Optimization of Adaptive Three-Mode GBN Scheme Control Parameters

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Abstract. *An adaptive three-mode system based on Go-Back-N (GBN) protocol is analyzed within this paper. An ideal mode selection procedure based on a-priori known packet error probability is defined. When packet error probability is unknown the system state transition is controlled by several system parameters. A procedure for optimal parameters selection is proposed and tested on a simulated system. The procedure is based on minimization of mean square deviation of the system throughput from the ideal one.*

Keywords

Go-Back-N, packet error probability, wireless communications, throughput, TS-ARQ scheme, optimization, control parameters

1. Introduction

One of the main disadvantages of "Go-Back-N" (GBN) protocol is the fact that system throughput significantly decreases when packet error rate (PER) increases. In order to solve this problem, several adaptive models of GBN protocol are proposed. An adaptive GBN scheme that dynamically adapts to varying channel conditions is proposed in [1] and further developed in [2–4]. In [5], the adaptive three-state system (TS-ARQ) that adapts the dynamic condition of the channel has been analyzed. In [6], the exact analysis of the throughput for the three-mode GBN (TM-GBN) system, based on retransmission cycles mechanism, is proposed. Throughput performances of various GBN adaptive schemes have been analyzed in [7–9].

The TM-GBN technique is proposed in order to improve system performances in the high noise case. Adaptation to the channel is done by classifying channel conditions into three states. The first state, denoted by L, is the low disturbances state. The moderate disturbances state is denoted by H, and intensive disturbances case is denoted by VH.

Formulated in this way, we get the three-state system. According to the current system state, the transmitter can apply the most appropriate procedure. In the L state, it follows standard GBN procedure. For the H state, the transmitter should switch to the multi-copy mode. Finally, for the VH state, the transmitter should continuously repeat packet until a positive acknowledgment is received.

The receiver provides corresponding acknowledgment for the each frame received. In the L mode, upon the receipt of α consecutive NAKs, the transmitter switches to the H mode, where the packets are emitted by n-copy GBN procedure. If the transmitter receives β consecutive ACKs in the H mode, the transmitter goes back to the L mode. If the transmitter receives γ consecutive NAKs in the H mode, then the transmitter will switch to the VH mode, in which it follows the procedure of continuous emitting of the same packet. The transmitter goes back to the H mode upon the receipt of δ consecutive positive acknowledgments. Channel state estimation and transmitter mode selection are based on the counting of positive and negative acknowledgments. These counters are compared with a given thresholds α, β, γ and δ in order to control the system and make decisions on the required system state transition. These parameters are essential for the adaptive system as the switching of the system state is controlled by them. In previous works, control parameters are obtained empirically. However, it is necessary to develop methods for determining these parameters in order to obtain optimal system. In this paper, we propose a technique for optimal control parameters selection.

The rest of this paper is organized as follows. In Section 2, the throughput analysis of general single-mode GBN mechanism and TM-GBN system are presented. In Section 3, optimization of control parameters is considered and discussed.

2. Adaptive GBN Protocol Analysis

Here we will give throughput analysis for single-mode adaptive and three-mode GBN protocol. The relations between the error probability and system throughput will be presented.

2.1 Single-Mode GBN Protocol Analysis

We will define the general model of GBN protocol considering the simplified scenario in which the receiver sends

only the positive acknowledgments (ACK), and the transmitter starts the packets retransmission after a timeout. Expiration of the time-out interval is equivalent to the reception of the negative acknowledgments (NAK) from the receiver. The transmitting station forms the packet, marks them with consecutive numbers and stores the packets in the transmit buffer.

The transmitter sends the packets, without waiting for the ACK from the receiver. After the packet has been sent, transmitter activates the time control mechanism. If the positive acknowledgment is not received until the time-out, the ongoing transmission is interrupted. Then the unacknowledged packet and all the successive ones (even those with positive acknowledgment received) are being re-sent.

If the ACK is received for the packet in the transmit buffer with the lowest number, this packet is discarded from the buffer, and packet transmission continues with the next packet.

On the receiving side, upon the packet reception, the receiver performs error control. If the received packet is correctly received, the receiver sends positive acknowledgments for this packet.

