

AN EFFECTIVE GO-BACK-N AUTOMATIC-REPEAT-REQUEST SCHEME FOR VARIABLE-ERROR-RATE CHANNELS

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Abstract

In non stationary channels, error rates vary considerably. This paper proposes an effective go-back-N (GBN) Automatic-Repeat-Request (ARQ) scheme which estimates the channel state in a simple manner, and adaptively switches its operation mode. It provides higher throughput than other comparable ARQ schemes in conditions of Land-Mobile-Satellite (LMS) channel.

Keywords

channel, model, Automatic-Repeat-Request (ARQ), Land-Mobile-Satellite (LMS)

1. Introduction

ARQ techniques are widely used for error control in data communication systems. Particularly, the GBN ARQ scheme is very popular because it provides higher throughput compared to Stop-and-Wait (SW) ARQ scheme and its implementation is simpler than Selective-Repeat (SR) ARQ scheme since it does not require buffering at the receiver side.

The operation procedure and throughput efficiency of the classic GBN ARQ scheme is well known [1]. The main drawback of this scheme is that, whenever a received block is detected in error, the receiver also rejects the next $N-1$ received blocks, even though many of them may be error-free. As a result, they must be retransmitted. This causes a waste of transmissions, which can result to severe deterioration of throughput performance. The larger round trip delay N is involved the worse throughput is achieved.

Sastry modified the classic GBN ARQ scheme [2] by transmitting the block detected in error continuously until a positive acknowledgement (ACK) is received which improves the efficiency when the block error probability P_e is larger than 0.5. Bruneel and Moenaclaey proposed an ARQ schemes [5] that further improves classic GBN efficiency when $P_e > 0.5$. Both improvements of classic GBN ARQ schemes gives better results only if the channel stays in a very noisy state. This paper proposes a GBN ARQ scheme for the channels where the error rates changes (P_e varies from as low as approaching zero to as high as 0.5 or above, possibly in a wireless communication environment such LMS systems). In this scheme, the transmitter estimates the channel state (low/high error rate) in a simple manner and adaptively changes its operation mode. It provides higher throughput than other comparable schemes under a wide range of error rate conditions.

The idea of dynamically changing the ARQ algorithm was previously considered in the technical literature [3],[4], and several schemes were proposed for non stationary channel applications. The approach taken in [3] assumes knowledge of the instantaneous block error probability, which is difficult to estimate. In [4] Yao makes estimation of the channel state by counting contiguous positive acknowledgements (ACK) respectively negative acknowledgements (NAK). In this paper we present new scheme which uses new approach to estimate channel state and at the end we compare this scheme with Yao's one in conditions of LMS channel.

2. Channel states and ARQ operation modes

The forward channel (from the transmitter to the receiver) is considered to have two states as they were proposed by Yao in [4], L states (low error rate) and H state (high error rate), as shown in figure 1. (Similar as Gilgert model.)

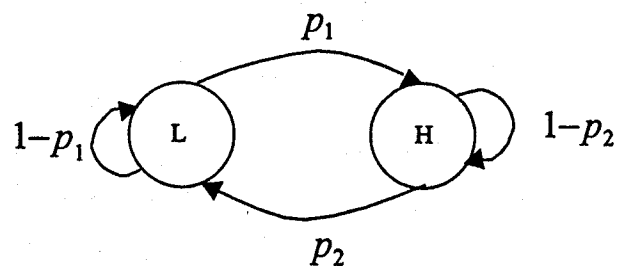


Fig. 1 Channel state model

The channel transits from state L to state H with a probability of p_1 and from state H to state L with a probability of p_2 .

