Performance of Land Mobile Satellite Communication (LMSC) Channel with Hybrid FEC/ARQ

Jing Zhu[1], Sumit Roy[2]
zhuj@ee.washington.edu, sumit.roy@intel.com
1. Department of Electrical Engineering, University of Washington
2. Wireless Technology Development, Intel Labs, Hillsboro, OR 97124

Abstract- **In this paper, we use Lutz's model [1] to investigate BER (bit error rate)/PER (packet error rate) performance of the LMSC channel with various FEC (forward error correction) coding as a function of different channel parameters. The problem of insufficient interleaving is studied. Next, hybrid FEC/ARQ techniques are evaluated for different(i.e. open, and rural) channels. We focus on the problem of joint optimization of system parameters, such as maximum retransmission number, and coding rate. Simulation results show that hybrid ARQ with proper parameters guarantees high TCP end-to-end throughput performance, and is a promising approach for high-speed satellite communications in the future.**

Key Words: satellite networks, ARQ/FEC, Internet

I. INTRODUCTION

The promise of the Global Internet for high-speed data services implies a network with both terrestrial wireless and satellite communication channels. However, the presence of a satellite segment introduces two particular problems that constitute the primary challenge for high-speed data services: burst errors [2] and long propagation delay [3]. To resist errors, ARQ and FEC have been widely adopted. - ARQ combats channel errors through retransmission and FEC through redundancy. ARQ retransmission is costly in satellite links due to the large latency introduced particularly for geo-synchronous networks. FEC also incurs extra delay caused by interleaving and moreover leads un-necessarily to lower bandwidth utilization in the event that the channel is in good state. In the literature, some earlier research focused on the performance of ARQ/FEC in satellite networks ([4], [5]) but they did not consider the problem of joint optimization of different systems parameters, such as maximum retransmission number, and coding rate.[6] proposed a detailed survey on current research results on ARQ/FEC in wireless networks, but did not include satellite networks, where the long propagation delay must be considered. We study the performance of ARQ/FEC over satellite networks in this paper. By simulation, we show that with proper combination of maximum retransmission number and coding rate, great improvements in TCP performance can be achieved.

Our paper is organized as follows. In Section 2, we introduce our simulation system for the satellite physical layer. We study output BER/PER performance of FEC in Section 3. Then, we focus on the scheme combining ARQ and FEC in Section 4. TCP end-to-end performance is evaluated as well. We also study the problem of joint optimization of system parameters, such as maximum retransmission number, code rate, and interleaving depth. Finally, we conclude the whole paper in Section 5.

II. SIMULATION SYSTEM

We simulate land mobile satellite communication channel by using the method proposed in [1]. It uses a Total Shadowing Model [1] that statistically combines Ricean fading and Rayleigh fading for received signal at a satellite, i.e.

$$\begin{aligned} P(S) &= X p(S|A,\sigma_d^2) + (1-X)\int_0^\infty p(S|S_0)p(S_0)dS_0 \\ &= X\frac{1}{\sigma_d^2}e^{-\frac{A^2+2S}{2\sigma_d^2}} I_0\left(\sqrt{2S}\frac{A}{\sigma_d^2}\right) + (1-X)\int_0^\infty \frac{1}{S_0}e^{-\frac{S}{S_0}} \times \\ &\qquad \frac{10}{\sqrt{2\pi}\sigma \ln 10}\frac{1}{S_0}e^{-\frac{(10\log S_0-\mu)^2}{2\sigma^2}}dS_0 \end{aligned} \tag{1}$$

The notations used in the above equation are shown as follows:

S_0: Mean received signal power;
A: Amplitude of the LOS (line of sight) componen;
σ_d^2: Diffuse signal power;
X: Time-share parameter ($0 \leq X \leq 1$).
μ: Mean of the log-normal distribution;
σ: Standard deviation of the log-normal distribution.

According to Eq.(1), the fading behaviour of the channel consists of two dominant states - in the unshadowed or "good" channel state, the channel is characterized by the presence of a LOS component, which implies higher average received power and Ricean fading. In the shadowed or bad state, the channel has no LOS component, implying low received power and Rayleigh fading. The parameter X is a long term measure that describes the fractional amount of time spent in good state. The short-term characteristics of the switching process are accurately described by a two-state Markov model.

