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A Simple Algorithm that Adapts one of Two Packet Sizes in a Wireless ARQ Protocol

Shiji M. Enchakilodil *Southern Illinois University Carbondale*

Neha Udar *Southern Illinois University Carbondale*

R. Viswanathan *Southern Illinois University Carbondale*, viswa@engr.siu.edu

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A Simple Algorithm that Adapts one of Two Packet Sizes in ^a Wireless ARQ Protocol

Shiji M. Enchakilodil, Neha Udar, and R. Viswanathan Department of Electrical & Computer Engineering Southern Illinois University at Carbondale Carbondale, IL 62901-6603

Abstract $-$ A recent algorithm of Modiano selects packet In this paper we modify the algorithm of Modiano so that the sizes in a selective repeat ARQ protocol based on the proposed scheme adapts between one of only two pre-
acknowledgement history of the most recently transmitted specified packet sizes. Our analysis follows closely the acknowledgement history of the most recently transmitted specified packet sizes. Our analysis follows closely the packets. In this paper we modify this algorithm so that analysis of [5], but in the process we also provide **packets. In this paper we modify this algorithm so that** analysis of [5], but in the process we also provide a simplified the choice of packet size is restricted to one of two pre-
solution to equation (8) in [5]. The re specified values. We provide a strategy for switching organized as follows. In section II, the algorithm of Modiano between these packet sizes and show that is optimal in the is briefly explained. In section III we discuss between these packet sizes and show that is optimal in the is briefly explained. In section III we discuss the proposed sense of maximizing the one step efficiency. The algorithm and derive its optimal parameters for maxim analyzed for a constant bit-error-rate channel and for two numerical and simulation results obtained in this study are state Gilbert-Elliot channel. The results show that the discussed. We conclude this study in section V. throughput efficiencies of this scheme under high and moderate bit-error-rates are slightly less than that of II. ADAPTIVE SCHEME OF MODIANO Modiano's algorithm. However the scheme is attractive because of its simplicity. Throughput, which is a measure of the efficiency of the

transmission errors caused by the channel degradations. In wireless links, there is a high probability of bit errors in a I. INTRODUCTION

A major concern in data communication is the control of

transmission errors caused by the channel degradations. In

wireless links, there is a high probability of bit errors in a

packet because of multi packet because of multi-path signal fading and interference. In order to improve the throughput efficiency of an ARQ protocol in these channels, a number of adaptive schemes holocol in diese channels, a name cold adaptive senemes
have been devised [1-5]. A scheme could adapt modulation where k is the number of information bits, h is the number of
and/or eading [1] and hot weap A DQ protocols and/or coding $[1]$, adapt between ARQ protocols $[2-4]$, or adapt the packet size [5]. Here we consider the adaptation of
packet size is in [5]. Too large a packet size results in
increased retransmissions and too small a packet would be
increased retransmissions and too small a p inept due to the fixed overhead required per packet.
Therefore, a packet size should be selected based on the error-rate encountered in the channel. In [5] an algorithm has . number of retransmissions out of M packet transmissions, $\frac{1}{2}$ has $\frac{1}{2}$ heart transmissions, $\frac{1}{2}$ heart transmissions, $\frac{1}{2}$ heart transmi been developed which chooses the packet size based on the three average efficiency can be expressed by averaging
equation (1) with respect to the conditional density of p given history of transmitted packets. If the number of retransmitted equation (1) packets is known, a packet size can be chosen which R , $f(p|R)$: maximizes the one-step efficiency of the protocol. A Markov chain analysis, which evaluates the steady state performance of the algorithm for static channel conditions, was also done. The algorithm assumes that the transmitter uses a framing mechanism to accommodate variable packet sizes. Hence, no If a uniform prior distribution for p is assumed then (2) can additional communication is required between the transmitter be simplified to yield [5] and the receiver for the purpose of coordinating the packet size.

solution to equation (8) in [5]. The rest of the paper is sense of maximizing the one step efficiency. The algorithm and derive its optimal parameters for maximizing throughput efficiency of the proposed adaptive scheme is the one-step efficiency of the protocol. In section IV the one-step efficiency of the protocol. In section IV,

protocol for delivering useful data, is dependent on the packet I. INTRODUCTION size, the overhead bits and the channel bit error rate. The A major concern in data communication is the control of a given channel error rate can be given by $[5]$

$$
EFF = \left(\frac{k}{k+h}\right) \frac{1}{(1-p)^{-(k+h)}}
$$
 (1)

maximize the expected efficiency of the protocol. If R is the number of retransmissions out of M packet transmissions,

