Throughput Optimization for Wireless LANs in the Presence of Packet Error Rate Constraints

Sayantan Choudhury, *Student Member, IEEE,* and Jerry D. Gibson, *Fellow, IEEE*

***Abstract*— In [1], we optimized single-user throughput by selecting the transmitted bit rate and payload size as a function of channel conditions. However, the approach did not consider a packet error rate (PER) constraint, and the payload size obtained could yield excessively high packet error rates. We propose and solve the optimization problem of maximizing throughput by varying the PHY layer data rate and the payload size subject to a packet error rate constraint. The resulting SNR thresholds for adapting the PHY data rate and the corresponding payload sizes are drastically different than those obtained without the PER constraint.**

***Index Terms*— IEEE 802.11 MAC, link adaptation, throughput optimization, packet error rate constraint.**

I. Introduction

Wireless local area networks (WLANs) are rapidly becoming part of our network infrastructure. The IEEE 802.11 WLAN physical layer (PHY) supports multiple data rates by using different modulation and channel coding schemes. The effective throughput in these WLANs is determined by a number of parameters, including transmission rate, payload and header size, constellation size, transmitted power, and received noise characteristics. When the channel is time varying in nature, the transmission parameters should be adapted according to channel conditions to improve link performance. In [1], we provided a theoretical formulation wherein payload length was considered as an optimization parameter and a cross-layer scheme was proposed that jointly optimizes payload length and data rate and dynamically adapts the payload length to maximize the throughput for additive white Gaussian noise (AWGN) and different fading channels. Results indicated that both the optimum payload length and the data rate are dependent on the channel under consideration.

However, it is also shown in [1] that maximizing throughput may lead to unacceptable packet loss rates. Therefore, to maximize effective throughput and maintain the packet loss rate at acceptable levels, we turned to simulations, and SNR ranges for switching between the several PHY layer data rates of IEEE 802.11a were determined by comparing plots of effective throughput at the different PHY layer data rates as a function of SNR with plots of the packet loss rate of each PHY layer data rate versus SNR. The resulting adaptation thresholds are much different when the packet error rate constraint is imposed.

Manuscript received August 28, 2007. The associate editor coordinating the review of this letter and approving it for publication was R. Nabar. This research has been supported by the California Micro Program, Applied Signal Technology, Dolby Labs, Inc., Mindspeed, and Qualcomm, Inc., by NSF Grant Nos. CCF-0429884 and CNS-0435527, and by the UC Discovery Grant Program and Nokia, Inc.

The authors are with the Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106 USA (e-mail: {sayantan, gibson}@ece.ucsb.edu).

Digital Object Identifier 10.1109/LCOMM.2008.071434.

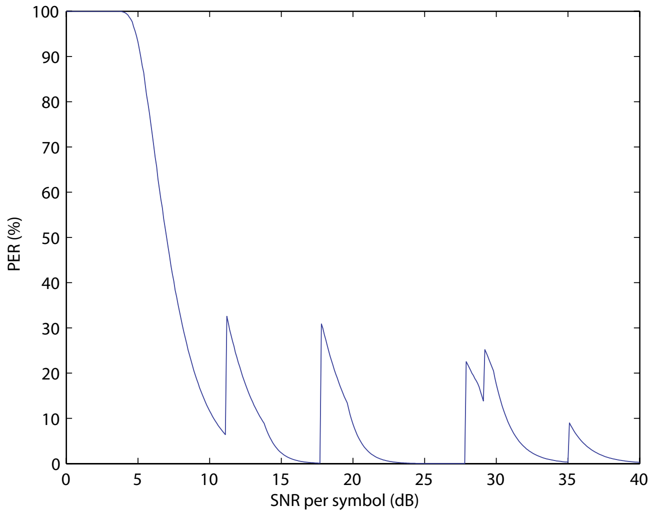


Fig. 1. Packet error rates for throughput optimization by variable payload length and variable PHY rate without a packet error rate constraint in Rayleigh fading.

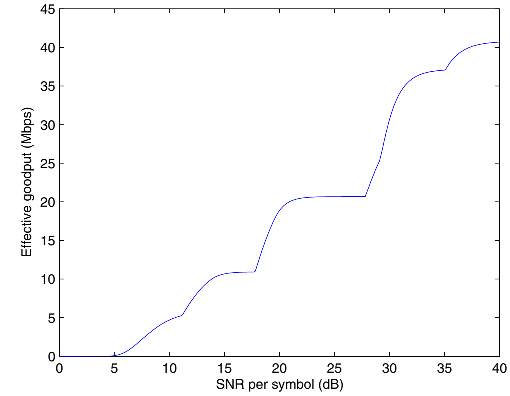
In this paper, we revisit the problem of throughput maximization by varying the payload length subject to a packet loss constraint, but we avoid simulations and the requirement of comparing two separate sets of plots by posing and solving a single optimization problem. As in [1], we are interested in multimedia applications, so we do not allow retransmissions in order to minimize latency and to reduce congestion on the wireless link. We assume that packet loss concealment is used to compensate for lost packets.

