An Adaptive Two-Copy Delayed SR-ARQ for Satellite Channels with Shadowing

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Abstract- **The paper focuses on improving performance of land mobile satellite channels (LMSC) at high band (K or EHF band), where shadowing is the primary impediment to reliable data transmission. Compared with multipath fading, shadowing exists on a longer time scale. Hence interleaving to combat shadowing introduces unacceptably large decoding delay. Here we propose an *adaptive two-copy delayed SR-ARQ* scheme whereby two copies of a packet are sent - the second with a delay relative to the first - in every transmission or retransmission. Closed-form expressions for *mean transmission time*, *success probability*, and *residual loss probability* are provided and simulation is used to validate the analysis. Furthermore, the issue of optimizing *delay* is addressed as well, and a simple yet effective strategy is suggested to support TCP traffic. By simulation, we compare the proposal with the normal SR-ARQ scheme in terms of TCP end-to-end throughput, and show great performance improvement achieved by our method.**

Key Words: satellite networks, TCP/IP

I. Introduction

Currently, there is a great deal of interest in extending satellite communications to higher bands (say K or EHF band) in order to achieve more data transmission bandwidth. [3] demonstrated that the primary negative impact on performance of land mobile satellite channel at high band (e.g. K or EHF) is shadowing due to blockage rather than multipath fading. Generally, the channel can be represented by a two-state Markov process as in [1]. In bad (shadowed) states, the average SNR is too low to correctly transmit signals even with powerful forward error correction (FEC) method, while in good (unshadowed) states, the large value of Rice factor guarantees reliable signal transmission even without much FEC protection. As is well known, interleaving is widely used with FEC to resist fading and improve the reliability of a wireless channel with burst errors. However, with increasing average error burst length as in shadow fading, the needed interleaving depth will be unacceptable for delay sensitive applications such as streaming media. A suitable alternative is a multiple copy retransmission scheme whereby a delay is inserted between copies of the retransmitted packet. This work seeks to extend the previous work in [2] to a satellite channel with shadowing - the mode of increasing the copy number with retransmission is modified from ([2]) because it is unstable in implementation. In this paper, we fix the copy number to two since it is possible to obtain analytical expressions for metric of interest (i.e. mean transmission time, transmission success probability, and residual loss probability).

Link level adaptive methods [4] are a natural fit for wireless communications because the most wireless channels are time-varying. With such techniques, the transmit parameters such as coding rate, packet length, ARQ type are adjusted (typically based on feedback from a cooperative receiver that provides current channel state information) to achieve optimized performance over time-varying channels. As can be intuitively appreciated, util-

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ity of any transmitter adaptation depends crucially on the efficiency and accuracy of channel state information (CSI). Naturally, shorter-term (compared to one round-trip time) channel variations cannot be tracked via ARQ over a satellite channel. However, it is feasible to track the longer term shadow fading channel so as to tune transmit parameters such as *delay time* between packet copies in our proposal.

The paper is organized as follows. In the next section, a model for two-copy ARQ is introduced and expressions for success probability for each transmission, mean transmission time, and residual loss probability is given in closed-form. In Section 3, we show numerical results so as to validate our analysis. We compare achieved end-to-end throughput for TCP traffic with our proposal to normal SR-ARQ scheme in Section 4 followed by conclusions in Section 5.

II. Two-Copy Delayed SR-ARQ

Two-copy delayed SR-ARQ is identical to normal SR-ARQ except that two identical copies of a data packet with in-between delay D are sent during each transmission or retransmission. Loss of both packets only results in negative acknowledgment (NACK), and leads to a retransmission. Such a scheme may be considered equivalent to link layer rate 1/2 coding.

A two-state Markov has been widely used to represent the shadowed channel process, at least to a first-order approximation. Thus the duration of a bad state (i.e the error burst length) is exponentially distributed with mean m. The parameters used in our analysis are listed below:

X : Fraction of time in good state;

Peg : Packet error rate in good states;

Peb : Packet error rate in bad states;

m : Mean length of bad state duration;

RTT : Round trip time of a satellite channel;

Bw : Bandwidth of a satellite channel.