One of the main communication system performance measures is system throughput. Throughput is defined as a ratio of a number of successfully received packets and a total number of transmitted packets.

The system throughput, in the single-copy GBN (SGBN) case, is

$$S_\mathrm{L} = \frac{1 - P_\mathrm{e}}{1 + (N - 1)P_\mathrm{e}} \qquad (1)$$

where P_e is packet error probability and N is a standard value for GBN protocol.

In the n-copy GBN case (nGBN) transmitter sends n copies of each packet. The transmission is successful if a positive acknowledgment is received for at least one copy. The system throughput in this case is

$$S_\mathrm{H} = \frac{1 - P_\mathrm{e}^n}{n + (N - 1)P_\mathrm{e}^n}. \qquad (2)$$

The continuous GBN procedure (CGBN) assumes that the same packet is transmitted until the positive acknowledgment is received. The system throughput is

$$S_\mathrm{V} = \frac{1 - P_\mathrm{e}}{1 + (N - 1)(1 - P_\mathrm{e})}. \qquad (3)$$

Figure 1 presents throughput dependence of packet error probability for all considered single-mode protocols, with $N = 10$ and $n = 2$ Figure 2 illustrates throughput vs. P_e, for single-mode protocols, with $n = 2$ and $N = 30$.
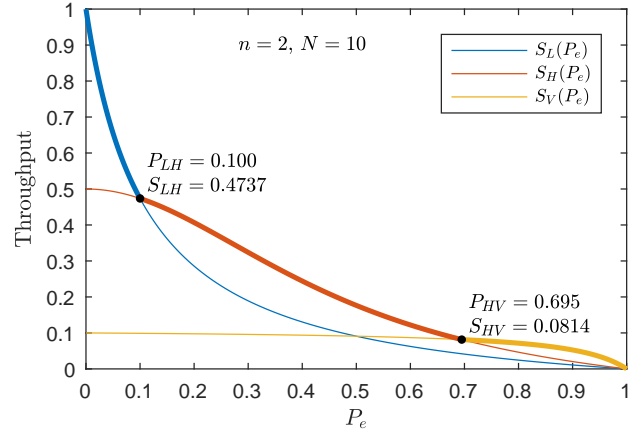

Fig. 1. System throughputs for $n = 2$ and $N = 10$. Probabilities P_HV and P_LH are obtained as intersection of the S_H curve with S_V and S_L curves.
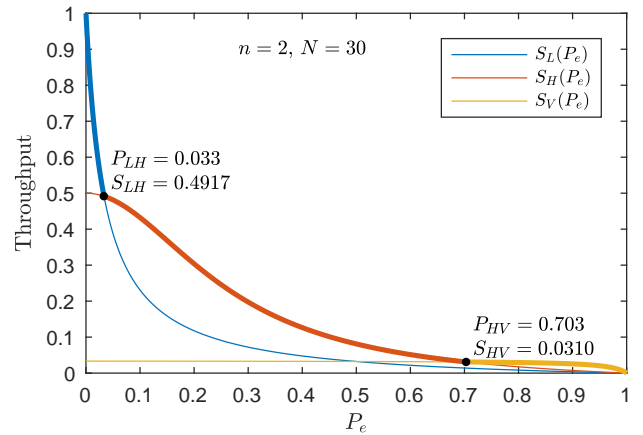

Fig. 2. System throughputs for $n = 2$, $N = 30$: Probabilities P_HV and P_LH are obtained as intersection of the S_H curve with S_V and S_L curves.

For each analyzed protocol we can identify range where it is the optimal protocol. Obviously for a very small probability of packet error SGBN protocol is optimal. The limit value of the packet error probability can be obtained by solving equation $S_\mathrm{L} = S_\mathrm{H}$ for unknown P_e. The smallest solution, denoted by P_LH is an upper limit when the SGBN protocol is optimal. P_LH can be obtained in a closed form for small n. For example:

$$P_\mathrm{LH} = \frac{1}{N}, \qquad \text{for } n = 2, \qquad (4)$$

$$P_\mathrm{LH} = \sqrt{\frac{1}{4} + \frac{2}{N}} - \frac{1}{2}, \qquad \text{for } n = 3. \qquad (5)$$

For large n value of P_LH can be obtained numerically.