Corresponding to the two channel states, there are two operation modes in the proposed GBN ARQ scheme. If the channel is in the L state, the transmitter follows the classic GBN ARQ procedure that throughput can be expressed by [2], [3]

$$\eta_{GBN} = \frac{1 - P_e}{1 + (N-1)P_e} \quad (1)$$

In this operation mode, the transmitter goes back N blocks upon reception of a NAK. If a NAK is received and $\alpha-1$ NAKs occurred in last K received acknowledgement messages, the transmitter would consider that the channel is transiting from L state to H state. The transition probability is

$$p_1 = [P_e^{\alpha+1} (1 - P_e)^{(K-1)-\alpha}] C(K-1, \alpha) \quad (2)$$

where $C(x, y) = \frac{x!}{y!(x-y)!}$

and where α can be expressed by $\alpha = \text{floor}(P_{S1}K)$

where the function $\text{floor}(x)$ rounds the elements of x to the nearest integers towards minus infinity. P_{S1} can be expressed by the next formula [4]

$$P_{S1} = \frac{n-1}{N} \quad (3)$$

which represents block error probability when n -copy ARQ throughput starts to be higher than GBN ARQ throughput.

In channel state H, the transmitter functions in n -copy transmission mode [3], which operates like the classic GBN ARQ scheme except for sending n copies of a block in each transmission. The throughput of an n -copy ARQ scheme is given in [3]

$$\eta_{n\text{-copy}} = \frac{1 - P_e^n}{n + (N-1)P_e^n} \quad (4)$$

If an ACK is received and $\beta-1$ ACKs occurred in last K received acknowledgement messages, the transmitter would consider that the channel is transiting from H state to L state. The transition probability is

$$p_2 = [P_e^\beta (1 - P_e)^{K-\beta}] C(K-1, \beta) \quad (5)$$

where β can be expressed by $\beta = \text{floor}(P_{S2}K)$ where P_{S2} should be $P_{S2} < P_{S1}$, it is advantageous to have $P_{S2} = 0$ for not very large K . In this case the transition from H to L state is the same as in Yao's ARQ scheme [4].

Note that the channel state model shown in the Fig. 1 does not define a channel environment. Instead, It is used by the transmitter to estimate the current channel state. Basically, the channel under consideration in this paper is disturbed by the random noise (which results in independent errors) although the error probability P_e may vary considerably from time to time. For simplicity we will assume that there is a noiseless feedback channel, i.e. no errors occur in the acknowledgement messages.

With the change of channel states (L/H), the proposed GBN ARQ scheme switches its operation modes (classic GBN and n -copy transmission). The decision of mode switching is made based on the estimation of the current block error probability P_e' from last K received acknowledgement messages. The operation mode switching is characterized by a transition matrix

$$T = \begin{bmatrix} 1-p_1 & p_1 \\ p_2 & 1-p_2 \end{bmatrix} \quad (6)$$

The flow chart shown in Fig. 2 summarizes the proposed ARQ scheme. There are three elements: the GBN transmission block and the n -copy transmission block as defined in [2], [3], and a channel state estimation block.

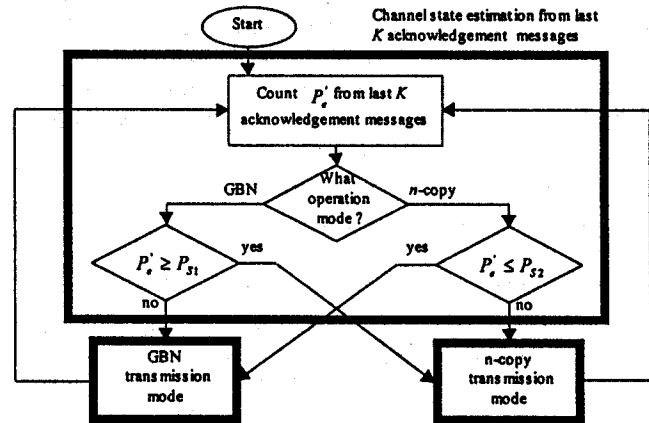


Fig. 2 Proposed ARQ scheme, transition between two operation modes

It is noted that a major element of the proposed scheme is a simple state estimator, based on counting estimation of block error probability P_e' from last K received acknowledgement messages. Other known channel estimation techniques include signal power measurements [4] and pilot tone transmissions [4]. In the approach with signal power measurements, an analog measure of the signal strength is made. The measurements need to be accurate over a wide dynamic signal range, which adds estimation complexity [4]. The pilot tone approach, which is often used to assist signal demodulation, can be applied for channel estimation. The pilot tone provides an explicit amplitude/phase reference relating to channel states, which also requires relatively

complex signal processing [4]. The method proposed in this paper estimates the channel states without measuring the signal power or other parameters. This method is more complex than Yao's one, but gives better results.