It is reasonable to assume $Peb \approx 1$, implying no successful transmission can be done in shadowing periods.

First, we consider transmission of two copies with a delay time (d) in between. Since the packet error rate is very small in good states compared with bad states, packet losses can be assumed to take place in only bad states. If the first copy is lost, receiving the second one correctly is dependent on the following events: the bad state ends before the transmission of the second copy and channel continues in good state for duration of packet transmission. The resulting probability is $(1-e^{-\frac{d}{m}})p_g(1-Peg)$, where $(1-e^{-\frac{d}{m}})$ is the probability for bad state ending before the transmission of the second packet, and p_g is the conditional probability of staying in a good state and $(1-Peg)$ is the probability of correctly transmitting packets in good states. Accurate estimation of p_g is difficult and therefore an intuitive approximation to p_g is given next. As the duration of a bad state is exponentially distributed, the correlation between two successive copies is reduced via the expression $e^{-\frac{d}{m}}$. For $d \rightarrow 0$, the second copy must encounter a good state with probability one for success. For d large ($\rightarrow \infty$), no relationship exists between two copies so that the second one has probability of X of being in good state, where X is the time share parameter. Since the above events a mutually exclusive, the desired result for p_g is the summation of the above two cases for any delay time d.

From the above, the probability for correctly receiving the second copy after losing the first as is given by

$$P_{Se}(d) = (1-e^{-\frac{d}{m}})(e^{-\frac{d}{m}} + X(1-e^{-\frac{d}{m}}))(1-Peg), \quad (1)$$

We next consider the success probability for transmission and retransmission, denoted by P_{St} and P_{Sr} respectively. The first copy of the transmission is the first one in the transmission sequence, leading to the probability of $X(1-Peg)$ to be correctly received. Therefore, we have

$$P_{St} = X(1-Peg) + (1-X(1-Peg))P_{Se}(D). \quad (2)$$

For retransmission, we know that the previous attempt must have failed. The delay time between the second copy of the previous attempt and the first copy of the current retransmission is RTT. We have,

$$P_{Sr} = P_{Se}(RTT) + (1-P_{Se}(RTT))P_{Se}(D) \quad (3)$$

If the maximum number of attempts for each packet is N, the packet loss probability $P_l^{(N)}$ after N attempts is

$$P_l^{(N)} = (1-P_{Sr})^{N-1}(1-P_{St}) \quad (4)$$

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Due to space limitations, further derivational details are omitted and the final result for the mean transmission time T is given below under the assumption of infinite retransmission attempts.

$$\begin{aligned} T \quad = \quad & \frac{(1-P_{St})}{P_{Sr}}[RTT + D + RTT P_{Sr} + D(1-P_{Se}(RTT))P_{Se}(D)] \\ & + X(1-Peg)RTT + (1-X(1-Peg))P_{Se}(D)(RTT+D) \end{aligned} \tag{5}$$

Eq.4 and Eq.5 are closed-form and can be used to provide performance estimate for applications that require delay bound guarantees. Clearly, the mean error burst length must be estimated in advance using a long-term CSE scheme. In the following section, we assume that the value of m is somehow known.

III. Numerical Results

In all simulations and analysis reported here, a link layer packet duration is chosen as the unit of time (a slot). Wireless channel bandwidth (Bw) is fixed at 1Mbps. Fig.1 shows the improvement in terms of success probability of the first transmission by increasing delay D. Our analytical results match simulation results quite well. From Fig.1, we also see that longer error bursts imply the need for longer delay time for same success probability as expected.

Fixing the maximum number of attempts at 3, we study the residual loss probability after retransmission in Fig.2. The results show that the residual loss probability is dramatically reduced by *delay* increasing. Fig.3 investigates the mean transmission time T of our proposal for two different average error burst length, 20 and 10. Results indicate that there exists an optimal point for the value of delay yielding the minimum mean transmission time.

