On Throughput Analysis of an Adaptive Error - Controle Scheme in Satellite Networks

Vladimir Vuković, Ranko Vojinović

***Abstract*: This paper presents an efficient method for exact throughput analysis of adaptive GBN scheme in error-prone satellite channels with two states. Method is based on using retransmission cycles without limitation on slow time-varying channels and condition that transmission of any frame starts and ends in the same transmitter mode.**

Keywords –**Printed antenna, Monopole antenna, Impedance matching.**

I. Introduction

Communication satellite have several properties that are radically different from terrestrial point-to-point links. Even though signals to and from satellite travel at speed of light, the large round-trip distance introduces a substantial delay. Further, satellite channels are error-prone. Transmissions errors on satellite lines are caused by a variety of different phenomena. The large round-trip propagation causes increasing transfer error probability.

Various adaptive methods for error control in dynamic conditions of channel operation are developed. An adaptive *go-back-N* (GBN) scheme with two or more operation modes that correspond to channel states is used in time-varying channel. When the probability of errors in the channel is low, adaptive GBN scheme operates as an ordinary single-copy procedure (mode *L*), while in high probability error conditions it operates as a multi-copy procedure (mode *H*). A switching from mode *L* to mode *H* is performed by counting continuous negative acknowledgements (NAK) for each frame, and the switching from mode *H* to mode *L* by counting continuous positive acknowledgements (ACK) for each block (a block consists of m-copies of the frame).

In throughput analysis of adaptive GBN scheme, some authors [1, 2] assumed that the frame transmission occurs in slow time-varying channels; therefore the transmission starts and ends in the same operation mode. They defined a throughput as a sum of multiplied stationary state probabilities of single operation modes and corresponding average throughput values that would be achieved if the system operates only in the given operation mode. Considering the fact that a lifecycle of any frame can start in one operation mode and end in another, it is evident that transitions between states will not occur in uniform time intervals. Therefore, adaptive GBN mechanism can be considered as embedded Markov's chain with two states. Compared to earlier analysis where the transition between states was defined only by the transition probability, there is a need to introduce an additional parameter – transition time.

Vladimir Vuković is with the National Employment Service, Belgrade, Serbia, e-mail:vvukovic@nsz.gov.rs
Ranko Vojinović is with the Police Directorate of Montenegro , Blvd Sv. Petra Cetinjskog 22 , 81 000 Podgorica, Montenegro,
e-mail: rankovoj@cg.yu

This paper introduces a new approach for the throughput analysis of an adaptive GBN scheme by retransmission cycles. A retransmission cycle is an assembly of events, which originates from the initial state, is followed by transient states caused by transmission errors, and ends with a final state resulting from a successful packet transmission Formally different, but fundamentally similar definitions of the throughput could be found in the literature. One of them regards to the (normalized) throughput as the ratio of the time needed for frame transmission and the average time duration of retransmission cycle.

The paper is organized as follows. In Section 2, we define retransmission cycles and derive an expression for the normalized throughput of the generalized adaptive two-mode GBN scheme with two groups of states. Section 3 graphically presents theoretical results for selected model parameters. Finally, we conclude with Section 4.

II. Throughput of Two-mode GBN Scheme

The state diagram of the generalized adaptive two-mode GBN scheme (2M-GBN) is shown in Fig. 1. This diagram contains two groups of states that correspond to the two-mode operation at the transmitter [3,4,5]. In *L* mode, transmitter employs the ordinary single-copy procedure. After receiving at least α continuous NAK's, the transmitter switches to the *H* mode and employs the multi-copy procedure. The transmitter returns to the *L* mode if it receives at least β continuous ACK's.