$$
EFFR(k) = \int_{p} \frac{k(1-p)^{k+h}}{(k+h)} f(p|R) dp
$$
 (2)

$$
EFF_{R}(k) = \int_{P} \left[\frac{k(1-p)^{k+h}}{(k+h)} \times \frac{\binom{M}{R} E^{R} (1-E)^{M-R}}{\int_{R}^{M} \int_{R} E^{R} (1-E)^{M-R}} \right] dp
$$

$$
E = 1 - (1 - p)^{\hat{k} + h} \tag{4}
$$

transmissions. This derivation assumes that the packet errors (8) are independent from packet to packet. This is valid in a
statio shannol or in a feding shannol where the shannol. Using the procedure similar to the one employed in section II static channel or in a fading channel where the channel $\frac{\text{Using the procedure is}}{\text{to arrive at (7), we get}}$ conditions do not change within the duration of M packets. The optimal value of k for next transmission can be found by choosing the value of k that maximizes the efficiency (3). A . A Simplified Expression for (3)

Let
$$
C = \int_{R}^{M} \left(\frac{M}{R} \right) E^{R} (1 - E)^{M - R} dp
$$
 (5) $S + h \sum_{R = t_{1}+1}^{M} \left(\frac{M}{R} \right) \cdot \beta(b_{s0}, R + 1)$

Using
$$
(4)-(5)
$$
, (3) becomes

$$
EFF_{R}(k) = \frac{k \times \binom{M}{R}}{C \times (k+h)}.
$$
\n
$$
\int_{p}^{1} (1-p)^{k+h} (1-(1-p)^{\hat{k}+h})^{R} ((1-p)^{\hat{k}+h})^{M-R} dp
$$
\n(6)\n
$$
\int_{p}^{1} (1-p)^{k+h} (1-(1-p)^{\hat{k}+h})^{R} ((1-p)^{\hat{k}+h})^{M-R} dp
$$
\n(7)

Using the beta function integral
\n
$$
\beta(a,b) = \int_0^1 x^{a-1} (1-x)^{b-1} dx = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)}
$$
in (6) and $b_s = b_{s0} + 1, b_{s1} = \frac{L+h+1}{S+h}$

employing routine manipulations yield the following simple Similarly, expression:

$$
EFF_R(k) = \frac{k}{k+h} \times \frac{\prod_{x=0}^{R} \left(\frac{1}{k+h} + M - x\right)}{\prod_{y=0}^{R} \left(\frac{k+h+1}{k+h} + M - y\right)} \qquad \qquad EFF_R(\hat{k} = L) = \frac{S}{S+h} \cdot \frac{\sum_{R=I_2}^{R} \left(\frac{1}{R}\right) \cdot \beta(b_i, R+1)}{\sum_{R=I_2}^{M} \left(\frac{M}{R}\right) \cdot \beta(b_{I_0}, R+1)} + \frac{\sum_{R=I_1}^{R} \left(\frac{1}{R}\right) \cdot \beta(b_{I_0}, R+1)}{\sum_{R=I_1}^{M} \left(\frac{M}{R}\right) \cdot \beta(b_{I_0}, R+1)} \qquad (7)
$$

This expression is a simplified equivalent of (8) in [5].

III. PROPOSED ALGORITHM

The proposed adaptive algorithm uses only two packet sizes, which can be termed as the short packet size (S) and the long (10) (10) packet size (I) . We appril at the thresholds for multiplier packet size (L) . We consider two thresholds for switching where between the short packet and the long packet. If the previous packet size is $k = S$ and if $R \leq t_1$, a switch from short to long is made. Otherwise, the transmission of short packets

continues for the next M consecutive packets. If $\hat{k} = L$ and $R \ge t_2$, a switch from long to short is made. Otherwise, the long packet size is continued for the next M transmissions.

When $\hat{k} = S$ the efficiency of the protocol can be given as

where
\n
$$
E = 1 - (1 - p)^{\hat{k} + h}
$$
\n
$$
= \int_{R}^{R} (k - s) ds = \int_{R}^{R} \left[\frac{S(1-p)^{S+h}}{(S+h)} \cdot f(p|R > t_1) \right] dp +
$$
\n
$$
= \int_{R}^{R} \left[\frac{L(1-p)^{L+h}}{(L+h)} \cdot f(p|R \le t_1) \right] dp
$$
\nand \hat{k} is the packet size used in the previous *M* transmissions. This derivation assumes that the packet errors

Continuous do not change within the duration of *M* packets.

\nThe optimal value of *k* for next transmission can be found by choosing the value of *k* that maximizes the efficiency (3).