3. Throughput analysis

The proposed GBN ARQ scheme operates in one of the two ARQ operation modes and switches adaptively between them. The throughput of the proposed scheme can be therefore expressed as an average of the throughput values of the two ARQ operation modes

$$\eta = \eta_{GBN}P_L + \eta_{n-copy}P_H \quad (7)$$

where P_L is the probability that the channel is in L state and the system operates in the classic GBN mode and P_H corresponds to H state and n -copy mode. Using matrix (6) we can write two linear equations with two unknowns P_L and P_H .

$$\begin{bmatrix} P_L & P_H \end{bmatrix} = \begin{bmatrix} P_L & P_H \end{bmatrix} \begin{bmatrix} 1-p_1 & p_1 \\ p_2 & 1-p_2 \end{bmatrix} \quad (8)$$

Solving of linear equations (8) gives $P_L = p_2 / (p_1 + p_2)$ and $P_H = p_1 / (p_1 + p_2)$.

It is easy to show that $\eta > \eta_{GBN}$ when $P_e > (n-1)/N$ [4]. It should be said, the proposed GBN

ARQ scheme outperforms the classic GBN ARQ scheme when the block error probability is larger than $(n-1)/N$.

Note that the classic GBN ARQ scheme is outperformed by Sastry's modification [2] and Moeneclaey and Bruneel's ARQ scheme [5] only when block error probability is larger than 0.5.

The throughput versus block error probability performance of the proposed GBN ARQ scheme ($P_{S1} = 0.1, P_{S2} = 0, K = 30, n = 2$) is shown in Fig. 3.

The performance curves of several comparable ARQ schemes are also shown in the same figure, which includes n -copy ARQ scheme ($n=2$) [3], classic GBN ARQ scheme [1], Sastry's modification of GBN ARQ scheme [2], Moeneclaey and Bruneel's ARQ scheme [5], and finally Yao's efficient GBN ARQ scheme [4] ($\alpha = 2, \beta = 30, n = 2$). It is analytically shown that the proposed scheme outperforms classic GBN ARQ scheme for $P_e > (n-1)/N$, and Fig. 3 indicates that, when

$P_e < (n-1)/N$ (N is assumed to be 10 in the figure), the three schemes provide approximately the same performance (classic GBN ARQ scheme, Yao's efficient GBN ARQ scheme, and proposed scheme). It is observed in Fig. 3 that, when the block error probability varies from 0 to 0.67, the proposed GBN ARQ scheme offers higher or similar throughput compared to other schemes except 2-copy scheme. A drawback of the 2-copy approach is that, compared to the proposed GBN ARQ scheme, its throughput is very low under low error rate conditions.