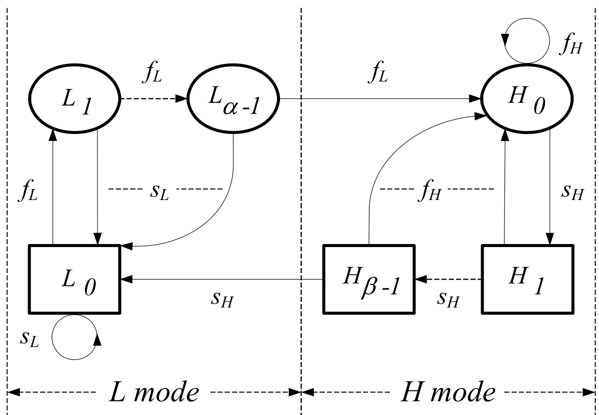

Figure 1. 2M-GBN scheme with two groups of states

States $L_0, H_1, \ldots, H_{\beta-1}$ represent the initial states that occur after successful transmissions, while $L_1, \ldots, L_{\alpha-1}, H_0$ represent the transient states that occur after erroneous transmissions. Transitions between states are characterized by transition probability and transition time. Transitions that lead to initial states after successful transmission are characterized with the following pairs: $s_L = [1 - p_L; k_L \cdot T_F]$ and $s_H = [1 - p_H; k_H \cdot T_F]$, while transitions that lead to transient states are characterized with $f_L = [p_L; m_L \cdot T_F]$ and $f_H = [p_H; m_H \cdot T_P]$. Transition error probabilities from states L_i $(i = 0,1,2,...,\alpha - 1)$ and H_i $(i = 0,1,2,...,\beta - 1)$ are denoted with $p_L = p_F^{k_L}$ and $p_H = p_F^{k_H}$ respectively, where p_F represents a probability of an erroneous frame transmission (frame error probability), and k_L and k_H number of frame copies in states L_i and H_i. Transition times to initial states are $k_L \cdot T_F$ and $k_H \cdot T_F$, and transition times to transient states are $m_L \cdot T_F = (k_L + N - 1) \cdot T_F$ and $m_H \cdot T_F = (k_H + N - 1) \cdot T_F$, where N represents *normalized round trip delay*, and T_F time duration of the frame transmission.

A. States Probabilities in Stationary Mode

According to the state diagram presented in Figure 1, after some math, we get stationary probabilities of single states:

$$P(L_i) = p_L^i \cdot \left[\frac{1 - p_L^\alpha}{q_L} + \frac{p_L^\alpha}{q_H^\beta} \cdot \frac{1 - q_H^\beta}{p_H} \right]^{-1}, \; i = 0,...,\alpha\text{-}1 \quad (1)$$

$$P(H_i) = q_H^i \cdot \left[\frac{1 - q_H^\beta}{p_H} + \frac{q_H^\beta}{p_L^\alpha} \cdot \frac{1 - p_L^\alpha}{q_L} \right]^{-1}, \; i = 0,...,\beta\text{-}1 \quad (2)$$

where $q_L = 1 - p_L$ and $q_H = 1 - p_H$ denote transition successful probabilities.

For further analysis, it is beneficial to introduce the following parameters:

$$LP = \frac{q_H^\beta}{p_L^\alpha} \quad (3)$$

$$HP = \sum_{i=1}^{\beta-1} q_H^i = \sum_{i=0}^{\beta-1} q_H^i - 1 = \frac{1 - q_H^\beta}{p_H} - 1 \quad (4)$$

so that it holds:

$$P(L_0) = LP \cdot P(H_0) \quad (5)$$

$$\sum_{i=1}^{\beta-1} P(H_i) = \sum_{i=1}^{\beta-1} q_H^i \cdot P(H_0) = HP \cdot P(H_0) \quad (6)$$

B. Average Time Duration of Retransmission Cycles

Based on the state diagram, there are several groups of different retransmission cycles. In this section they will be classified based on the starting initial state and calculation of average time duration of retransmission cycle for single groups.

B.1 Retransmission Cycles from State L_0

The group of retransmission cycles LH with starting initial state L_0 is depicted on Figure 2 and it consists of two sub-groups that end in initial states L_0 i H_1. Sub-group *LH1* represents transitions from state L_0 to L_0, while sub-group *LH2*, represents transitions from state L_0 to H_1.

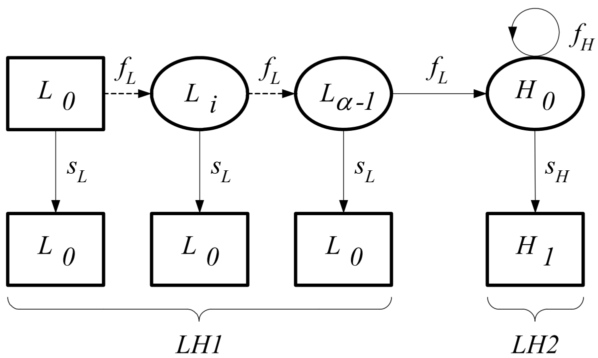

Figure 2. Group of retransmission cycles from starting state L_0

a) retransmission cycles L_0→... →L_i→... →L_0, i=0,1,2,...,α-1

Average time duration of retransmission cycle for group LH1 is calculated as follows:

$$\overline{T}_{LH1} = \sum_{i=0}^{\alpha-1} \left(i \cdot m_L + k_L \right) \cdot T_F \cdot p_L^i \cdot q_L = \left(\frac{1 - p_L^\alpha}{S_{ll}} - \alpha \cdot m_L \cdot p_L^\alpha \right) \cdot T_F \quad (7)$$

where,

$$S_{ll} = \left(k_L + m_L \cdot \frac{p_L}{q_L} \right)^{-1} \quad (8)$$

denotes the throughput of a single-mode GBN (1M-GBN) scheme with states L_0 i L_1

b) retransmission cycles L_0→... →$L_{\alpha-\square}$ →H_0→H_1

Average time duration of retransmission cycle for group LH2 is calculated as follows:

$$\overline{T}_{LH2} = \sum_{k=0}^{+\infty} \left[\alpha \cdot m_L + k \cdot m_H + k_H\right] \cdot T_F \cdot p_L^{\alpha} \cdot p_H^{k} \cdot q_H$$
$$= \left(\frac{p_L^{\alpha}}{S_{hh}} + \alpha \cdot m_L \cdot p_L^{\alpha}\right) \cdot T_F \qquad (9)$$

where,

$$S_{hh} = \left(k_H + m_H \cdot \frac{p_H}{q_H}\right)^{-1} \qquad (10)$$

denotes the throughput of a single-mode GBN (1M-GBN) scheme with states H_0 i H_1.