\n*A.* A Simplified Expression for (3)

\nLet
$$
C = \int_{p}^{M} \begin{pmatrix} M \\ R \end{pmatrix} E^{R} (1 - E)^{M-R} dp
$$

\nUsing (4)-(5), (3) becomes

\n
$$
k \times \begin{pmatrix} M \\ R \end{pmatrix}.
$$
\n
$$
EFF_{R}(\hat{k} = S) = \frac{S}{S+h} \cdot \frac{\sum_{R=I_{1}+1}^{M} {M \choose R} \cdot \beta(b_{s}, R+1)}{\sum_{R=I_{1}+1}^{M} {M \choose R} \cdot \beta(b_{s0}, R+1)} + \frac{\sum_{R=I_{1}+1}^{M} {M \choose R} \cdot \beta(b_{s0}, R+1)}{\sum_{R=I_{1}+1}^{M} {M \choose R} \cdot \beta(b_{s1}, R+1)}
$$
\n
$$
EFF_{R}(k) = \frac{k \times \begin{pmatrix} M \\ R \end{pmatrix}}{C \times (k+h)}.
$$
\n(1 - n)^{k+h} (1 - (1 - n)^{k+h})^{R} ((1 - n)^{k+h})^{M-R} dp

\n(6)

\n(9)

$$
\text{where } b_{s0} = \frac{1}{S+h} + (M - R),
$$
\n
$$
{}^{1}(1-x)^{b-1} dx = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)} \text{ in (6) and } b_{s} = b_{s0} + 1, b_{s1} = \frac{L+h+1}{S+h} + (M - R).
$$

$$
M - x
$$
\n
$$
+ M - y
$$
\n
$$
+ M - y
$$
\n
$$
= \sum_{R = t_2}^{n} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
+ M - y
$$
\n
$$
= \sum_{R = t_2}^{n} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = 0}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = 0}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = 0}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = 0}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta(b_1, R + 1)
$$
\n
$$
= \sum_{R = t_2}^{t_2 - 1} {M \choose R} \cdot \beta
$$

$$
b_{l} = \frac{S+h+1}{L+h} + (M-R), b_{l0} = \frac{1}{L+h} + (M-R),
$$

$$
b_{l1} = b_{l0} + 1
$$

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Authorized licensed use limited to: Southern Illinois University Carbondale. Downloaded on May 30, 2009 at 16:09 from IEEE Xplore. Restrictions apply.

It can be shown theoretically that S S_{+h} L $_{R_{-h}$ L^{+h} $t_1 = 0$ ($t_2 = 1$) maximizes the expression (9) ((10)). To prove this we show that each of the two factors in (9) is maximized at $t_1 = 0$ and that each of the two factors in (10) Using (11) through (15) along with $t_1 = 0 (M = M_s)$, is maximized at $t_2 = 1$ (complete proof is given in [6]). $t_2 = 1(M = M_L)$ yield Therefore, the optimum algorithm switches the packet size from short to long, if and only if, while in short packet mode, the number of re-transmissions in M successive transmissions is zero. Similarly, the optimum algorithm switches the Similarly, the optimum algorithm switches the packet size from long to short, if and only if, while in long packet mode, the number of re-transmissions in M successive transmissions is one or more. The M value used while in S mode and the value used while in L mode need not be identical. In fact, in our simulation, the transmission history is kept at 10, 000 bits, which translates to an M value of $M_s = \lfloor 10,000/S \rfloor$ in the S mode and an M value of $M_L = \left\lceil 10,000 / L \right\rceil$ in the L mode.

III.A Steady-state efficiency in fixed error rate channel

To calculate the steady-state performance of the proposed algorithm, we consider a two-state Markov chain model

$$
p_{SL} = \sum_{R=0}^{t_1} {M \choose R} E_S^R (1 - E_S)^{M-R}
$$
\n(11)

$$
p_{LS} = \sum_{R=t_2}^{M} {M \choose R} E_L^R (1 - E_L)^{M - R}
$$
\n(12)

By denoting the steady-state probability of short (long) packet state as $P_S(P_L)$, we have $P_L = 1 - P_S$ and

$$
P_S = \frac{p_{LS}}{p_{SL} + p_{LS}}\tag{13}
$$

Therefore, the efficiency of the proposed protocol is

$$
EFF(p) = \frac{S}{S+h} \cdot P_S \cdot q^{S+h} + \frac{L}{L+h} \cdot P_L \cdot q^{L+h}
$$
\n(14)

$$
EFF(p) = \frac{1 - q^{(L+h)M}L}{1 - q^{(L+h)M}L + q^{(S+h)M}S}
$$

$$
\cdot \frac{S}{S+h} \cdot q^{(S+h)} + \frac{L}{L+h} \cdot q^{(L+h)}
$$

$$
\cdot \frac{q^{(S+h)M}S}{1 - q^{(L+h)M}L + q^{(S+h)M}S}
$$
(15)