The optimal delay for achieving the minimum average transmission time can be found from

$$\frac{dT}{dD} \quad = \quad 0 \tag{6}$$

It is however tedious to explicitly solve Eq.6; Fig.1-3 have further shown that $2m$ is a good selection for D considering of P_{Ts}, $P_l^{(N)}$, and T. Therefore, in subsequent simulations of TCP performance, use $D = 2m$. Fig.4 results indicate that longer average burst error length leads to the smaller residual loss probability and longer mean transmission time.

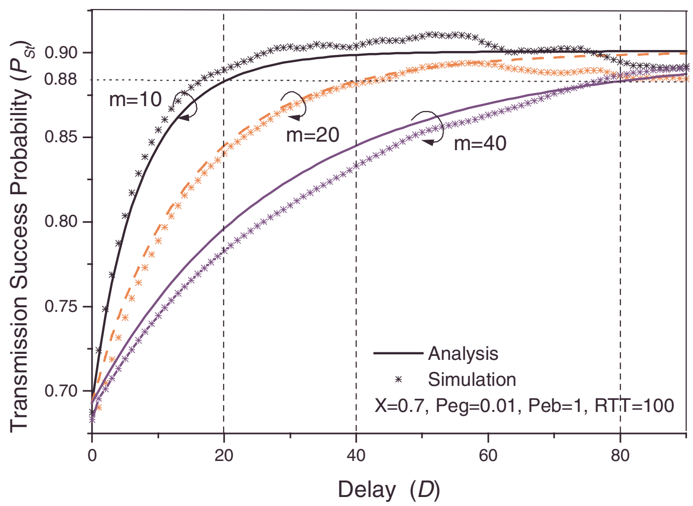


Figure 1: Success Probability of Transmission

IV. On TCP Performance

In this section, we study the performance of TCP over two-copy delayed SR-ARQ. Although TCP traffic is not delay sensitive, the long persistence time due to retransmission results in buffer overflow degrading the whole performance significantly, especially for the long propagation delay network. Two-copy delayed SR-ARQ greatly increases success probability of each transmission/retransmission with consequent improvement in TCP end-to-end throughput. However, the large values of the delay time may exceed desired delay bounds; thus the delay is bounded by half RTT and set using the following equation.

$$D = min(2m, \frac{RTT}{2}) \tag{7}$$

For a fixed maximum copy number (say 8), the maximum retransmission times for normal SR-ARQ is 7, and 3 for our proposed two-copy delayed SR-ARQ. Fig.5 shows that the TCP end-to-end throughput is improved by using our scheme, especially when the average error burst length is short. When the error burst length increases, the performance improvement using our proposal is reduced. In other words, the two-copy delayed SR-ARQ is more suitable for the faster shadowing fading channel with shorter error burst length compared with round trip time.

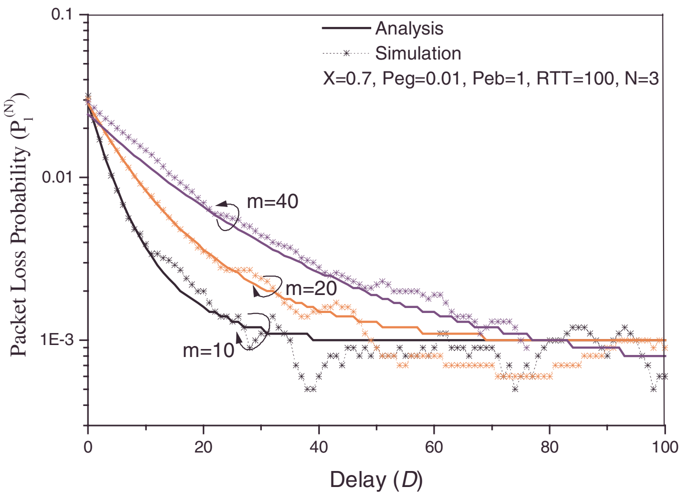


Figure 2: Packet Loss Probability after N attempts ($N = 3$)