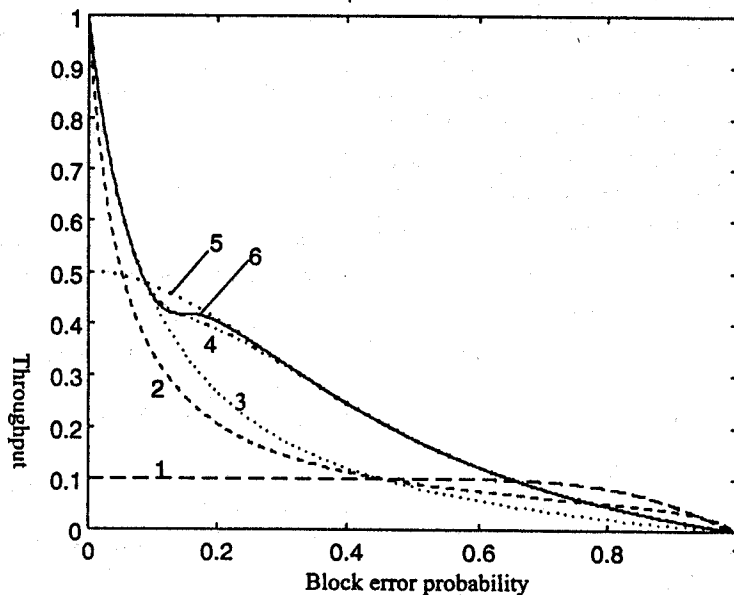


Fig. 3 Throughput versus block error probability. ($N=10$); 1: Moeneclaey and Bruneel's scheme [5]; 2: Sastry's modification of GBN scheme; 3: GBN scheme; 4: proposed GBN scheme ($P_{S1} = 0.1, P_{S2} = 0, K = 30, n = 2$); 5: 2-copy scheme; 6: Yao's efficient GBN scheme ($\alpha = 2, \beta = 30, n = 2$).

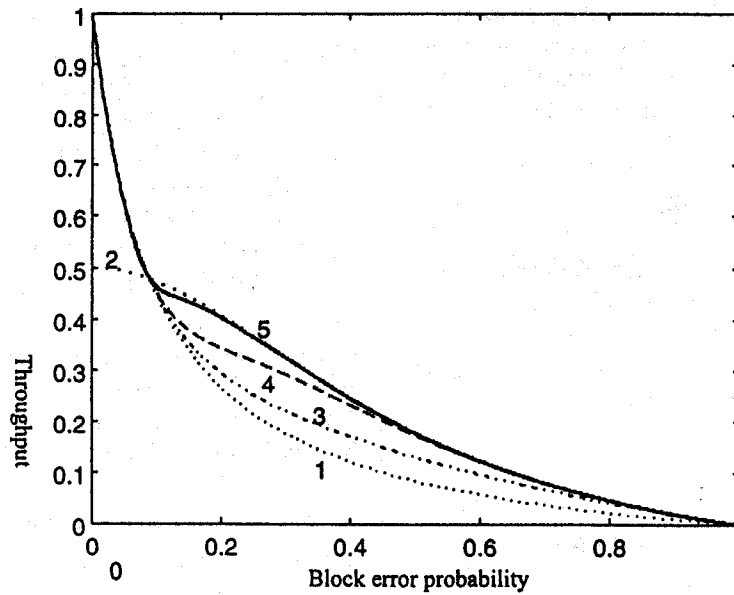
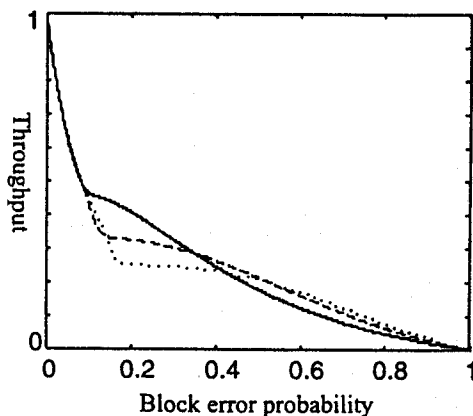
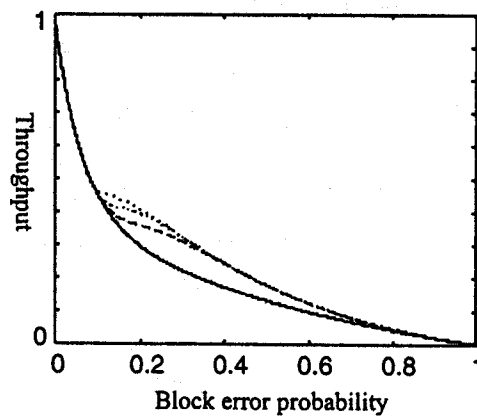


Fig. 4 Throughput versus block error probability. ($N=10$) 1: GBN scheme (dotted); 2: 2-copy scheme (dotted); 3, 4, 5: proposed GBN scheme ($P_{S1} = 0.1, P_{S2} = 0, n = 2$) for 3: $K = 10$ (dash-dot); 4: $K = 20$ (dashed); 5: $K = 40$ (solid)