III.B PERFORMANCE OF THE PROPOSED ALGORITHM UNDER CHANGING BIT-ERROR-RATE CONDITIONS

where the state of the system is described by the packet size We assume a Gilbert-Elliot model for the changing bit-error-
heing used. Transitions between the two nacket sizes take rate (BER) conditions of a time varying c being used. Transitions between the two packet sizes take rate (BER) conditions of a time varying channel. The channel place according to the transition probabilities, p_{SL} for and the optimal packet size may be either short or long. In transition from short to long and p_{LS} for transition from long this model we assume that the transitions between the two to short. These transition probabilities can be given as states occur according to the exponential random process of follows: rate μ_G for transitions from the good state to the bad state and μ_B for transitions from the bad state to the good state. As in [5], we assume the rate of transition between the two states to be same in both directions $(\mu = \mu_G = \mu_B)$. where $E_s = 1-(1-p)^{S+h} = 1-q^{S+h}$ Therefore, the amount of time the channel spends in the good state (and the bad state) is exponentially distributed with an average value of $\rho = 1 / \mu$. For a channel rate R_c , the average number of bits between channel transitions is simply $b = \rho R_c$. We resort to simulation in order to study the throughput performance under the above channel model. It is where $E_L = 1-(1-p)^{L+h} = 1-q^{L+h}$ to be noted that the switch between short and the long packets could happen only after *M* successive transmissions whereas could happen only after M successive transmissions whereas the channel state could switch within an M transmission cycle. The throughput efficiency is calculated as

By denoting the steady-state probability of short (long)
$$
EFF = P_{gs} \frac{S}{S+h} \left(1 - p_g\right)^{s+h} + P_{gl} \frac{L}{L+h} \left(1 - p_g\right)^{L+h}
$$

\n
$$
P_S = \frac{p_{LS}}{p_{SL} + p_{LS}}
$$

\n(13)
$$
+ P_{bs} \frac{S}{S+h} \left(1 - p_g\right)^{s+h} + P_{bl} \frac{L}{L+h} \left(1 - p_g\right)^{L+h}
$$

(16)

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where P_{xy} is the steady-state probability with first subscript V. CONCLUSIONS indicating good (g) or bad (b) channel state and the second In this paper we proposed a modification to the adaptive
subscript indicating short (s) or long (l) packet size and alogarithm of Modiano for eduction polar in an subscript indicating short (s) or long (1) packet size and algorithm of Modiano, for adapting packet sizes in an ARQ
p_c (p_b) is the good (bad) channel BER.
protocol depending on the channel error rate. The proposed

efficiency results for the proposed algorithm are computed using (15). For studying the adaptive algorithm of Modiano, simulation with 200 packet sizes, identical to the one in [5] is employed. A simulation study was employed to compute the REFERENCES efficiency for the two-state channel. Figures 1-5 show the efficiency performances vs. the channel BER for a [1] A.J. Goldsmith and S. Chua, "Adaptive coded modulation transmission history of 10,000 bits and $h = 40$ bits. The fading channels," IEEE Trans on. Commun., pp. 1218efficiencies obtained with the optimal algorithm (with 1230, Oct. 1997. optimal packet size of a perfect retransmission algorithm [5]) $\begin{bmatrix} 2 \ 2 \ 1 \end{bmatrix}$ M. Moeneclaey, H. Bruneel, "Efficient ARQ and fixed packet size schemes with sizes 200 and 2000, $\begin{bmatrix} 2 \ 1 \end{bmatrix}$ M. Moeneclaey, H. respectively, are also shown in these figures. In Fig. 1-3 pp. 986-987, 1984. where $L = 2000$ and S is varied, it can be observed that the pp. 98-7 1984.
 $\begin{bmatrix} 3 \end{bmatrix}$ A.R.K. Sastry, Improving automatic repeat request
 $\begin{bmatrix} 3 & 0 \end{bmatrix}$ A.R.K. Sastry, Improving automatic repeat request efficiency at high and medium BERS are affected. As the (ARQ) performance on satellite channels under high error
short packet size increases, the efficiency of the proposed rate conditions, IEEE Transactions on Communicati algorithm gradually decreases at high BERs, but at medium $\frac{1}{\sqrt{6}}$ Vol. 23, No. 4, pp. 436-439, 1975. BERs the efficiency increases. At low BERs, the efficiency $\begin{bmatrix} 4 \ 1 \ 1 \end{bmatrix}$ Y. Yao, "An effective Go-EXERE STATE STATE THE STATE STATE SURFACT STATE STATE STATE STATE STATE OF SERIS the efficiency increases. At low BERS, the efficiency