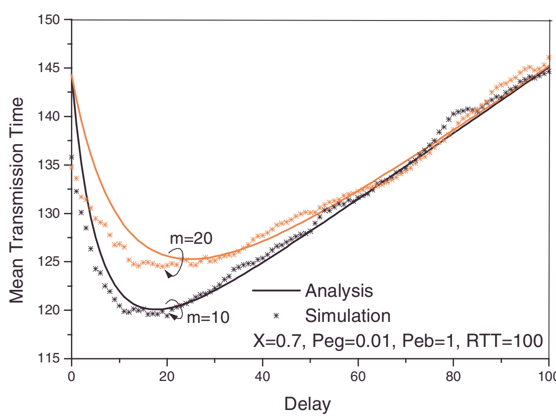
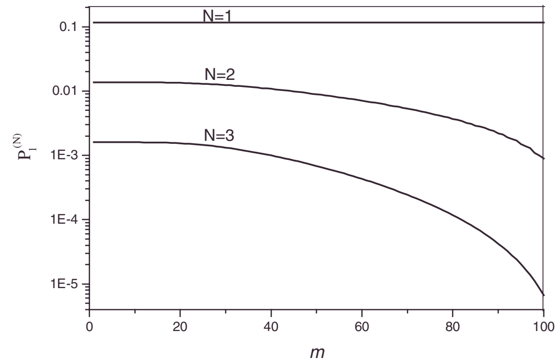


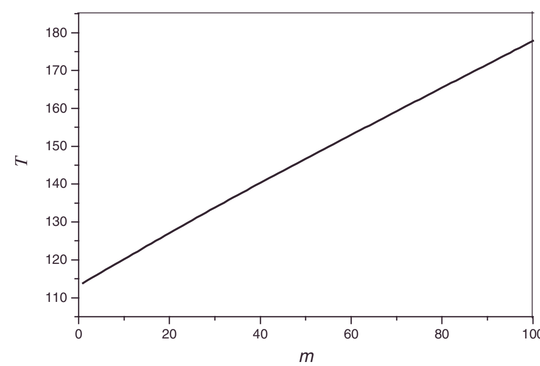
Figure 3: Mean Transmission Time

V. Conclusion

In this paper, we proposed an adaptive two-copy delayed SR-ARQ for the shadowing satellite channel in the K band or EHF band. In consideration of longer fading periods due to shadowing compared with multipath fading, a two-copy with delay ARQ method was suggested in place of interleaving to combat burst errors. Analytical results showed that success probability of each transmission is significantly improved, and mean transmission time is reduced as well. Simulation was performed to compare our scheme with normal SR-ARQ in terms of TCP end-to-end throughput, indicating that our proposal achieves significant performance improvement especially for the fast shadowing channels.



a) Residual Packet Loss Probability After N Attempts



b) Mean Transmission Time (N=∞)

Figure 4: The Performance of $D = 2m$ ($RTT = 100$, $X = 0.7$, $Peg = 0.01$)

The assumption of the error burst length being exponentially distributed might be not quite accurate for some cases. The future work is to develop an accurate model and/or an estimation method for long-term PDF (Probability Density Function) of the shadowing process, and use it to compute the optimal value of the delay leading to further performance improvement of our proposals.

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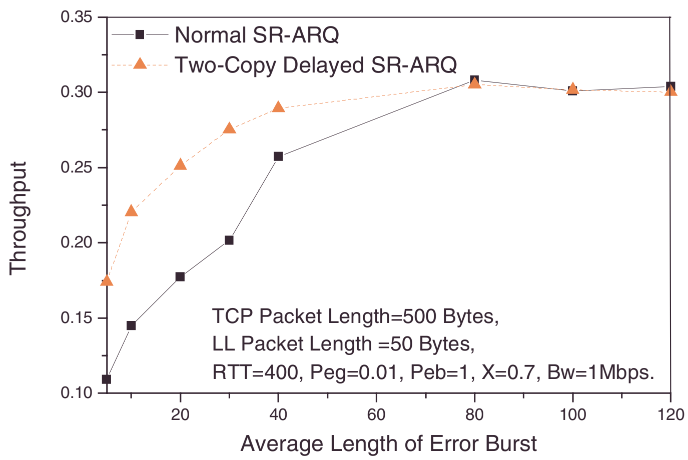

Figure 5: TCP End-to-End Throughput Comparison (Buffer Size=20000 bytes)

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