Fig.1 shows a schematic for the Lutz model: first, a complex Gaussian process is filtered to produce a desired multipath fading characteristic. For Ricean fading, a LOS component is added based on a a given Rice factor K. For Rayleigh fading, the fading envelope is scaled by log-normal statistics. The switching between Ricean and Raleigh fading is controlled by a two-state continuous time Markov process. The input signal $s(t)$ is multiplied by the fading signal and observed in additive Gaussian noise to produce the received signal $r(t)$. In our work, we do not use filtered gaussian noise method to generate the multipath fading signal - instead, the sum of random sinusoids method suggested by Jake's model is used with 10 sinusoids.

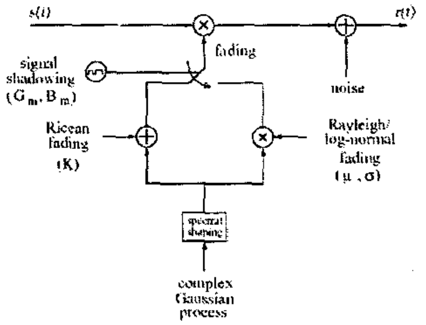


Fig. 1. Lutz's Model for Satellite Channels

We use Matlab to simulate the satellite physical layer (see Fig.2) with the Lutz channel model. An outer (n, k) RS code over GF(n) is symbol-interleaved to depth D (coding rate $r = k/n$). The output of the interleaver is convolutionally encoded with a binary code, where the coding rate is R, the constraint length is N, and the generator matrix is G. Finally, M-PSK or M-QAM is utilized to modulate the signal. After demodulation, the received signal is hard limited followed by Viterbi decoding of the convolutional code - this follows the suggestion of CCSDS (Consultative Committee on Space Data Systems) coding standard for deep-space communication [1].

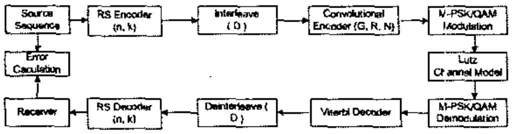


Fig. 2. Block Diagram of Simulating The Satellite Physical Layer

The parameters of the above system are:

f_dT: The product of the Doppler frequency and a symbol duration;
Bw: The bandwidth of the satellite channel (symbol per second);
T_{sim}: Simulation duration time;
C_t: The average total length of a good state and a bad state in Lutz channel model;
X: The good state time-share parameter in Lutz channel model;
G_t: The average length of good states, which is given by C_tX;
B_t: The average length of bad states, which is given by $C_t(1-X)$;
SNR: The signal noise power ratio.

III. OUTPUT BER/PER PERFORMANCE OF FORWARD ERROR CORRECTION CODING

Forward Error Correction (FEC) coding is the process of adding redundancy to a bit stream according to some rule known to both the transmitter and receiver. In the event that the data stream is corrupted by channel impairment, this redundancy can be used to compensate for some of these errors. As is well-known, FEC is efficient and has good performance in a AWGN channel, which is characterized by an i.i.d. model. But how FEC works in a satellite channel with burst errors requires further study.

We assume that the bandwidth of the satellite channel is 4800 symbols per second, and BPSK is used to modulate the signal for a net bit-rate of 4800 bps. SNR is 6dB. The product of the fading speed and symbol duration (f_dT) is 0.01. In bad states of the channel, the log-normal Rayleigh fading is characterized by $\mu = -20.8dB$ and $\sigma = -0.09dB$, and in good states of the channel, the Rice factor K is 20dB,

A general method to resist burst error of a fading channel is interleaving. However, it is difficult to decide on an optimal value of the interleaving depth D in a time-varying fading channel. If the interleavers are designed for worst case scenarios, in many cases it may lead to unnecessarily long channel delays.

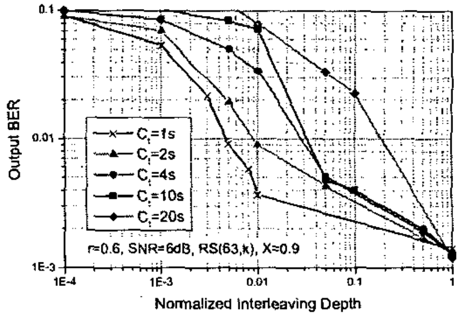
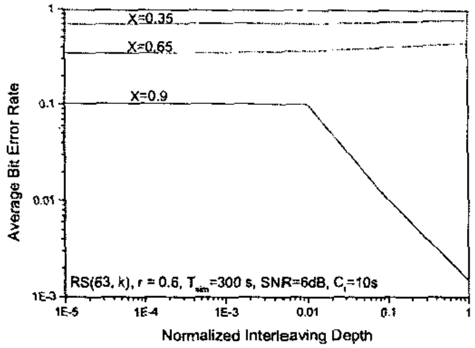