There are four design parameters in the proposed GBN ARQ scheme - P_{S1}, P_{S2}, K, n - in which P_{S1}, P_{S2} , and K are related to the channel state estimation model. In Fig. 3, we assume $P_{S1} = 0.1, P_{S2} = 0, K = 30$. If P_{S1} and P_{S2} remains the same and K is chosen to be 10, 20, and 40 respectively, the proposed GBN ARQ scheme results in throughput curves as shown in figure 4. The performance of the proposed GBN ARQ scheme not only approaches that of GBN ARQ scheme for low error rates, but also approaches that of 2-copy ARQ scheme under high error rate conditions. In Fig. 4, It can be seen that the larger K is the better performance of the proposed GBN ARQ scheme is achieved. Comparing Fig.3 and 4, It is concluded that the proposed GBN ARQ scheme gives much better performance than other comparable schemes under wide range of error rate conditions.



(a)



(b)

Fig. 5 Throughput versus block error probability. Effects of the design parameters on the proposed GBN ARQ scheme $N=10$:

- (a) $P_{S2} = 0, K = 40$; solid: $n=2$, dashed: $n=3$, dotted: $n=4$.
- (b) $P_{S1} = 0.1, K = 40$; dotted: $P_{S2} = 0$, dash-dot: $P_{S2} = 0.025$, dashed: $P_{S2} = 0.05$, solid: $P_{S2} = 0.1$

The effects of the ARQ design parameters are further examined in Fig. 5(a),(b). It is shown in Fig. 5(a) that although larger value of n results in improved throughput performance when the error rate is very high, a substantial throughput reduction is observed under other error rate conditions. A larger value of P_{S2} causes higher probability of being in state L (with GBN operations) and, as shown in Fig. 5(b), yields lower throughput within the error range in which the ARQ operation mode switches.

4. Simulation results of proposed GBN ARQ scheme in LMS channel conditions

This section examines the performance of the proposed GBN ARQ scheme and Yao's GBN ARQ scheme in the conditions of the LMS channel. The channel model proposed by Corazza and Vatalaro [6] with the binary-phase-shift-keying (BPSK) modulation was applied in performance evaluation. The cyclic redundancy check (CRC) procedure with generating polynomial $x^{15} + x^{14} + x^2 + 1$ was used as an error-detection procedure. The packet length was considered to be 512 bits, the elevation angle equaled to $\alpha = 20^\circ$ and the satellite altitude was 1350 km.

Let us assume that \mathcal{G}_i represents a BPSK symbol sample transmitted at time i . The corresponding received sample at the input of the coherent demodulator is $r_i = a_i \mathcal{G}_i + n_i$ where a_i is areal random variable equal to the envelope of the channel attenuation with probability density function given by (1) in [6], and n_i is a sample of a zero mean complex additive white Gaussian noise (AWGN).

The conditional bit error probability for BPSK modulation given the fading attenuation due to shadowing a_i in the i th channel state is given by

$$P_{b_i} = Q \sqrt{2 \frac{a_i E_b}{N_0}} \quad (9)$$

where E_b represents energy per bit, N_0 stands for the noise density, and the $Q(x)$ can be expressed by

$$Q(x) = \frac{1}{2} \operatorname{erfc} \left(\frac{x}{\sqrt{2}} \right) \quad [7]$$

where the $\operatorname{erfc}(x)$ is the error function.