II. Link Adaptation with Packet Error Rate Constraint

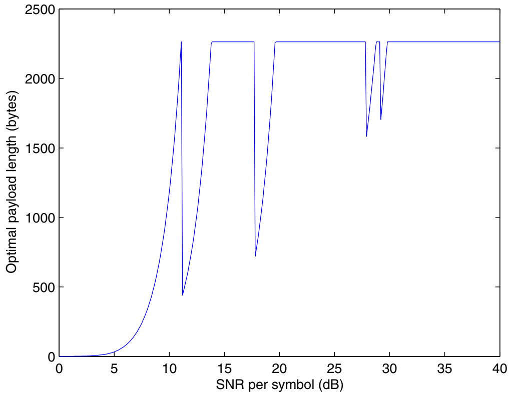
Figure 2, taken directly from [1], plots the effective throughput, payload length and PHY mode obtained in order to maximize throughput in Rayleigh fading without a packet error rate constraint. In Figure 1, we plot the packet error rate (PER) corresponding to the throughput maximizing rate switching algorithm in Fig. 2. As seen from Figure 1, the packet error rate can be as high as 30% at SNRs above 10 dB. Packet error rates greater than 10% are likely unsuitable for most applications. Clearly, when varying payload length to maximize throughput, it is important to impose a constraint on the packet loss rate.

The throughput optimization problem with a packet error constraint can be posed as

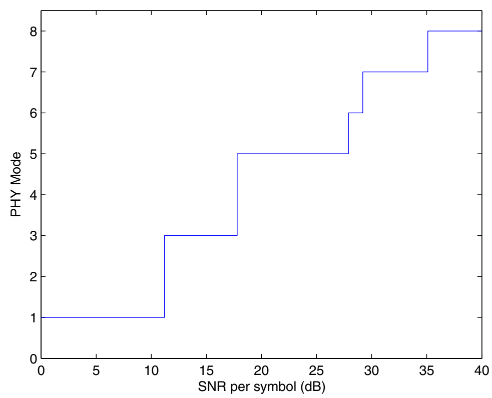
$$\max_{j,L} T(j) = \frac{L}{L + C_j} * R_j * P_s^j(\gamma_s, L) \qquad (1)$$



(a) Effective throughput without a packet error rate constraint

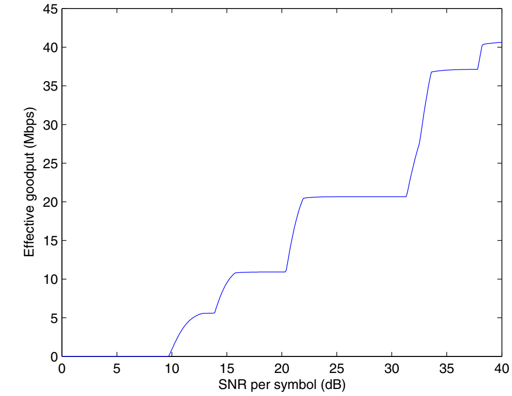


(b) Optimal payload length without packet error rate constraint

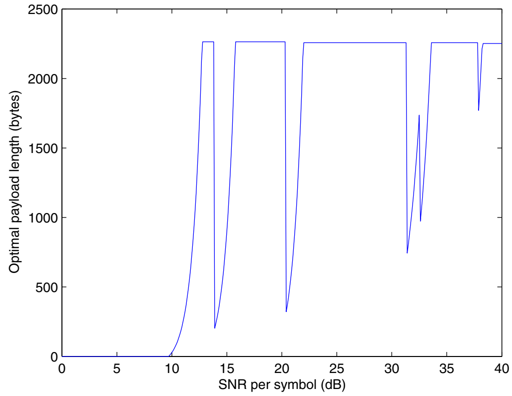


(c) Rate adaptation without packet error rate constraint

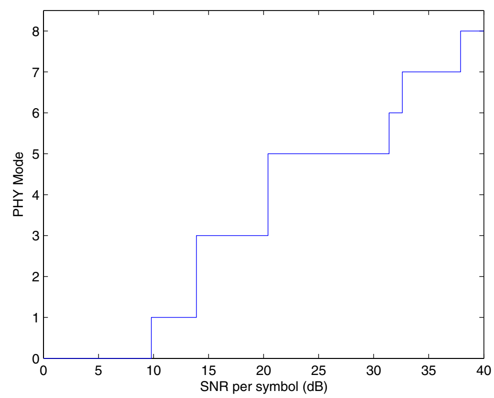
Fig. 2. Optimal link adaptation to maximize throughput without packet error rate constraint in Rayleigh fading.