Fig. 3. Effect of Interleaving Depth on Output BER

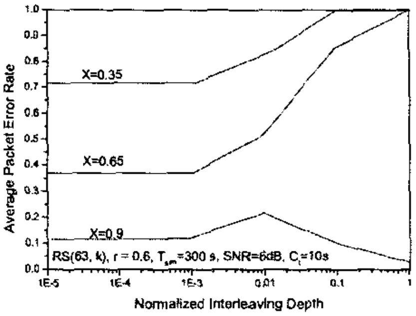
First, we study the effect of insufficient interleaving on output BER performance. In our simulation, we use RS code $(63, k)$ and the coding rate is 0.6. The good state time-share parameter X is 0.9. And we denote interleaving depth with D, which is normalized by the whole simulation time (1000 seconds) (i.e. $D = 1$ and $D = 0$ corresponding to sufficient interleaving and non-interleaving respectively). From Fig.3, we can see that greater interleaving leads to the better performance. Accordingly, the delay caused by interleaving/deinterleaaving is longer. Fig.3 also indicates that with interleaving method, slower fading speed (i.e. larger value of C_t) yields the better performance in terms of bit error rate.

---

[1] The difference is that AWGN channel is assumed by CCSDS, but we consider a satellite channel, which is characterized by Lutz model.

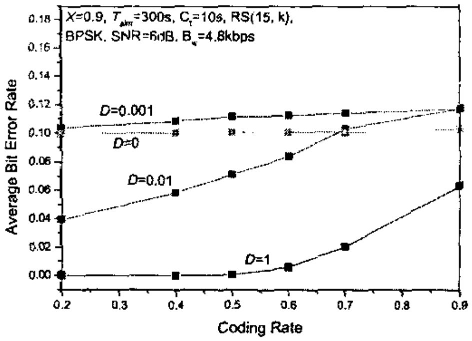


a) Average Bit Error Rate

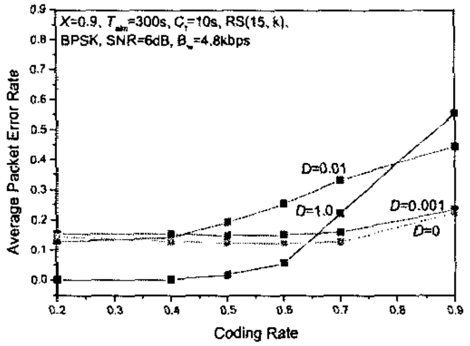


b) Average Packet Error Rate

Fig. 4. Effect of Interleaving Depth with different X on Output BER and PER



a) Average Bit Error Rate



b) Average Packet Error Rate

Fig. 5. Effect of Interleaving Depth with different code rate on Output BER and PER

Above we consider output bit error rate performance. Since data are sent in the unit of packets, we now consider the packet error rate (PER). Fig.4 compares the effect of interleaving depth on both BER and PER (packet error rate) where 75 bytes length link layer packets are assumed. We see that for the worse channels (X=0.65, 0.35), BER does not change much with increasing interleaving depth, but PER increases accordingly - the main reason being insufficient interleaving. However, for the same bit error rate, longer interleaving results in more packet error rate as it disperses the same bit errors over greater number of packets. For, $X = 0.9$, the average bit error rate improves significantly after the normalized interleaving depth exceeds 0.01, implying that interleaving is long enough to take effect. Accordingly, the average packet error rate increases first with interleaving depth increasing, then improves after interleaving depth is longer than 0.01. For our simulation time of 300 seconds, the delay caused by interleaving with normalized depth of 0.01 is approximately 3 seconds, which is unacceptable.

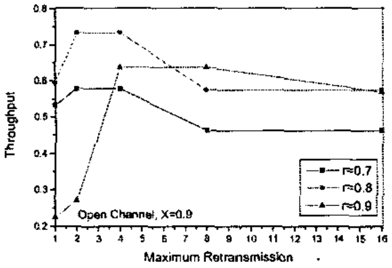
Fig.5 shows how interleaving takes effects on the error performance of FEC (a link layer packet length is assumed as 50 bytes). We see that coding rate must be low enough to acquire performance improvement with interleaving, especially in terms of PER (packet error rate). Fig.5b indicates that with coding rate less than 0.65, the full interleaving ($D = 1$) scheme performs best. Otherwise, the scheme without interleaving ($D = 0$) is the best.