For P_e higher than P_LH throughput obtained with nGBN protocol outperform SGBN case. In a similar way we can define upper limit for nGBN protocol by equating S_H and S_V and solving obtained equation for unknown limit P_HV. For $n = 2$ the solution is

$$P_\mathrm{HV} = \frac{1 + \sqrt{8N^2 - 24N + 17}}{4N - 4}. \qquad (6)$$

For higher values of n the solution can be found numerically. Now we have ranges for each protocol:

$$0 \leq P_e \leq P_{LH} \implies \text{SGBN protocol is optimal,}$$
$$P_{LH} < P_e \leq P_{HV} \implies \text{nGBN protocol is optimal,}$$
$$P_{HV} < P_e < 1 \implies \text{CGBN protocol is optimal.}$$

Limits P_{LH} and P_{HV} depend only on the system parameters N and n.

Presented results lead us to the conclusion that protocol choice highly depends on packet error probability. In the stationary channel case when P_e is a-priori known (or could be estimated) single protocol can be used. Adaptive systems [10] are able to track changes in the environment and to adjust system parameters in order to achieve optimal performances. For nonstationary channels, an adaptive procedure for transmitting protocol selection is implemented.

Having in mind that any adaptive system, where P_e is unknown, could not have better throughput than the system with optimally selected protocol, we can define optimal throughput S_{opt} as

$$S_{opt}(P_e) = \max\{S_L(P_e), S_H(P_e), S_V(P_e)\}. \tag{7}$$

Optimal throughput is presented in Figs. 1 and 2 with thick line. This case is an ideal one and can be used as a reference for adaptive system parameters optimization.

2.2 Three-Mode GBN Protocol Analysis

Let us review the basic foundations of the three-mode channel model, the concept which has been presented in details in [5].

TM-GBN model is given as scheme that uses three different methods of GBN protocols SGBN, nGBN, and CGBN. The transmitter sends the data packets to the receiver over the forward channel, and the receiver sends acknowledgments through the backward channel. In accordance with this model, transmitter's operating modes are different: in a state L - where the packet error probability is low, the transmitter follows basic SGBN procedure; in a state H - characterized by higher packet error probability, the transmitter operates in a n-copy mode; and in a state VH - where the packet error probability is very high, transmitter sends packet copies continuously until the first positive acknowledgment is received.

Switching from mode L to mode H, and from mode H to mode VH is managed by counting continuous NAKs for each packet and the switching from mode H to mode L, and from mode VH to mode H, by counting continuous ACKs for each packet. The receiver provides ACK for each received packet including the copies in the n-copy mode. The packets have been emitted in one of three possible ways. In the L mode, the standard GBN procedure is followed. Upon the reception of α consecutive NAKs, the transmitter switches to H mode, where the packets are emitted by the nGBN procedure. If the transmitter receives β consecutive ACKs in H mode, the transmitter returns to L mode. If the transmitter receives γ consecutive NAKs, while it is in H mode, the transmitter will switch to VH mode, in which it continuously emits the same packet. The transmitter returns to H mode upon the reception of δ consecutive ACKs.

Detailed analysis of TM-GBN system throughput is given in [6]. Here we will review final analysis results. The system throughput S_G is given by

$$\frac{1}{S_G} = \frac{C_L}{S_L} + \frac{C_H}{S_H} + \frac{C_V}{S_V} \tag{8}$$

where S_L, S_H and S_V are defined by (1), (2) and (3). According to [6], C_L, C_H and C_V are calculated as

$$C_L = \frac{(1 - P_L^\alpha)L}{L + H + V}, \tag{9}$$

$$C_H = \frac{(1 - P_H^\gamma)P_L^\alpha L + (1 - P_H^{\gamma+1})H}{L + H + V}, \tag{10}$$

$$C_V = \frac{P_L^\alpha P_H^\gamma L + P_H^{\gamma+1} H + V}{L + H + V} \tag{11}$$

with

$$L = \frac{(1 - P_H)^\beta}{P_L^\alpha}, \tag{12}$$

$$H = \frac{1 - (1 - P_H)^\beta}{P_H}, \tag{13}$$

$$V = \frac{1 - (1 - P_V)^{\delta-1}}{(1 - P_V)^{\delta-1}} \frac{P_H^\gamma}{P_V} \tag{14}$$

and

$$P_L = P_e,$$
$$P_H = P_e^n,$$
$$P_V = P_e.$$

It is obvious that the system throughput depends on packet error probability P_e and on system parameters N, n, α, β, γ and δ.