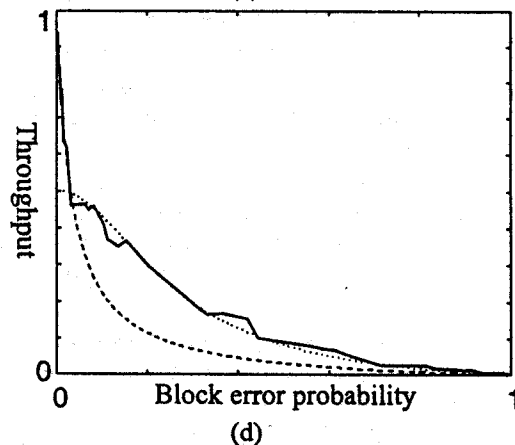
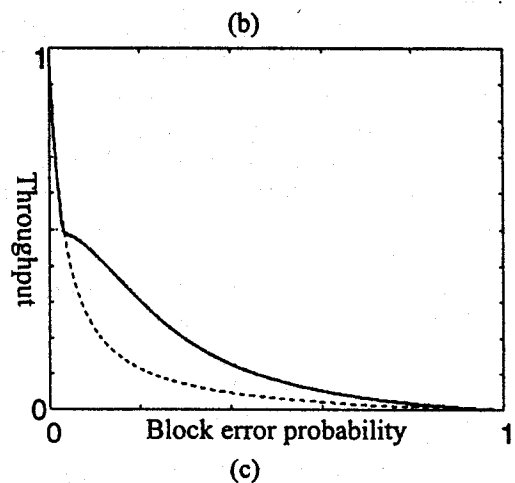
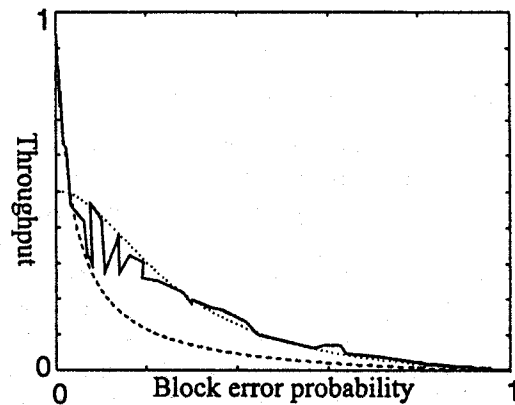
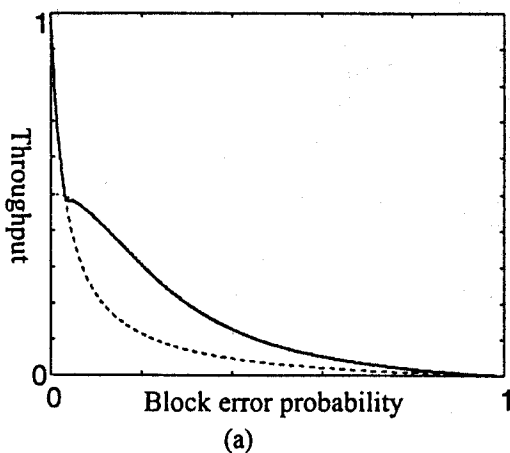


Fig. 6 Throughput versus block error probability. Analytical and simulated throughput performance of Yao's GBN ARQ scheme (a), (b) ($N = 30, n = 2, \alpha = 2, \beta = 200$) (solid), Go-Back-N (dashed), 2-copy (dotted), and proposed GBN ARQ scheme (c), (d) ($N = 30, n = 2, P_{S1} = 1/30, P_{S2} = 0, K = 200$). (solid), Go-Back-N (dashed), 2-copy (dotted)

It can be seen in Fig. 6 (a), (b) that analytically both Yao's GBN ARQ scheme and the proposed GBN ARQ scheme give the same throughput performance. Applying these schemes to the LMS channel the significant differences will appear in the range of block error rates where ARQ operation modes switch. Yao's GBN ARQ

scheme acts very unstable in this area whereas the proposed GBN ARQ scheme has only small drifts.

5. Conclusion

As discussed in [3], the knowledge of the block error probability is required in order to optimize an ARQ scheme. This paper proposed an effective GBN ARQ scheme which simply estimates the channel state (block error probability) based on the acknowledgment messages received and adaptively switches its ARQ operation mode. It gives higher throughput performance than other comparable ARQ schemes under a wide range of error rate conditions. This is particularly applicable to non stationary channels where error rates vary considerably therefore the proposed GBN ARQ scheme was compared with similar Yao's GBN ARQ scheme in the LMS channel conditions. The achieved throughput performance of the proposed GBN ARQ scheme is better than Yao's GBN ARQ one. As mentioned in [4], the proposed GBN ARQ scheme can be generalized to consider more channel states. For example, tree-state channel model with the ARQ scheme consisting of three operation modes, i.e. classic GBN, n -copy, Moeneclaey and Brunel's scheme [5].

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