In general, if we want to use interleaving method to correct burst errors in the bad state of the channel, the interleaving depth must be very long, leading to interleaving delays of several seconds. Moreover, the coding rate must be low enough. Otherwise, interleaving will result in error spreading, which is very harmful to the whole performance. In our following discussion on hybrid ARQ/FEC, we therefore do not employ interleaving.

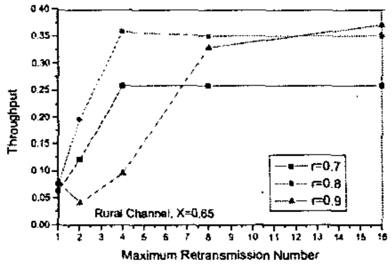
In conclusion, FEC has worst performance when the correlation of the channel becomes greater. To improve the performance, we can use two methods - reducing coding rate and increasing interleaving depth. However, the former one has low bandwidth utilization in the event of the channel being in good states, and the latter one introduces the extra long interleaving delay. In the next section, we turn to another method to resist wireless losses.

IV. TCP PERFORMANCE WITH ARQ/FEC

We used ns2 [8] to evaluate TCP performance. We consider two typical channels: open channel, rural channel. All channels are assumed to support the same data rate of 4800 bps, a Rice factor 20dB, and SNR of 6dB. BPSK is used for modulation. The link layer packet length is 50 bytes, and RS code (15, k) is used for FEC. The distinguishing characteristic of the channels is the value of the good state time-share parameter X. For the open channel $X = 0.9$ and for the rural channel $X = 0.65$. And the average total length C_t of a good state and a bad state is 10 seconds. Fig.6 shows TCP end-to-end throughput (normalized by the maximum capacity) under different coding rates. Obviously, the open channel has the best performance. Moreover, compared with rate r=0.7 and 0.9, the coding rate of 0.8 has the best performance (i.e. achieving higher throughput with less maximum retransmission number). In the rural channel, because of the longer duration time of the bad state, we need more retransmission to achieve peak throughput performance, which is significantly poorer than the open channel peak throughput.



a) Open Channel



b) Rural Channel

Fig. 6. TCP End-to-End Throughput Comparison

V. CONCLUSIONS

From above results, we can conclude that HARQ with proper coding rate and retransmission attempts can greatly improve TCP end-to-end performance in a satellite channel. It is a promising technology in future satellite communications to support reliable data traffic (i.e. TCP). Additionally, the interleaving method must be carefully used, with supported by enough coding rate, otherwise the error spreading will lead to great performance degradation. In future work, we propose to investigate channel-adaptive HARQ for enhanced performance in LMSC channels at K-band.

REFERENCES

[1] Lutz, E., D. Cygen, M. Dippold, F. Dolainsky, and W. Papke, The Land Mobile Satellite Communication Channel - Recording, Statistics, and Channel Model, IEEE Trans. on Vehicular Tech. , Vol . 40, No. 2, May 1991, pp.375-386.
[2] M. Zorzi and R.R. Rao, Perspectives on the Impact of Error Statistics on Protocols for Wireless Networks, IEEE Personal Communications, Oct. 1999.
[3] P. Chanralambos, V. S. Frost, and J. B. Evans, Performance of TCP extensions on Noisy High BDP Networks, IEEE Communications Letters, vol. 3, no. 10, Oct. 1999.
[4] J. B. Schodorf, EHF Satellite Communications on The Move: Baseband Considerations, Technical Report 1055, Feb. 2000.
[5] J. L. Mineweaser, J. S. Stadler, S. Tsao, and M. Flanagan, Improving TCP/IP Performance For The Land Mobile Satellite Channel, vol.1, pp. 711-718, MILCOM 2001.
[6] G. Xylomenos and G. C. Polyzos, Link Layer Support for Quality of Service on Wireless Internet Links, IEEE Personal Communications, Oct. 1999.
[7] M. Rice et al.,K-band land-mobile satellite characterization using ACTS, Intl. J. Sat. Comm., pp.283-296, January 1996.
[8] Networks Simulator 2, http: //www.isi.edu/ nsnam/ ns