(a) Effective throughput with a packet error rate constraint



(b) Optimal payload length with packet error rate constraint



(c) Rate adaptation with packet error rate constraint

Fig. 3. Optimal link adaptation to maximize throughput with a maximum packet error rate constraint of 1% in Rayleigh fading

subject to the constraint $PER(j) \leq PER_t$, where
$T(j)$: Effective throughput for PHY mode j,
L: payload length in bits,
j: PHY mode,
C_j: header and DCF overhead corresponding to rate 'j' in bits,
R_j: data rate corresponding to PHY mode j,
$P_s^j()$: packet success rate (PSR) defined as the probability of receiving a packet correctly corresponding to PHY mode j as in [1],
γ_s: SNR per symbol,
PER_t: specified packet error rate threshold.

The packet error rate constraint imposes a constraint on the payload length since $PER(j) < PER_t$ implies

$$1 - (1 - P_u^j(\gamma_s))^L \leq PER_t \tag{2}$$

where $P_u^j(\gamma_s)$ is the union bound of the first-event error probability corresponding to PHY mode j [1].

TABLE I
LINK ADAPTATION THRESHOLDS WITH AND WITHOUT A MAXIMUM PACKET ERROR RATE CONSTRAINT OF 1% IN RAYLEIGH FADING

Data Rate(Mbps)	6	12	24	36	48	54
SNR range(dB) with PER constraint	10-14	14-21	21-31	31-32	32-38	>38
SNR range(dB) without PER constraint	0-11	11-18	18-28	28-29	29-35	>35

Hence, the payload length is constrained by

$$L \leq \frac{log(1 - PER_t)}{log(1 - P_u^j(\gamma_s))} \tag{3}$$

We show below that the optimization problem in Eq. (1) is strictly concave at low BERs, which implies that when the payload length constraint is satisfied, the solution to the unconstrained problem is the same as the solution of the constrained problem. In the event the payload length constraint is not satisfied by the global minimizer, the solution to the problem is at the boundary of the payload constraint as given by Eq. (3).

Now, we show that the the optimization problem in Eq. (1) is strictly concave at low BERs. For low BERs, the packet error rate can be approximated as

$$P_e^j(L, \gamma_s) \approx L * P_u^j(\gamma_s)) \tag{4}$$

Hence the throughput expression in Eq. (1) can be simplified to

$$T(j) = \frac{L}{L + C_j} * R_j * (1 - L * P_u^j(\gamma_s))) \tag{5}$$

By taking the second derivative and simplifying, we obtain

$$T''(j) = \frac{-2 * (C_j^2 * P_u^j(\gamma_s) + C_j)}{(L + C_j)^3} \tag{6}$$

which is strictly negative and hence the throughput function given in Eq. (1) is strictly concave [2].

The effective throughput with and without a packet error rate constraint are plotted in Figs 3(a) and 2(a), respectively. We see that by imposing a packet error rate constraint, significantly higher SNRs are required to maximize throughput. Additionally, comparing Figs. 2(c) and 3(c), we see that PHY mode 1 corresponding to a data rate of 6 Mbps can be used only at SNRs above 10 dB when the packet error constraint of 1% is imposed.

From Figs. 2(b) and 3(b), we see the dramatically shorter payload lengths required at the rate switching points in order to satisfy the 1% packet error rate constraint. In practice, the packet error rate should be selected based on the application (e.g. voice or video) requirements so that the link adaptation thresholds can be obtained to maximize throughput without significantly affecting the overall performance of the application (e.g voice or video quality).

In Table I, we compare the link adaptation thresholds with and without a PER constraint. The most obvious impact of the 1% PER constraint is that the link cannot be used at SNRs less than 10 dB. In this situation, the user could choose to allow retransmissions, thus increasing latency and perhaps increasing the load on the access point, or a higher PER could be accepted, and new link adaptation points could be generated using our method. These choices depend upon the application and on the number of users to be supported by the link. For most of the data rates, the switching points from a low data rate to the next higher data rate needs an additional 2-3 dB for the constrained link adaptation scheme compared to the unconstrained link adaptation scheme. For example, the switching from 6 Mbps to 12 Mbps takes place at 11 dB in the unconstrained link adaptation scheme whereas in the constrained case, the transition point is near 14 dB.

III. CONCLUSIONS

We have presented a theoretical framework for achieving higher throughputs by careful adaptation of payload length and data rates in the presence of a packet error rate constraint. We show that the introduction of the packet error rate constraint drastically changes the operating SNR regions and the payload sizes from the unconstrained optimization problem. Hence for voice and video transmission, one can select the PER constraint needed for the particular application and then choose the optimal payload length and SNR regions for each data rate to maximize throughput by considering the constrained optimization problem as posed and solved in this paper.

REFERENCES

[1] S. Choudhury and J. D. Gibson, “Payload length and rate adaptation for multimedia communications in wireless LANs,” *IEEE J. Select. Areas Commun.* (special issue on cross-layer optimized wireless multimedia communications), vol. 25, no. 4, pp. 796–807, May 2007.

[2] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge University Press, March 2004.