3. Parameters Optimization

In order to find optimal parameters, we should define optimization criterion. The optimization criterion should be based on the system throughput S_G. Since it depends on channel conditions (packet error rate P_e) averaging (integration) over all possible values of P_e should be used. The system optimization problem can be formulated as

$$\arg \min_{n,N,\alpha,\beta,\gamma,\delta} J(n, N, \alpha, \beta, \gamma, \delta). \tag{15}$$

Having in mind that in ideal case system throughput should be S_{opt} defined by (7), we can define cost function (optimization criterion) J as mean squared deviation of the system throughput S_G from the optimal throughput S_{opt}

$$J(n, N, \alpha, \beta, \gamma, \delta) = \int_0^1 \left(S_{opt}(P_e) - S_G(P_e)\right)^2 dP_e. \tag{16}$$

Note that integration limits in (16) could be reduced to $P_{\min}, P_{\max}$ if we expect that the packet error probability is within the range $P_{\min} \leq P_e \leq P_{\max}$.

Another approach could be that we optimize system for a given set of M error probabilities $\{P_1, P_2, \ldots, P_M\}$. In this case, the optimization criterion J could be defined as

$$J(n, N, \alpha, \beta, \gamma, \delta) = \sum_{k=1}^{M} (S_{\text{opt}}(P_k) - S_G(P_k))^2. \quad (17)$$

In all considered cases the function that should be minimized depends on integer parameters. Integer values of the parameters imply that classical minimization methods could not be directly applied.

When the minimization domain is finite, the direct search over all possible parameters combinations is a method that will surely lead us to the optimal solution. However, if the number of the minimization parameters is high, and when each parameter can achieve values from a large finite set, this approach could be inefficient. Of course, the optimization could be performed with other optimization methods as well [11], [12].

In the sequel, we will consider optimization with fixed N and n values. The ranges for remaining parameters are determined heuristically as

$$1 \leq \alpha \leq 5,$$
$$1 \leq \beta \leq 100,$$
$$1 \leq \gamma \leq 40,$$
$$1 \leq \delta \leq 30.$$

In this case, the minimization implies calculation of $J(n, N, \alpha, \beta, \gamma, \delta)$ for a given N and n and for each combination of parameters α, β, γ, and δ. The total number of combinations is $5 \times 100 \times 40 \times 30 = 600,000$. The minimum of J is found and corresponding optimal parameters (within considered ranges) are obtained.

The optimization results for $N = 10$ and $n = 2$ are given in Fig. 3 (upper subplot). Obtained throughput is presented by thin black line, and theoretically optimal throughput with a thick gray line. We can see that for selected parameters actual throughput is very close to the ideal one. Deviation from the ideal throughput, used for criterion J calculation, is presented in the lower subplot. The same procedure is repeated for $N = 30$ and $n = 2$ case. The results are presented in Fig. 4.