If T. Yao, "An effective Go-Back-N ARQ scheme for

is quite close to that of the opti is quite close to that of the optimum argorithm. In Fig. 4-3 variable-error-rate channels", IEEE Transactions we show results for $L=1500$, $S=150$ and $S=200$, respectively. Communications Vol. 43, No.1, pp. 20-23, Jan.1 Though not shown here, we examined values of L down to $\begin{bmatrix} 5 \end{bmatrix}$ E. Modiano, "An adaptive algorithm for optimizing the 750 and values of S up to 250. The steady-state efficiency of
the proposed algorithm is somewhat close to that of the
adaptive algorithm of Modiano when S=150 and L=1500 or
 $\frac{Net_SN}$, Vol. 5, pp. 279-286, July 1999. adaptive algorithm of Modiano when $S=150$ and $L=1500$ or $\begin{bmatrix} 6 \end{bmatrix}$ S.M. Enchakilodil, "A simple algorithm that adapts one $\begin{bmatrix} 2000. \end{bmatrix}$. The efficiency is lower than that of Modiano's for of two packet siz BERs in the vicinity of 10^{-4} and in the vicinity of 10^{-2} . The
reduction at high BER is due to the fact that Mdiano's
reduction at high BER is due to the fact that Mdiano's
Southern Illinois University at Carbondale, scheme considers short packet sizes starting from 10 bits 62901, July 2004. whereas the proposed procedure has only a fixed short packet size. The performance at very low BERs is closer to that of the optimal and is slightly better than that of Modiano's $\overline{0.9}$ $\overline{0.9}$ proposed algorithm
scheme.

For the Gilbert-Elliott channel, Fig. 6 shows the average 0.7 efficiency vs. the average amount of time between channel state transitions. To obtain this graph we used a fixed
transmission history of $M = 50$ (for both short and long
nackets modes), a channel transmission rate (R_C) of 100. transmission history of $M = 50$ (for both short and long u $\frac{5}{6}$ 0.5 packets modes), a channel transmission rate (R_C) of 100, $E_{0.4}$ 000 bps, the good channel BER of 10^{-5} , the bad channel BER of 10^{-3} , and ρ values from 0 to 5. The average efficiency of the proposed algorithm in good state is 0.94 and in the bad 0.2 state is 0.6 (giving an average efficiency of 0.77). 0.1 Corresponding values for Modiano's algorithm are 0.96 and $\frac{1}{166}$ $\frac{1}{165}$ $\frac{1}{164}$ $\frac{1}{163}$ $\frac{1}{162}$ 0.65, respectively. The performance of the proposed $1\overline{E}-6$ 1 E-5 1 E-4 1 bit-error-rate algorithm is quite close to the performance of the Modiano algorithm in the Gilbert-Elliott channel.

protocol depending on the channel error rate. The proposed adaptive algorithm adapts one of two packet sizes, achieving nearly the efficiency of the Modiano algorithm. A slight IV. NUMERICAL AND SIMULATION RESULTS reduction in efficiency, as compared to the Modiano algorithm, does occur at high and moderate channel bit error For constant BER channel, the steady-state throughput rates, but the simplicity counter balances the deterioration in efficiency results for the proposed algorithm are computed rates, but the simplicity counter balances th

scheme for high error rate channels", Electronics Letter 20,

Fig. 1. Steady State performance comparison of optimal, fixed, adaptive (Modiano), and proposed algorithms with $M=10,000$ bits, $S = 100, L = 2000$

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Fig..2. Steady State performanee eomparison of optimal, fixed, adaptive (Modiano), and proposed algorithms with $M=10,000$ bits, $S = 150, L = 2000$
 $= 0.5$ $S = 150, L = 2000$

adaptive (Modiano), and proposed algorithms with $M=10,000$ bits, $S = 200, L=2000$

Fig. 4. Steady State performance comparison of optimal, fixed, $S=150, L=1500$

adaptive (Modiano), and proposed algorithms with $M=10,000$ bits, $S = 200, L = 1500$

Fig.3. Steady State performance comparison of optimal, fixed, of time between channel state transitions for $S = 250$, $L = 1000$, adaptive (Modiano), and proposed algorithms with $M=10,000$ bits, $P_g = 10^{-5}$, $P_b = 10^{-3}$.

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