4 is available, we have removed mode 2 and mode 5 in the following selection rate algorithm. Figure 5 shows the RBAR performance for 802.11a with the same network topology than before. RBAR has good performance when it selects the low rate modes. In this case, the reservation subheader which carries the rate and length of data, does not make significant overhead over sending data. We should consider that reservation subheader should always be sent using the basic mode. However, when RBAR selects modes with high data rate this overhead becomes significant. For example, Figure 5 shows that there is up to 5 Mbps difference between RBAR and the maximum available throughput for mode 8.

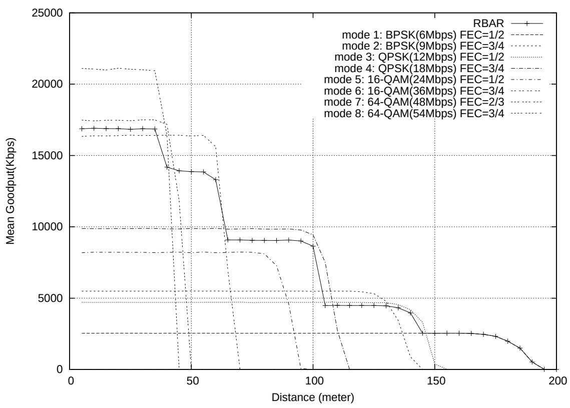

Fig. 5. Mean goodput of single CBR connection for RBAR

To solve this problem, Holland has proposed a simple prediction algorithm called Predictive RBAR (P-RBAR) [7] to select the best rate according to the channel conditions. The scheme uses a cache to save the most recent rates as they are discovered. After several successful transmissions, there is no need to wait for reservation subheader. We evaluated P-RBAR algorithm for 802.11a and, as shown in Figure 6, the maximum available goodput can be obtained for each distance.

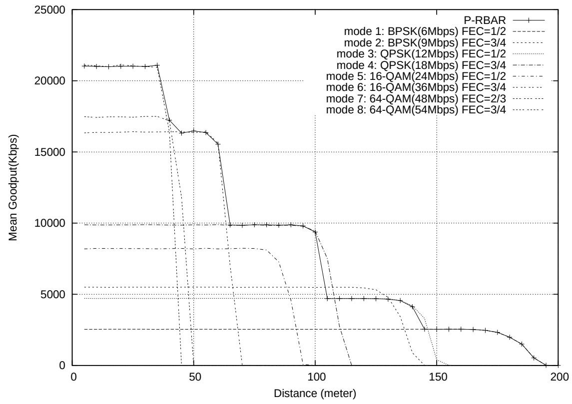

Fig. 6. Mean goodput of single CBR connection for P-RBAR

V. CONCLUSIONS AND FUTURE WORK

In this paper performance of 802.11a wireless standard is investigated by calculating mean throughput. We have evaluated throughput performance of each mode using a simple topology. Simulations show that two modes are not useful without extra power control mechanism. Then we have evaluated RBAR and P-RBAR mechanisms to select the best rate according to the SNR estimated. Using a suitable predictor mechanism, P-RBAR can reach the maximum available goodputs, which are variable for different SNR.

In future works, we will investigate possible mechanisms to provide more coverage range taking into account the application QoS requirements in selecting the best mode.

ACKNOWLEDGMENT

We would like to thanks Gavin Holland for providing us his ns2-based simulation environment for 802.11b.

REFERENCES

[1] IEEE 802.11 WG, Part 11b, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", Standard Specification, IEEE, 1999.

[2] IEEE 802.11 WG, Part 11a, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", High-speed Physical Layer in the 5 GHz Band, Standard Specification, IEEE, 1999.

[3] D. Qiao, S. Choi, "Goodput Enhancement of IEEE 802.11a Wireless LAN via Link Adaptation", In *Proceedings of the* IEEE *ICC'01*, Helsinki, Finland, June 2001.

[4] H. Yin, Z. Kostic, K. Leung,"Multirate 802.11a Networks: System Performance Evaluation", 36th Annual *Conference on Information Sciences and Systems*, *CISS* 2002.

[5] H. Yin, Z. Kostic, K. Leung, "Multirate 802.11a Networks: Data Rate and MAC Fragmentation Adaptation", 36th Annual *Conference on Information Sciences and Systems CISS* 2002.

[6] A.J. van der Vegt,"Auto Rate Fallback Algorithm for IEEE 802.11a Standard", High Performance Computing Group Faculty of Physics and Astronomy Utrecht University, available at http://www.phys.uu.nl/~vdvegt/docs/gron/

[7] G. Holland, N. Vaidya and P. Bahl, "A Rate-Adaptive MAC Protocol for Multi-Hop Wireless Networks", *MOBICOM*, Rome, July 2001.

[8] "The Rice University Monarch Project, Mobile Networking Architectures", http://www.monarch.cs.rice.edu/

[9] M. Takai, J. Martin, and R. Bagrodia, "Effects of Wireless Physical Layer Modeling in Mobile Ad Hoc Networks", In *Proceedings of MobiHoc* 2001.

[10] "ns Simulator", http://www.isi.edu/nsnam/ns/

[11] M. B. Pursley and D. J. Taipale, "Error Probabilities for Spread-Spectrum Packet Radio with Convolutional Codes and Viterbi Decoding", IEEE *Transactions on Communications*, vol. COM-35, no. 1, pp. 1-12, Jan 1987.

[12] P. Frenger, "Multi-Rate Convolutional Codes", *Thechnical Report* No.21, Communication System Group, Chalmers University of Technology, Sweden.

[13] "Cisco Aironet 1200 Series Access Point Hardwara Installation Guide", available in http://www.cisco.com

[14] J. G. Proakis, "Digital Communications", 3rd ed., McGraw Hill, New York, NY, 1995.