From Figs. 3 and 4 we can conclude that adaptive system is very close to the ideal one. The highest deviation appears around $P_e = P_{\text{HL}}$ i.e. when the system switches from standard GBN protocol to nGBN protocol and vice versa. Large values of β imply that when α consecutive errors are detected in the L mode (standard GBN protocol) and system switches to H mode (nGBN protocol) the system will go back to L mode very slowly (after β consecutive positive acknowledgments).
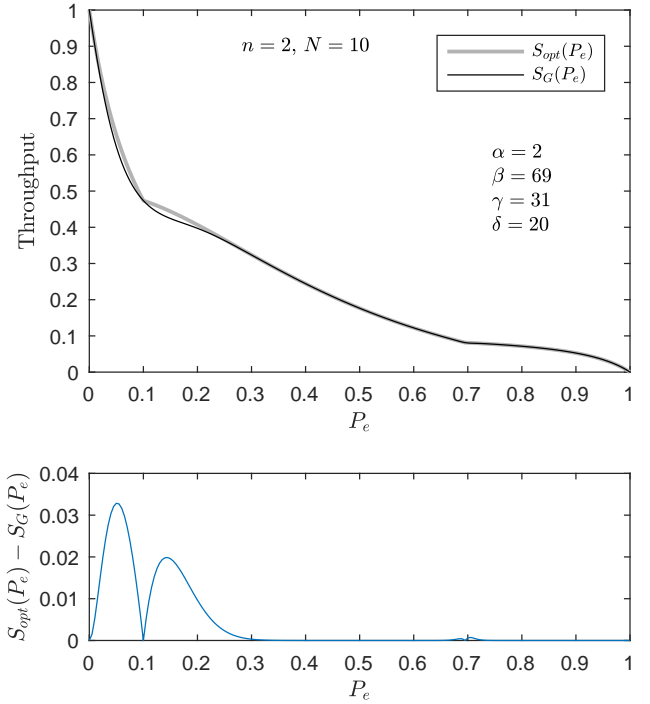
Fig. 3. Optimization of the system parameters for $n = 2$, $N = 10$. Throughput achieved through parameters optimization is presented with a thin black line. The thick gray line is theoretically optimal throughput for considered case. Deviation from the optimal throughput is presented in the lower subplot.
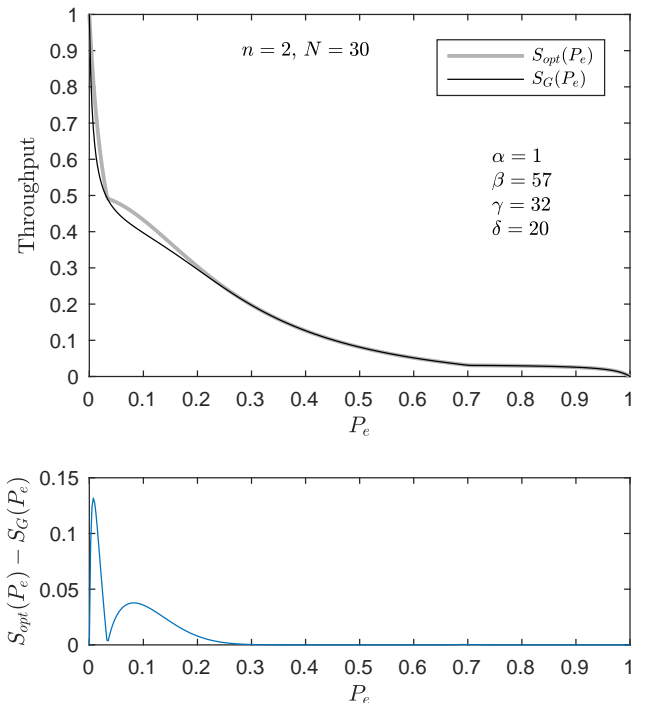
Fig. 4. Optimization of the system parameters for $n = 2$, $N = 30$. Throughput achieved through parameters optimization is presented with a thin black line. The thick gray line is theoretically optimal throughput for considered case. Deviation from the optimal throughput is presented in the lower subplot.

Note that the parameters optimization procedure should be performed once, so the high computational load caused by direct search procedure does not degrade system operating performances.

4. Conclusion

Three-mode GBN protocol is analyzed. The ideal case when we can select the optimal mode based on the a-priori known packet error probability is studied. This case is used in order to define optimization criterion. The procedure for adaptive system parameters optimization is derived. The optimization is performed and optimal system throughput is obtained for two system scenarios.

The presented results show that parameters choice in three-mode GBN system is very important. The optimization procedure is based on direct search within predefined parameter ranges. A large number of parameters combinations is not preferred, but when parameters take integer values this technique is highly reliable. It guarantees that our optimization procedure will not result in eventual local minimum and suboptimal parameters combination within considered ranges.

Acknowledgments

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