Average time duration of retransmission cycles that originate from state L_0 equals to a sum of average time durations of single groups. Combining (7) and (9), we get:

$$\overline{T}_{LH} = \overline{T}_{LH1} + \overline{T}_{LH2} = \left(\frac{1 - p_L^{\alpha}}{S_{ll}} + \frac{p_L^{\alpha}}{S_{hh}}\right) \cdot T_F \qquad (11)$$

B.2. Retransmission Cycles from States $H_1, H_2, \ldots, H_{\beta-1}$

The group of retransmission cycles *HH(i)* with starting initial state H_i $(i = 1, 2, \ldots, \beta - 1)$ is depicted in Figure 3. It consists of one sub-group that ends in initial states H_{i+1} and H_1, with the assumption that $H_\beta \equiv L_0$. is a true statement.

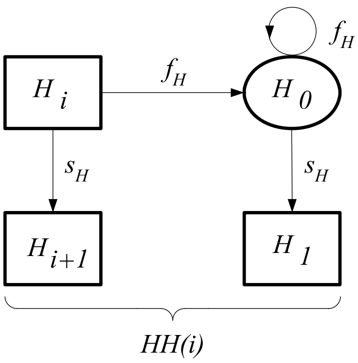

Figure 3. Group of retransimission cycles from state H_i, i = 1,2,…, β-1

a) retransmission cycles $H_i \rightarrow H_{i+1}$ $(H_\beta \equiv L_0)$ and $H_i \rightarrow H_0 \rightarrow H_1$, $i = 1, 2, \ldots, \beta - 1$

Average time duration of retransmission cycles for group HH(i) is as follows:

$$\overline{T}_{HH(i)} = \left[k_H \cdot q_H + \sum_{k=0}^{+\infty} \left(m_H + k \cdot m_H + k_H\right) \cdot p_H \cdot p_H^{k} \cdot q_H\right] \cdot T_F$$
$$= \frac{T_F}{S_{hh}} \qquad (12)$$

Considering that the average time durations of retransmission cycles that originate from state H_i are equal and independent from order state *i*, it can be written as:

$$\overline{T}_{HH} = \overline{T}_{HH(i)} = \frac{T_F}{S_{hh}}; \qquad i = 1,2,\ldots,\beta\text{-}1 \qquad (13)$$

C. Throughput Calculation for 2M-GBN Scheme with Two Groups of States

To calculate the throughput of 2M-GBN scheme with two groups of states, average time duration of all retransmission cycles shall be first determined, considering the frequency of their occurrences. If $R = \{L_0, H_1, H_2, \ldots H_{\beta-1}\}$ represents a set of all initial states, average time duration of retransmission cycles $\overline{T}_R$ can be calculated as follows:

$$\overline{T}_R = \overline{T}_{LH} \cdot P(L_0 / R) + \overline{T}_{HH} \cdot \sum_{i=1}^{\beta-1} P(H_i / R) \qquad (14)$$

where $P(X/R)$ denotes conditional probability of occurrence of initial state $X \in R$. Since the occurrences of initial states are mutually exclusive events, then:

$$P(X/R) = \frac{P(X)}{P(R)} = \frac{P(X)}{P(L_0) + \sum_{i=1}^{\beta-1} P(H_i)} \qquad (15)$$

Having in mind (5) and (6), after supstitution in (14) and (15), we get :

$$\overline{T}_R = \frac{LP \cdot \overline{T}_{LH} + HP \cdot \overline{T}_{HH}}{LP + HP} \qquad (16)$$

that gives result for throughput of adaptive 2M-GBN scheme with two groups of states:

$$S_R = \frac{T_F}{\overline{T}_R} = \frac{LP + HP}{LP \cdot \overline{T}_{LH} + HP \cdot \overline{T}_{HH}} \cdot T_F \qquad (17)$$

By supstituting the statement for average time duration of retransmission cycles $\overline{T}_{LH}$ i $\overline{T}_{HH}$, and using (11) and (13), above given throughput calculation can be presented in an alternative form as follows:

$$\frac{1}{S_R} = \left(\frac{1 - p_L^{\alpha}}{S_{ll}} + \frac{p_L^{\alpha}}{S_{hh}}\right) \cdot \frac{LP}{LP + HP} + \frac{1}{S_{hh}} \cdot \frac{HP}{LP + HP} \qquad (18)$$

III. NUMERICAL RESULTS

This paper analyzes how parameters α and β can affect on the throughput of an adaptive GBN model with two groups of states.

Figure 4 depicts the troughput of single-mode i two-mode GBN scheme for single-copy and three-copy mechanisam as a function of frame error probability for various values of α and β. Solid and dotted line present graphs that were created based on theorethical throughput of a single-copy and three-copy single-mode 1M-GBN scheme. Graphs with “o”, “+” and “*” symbols are get by using the theoretical statement for two-mode GBN mechanism (2M-GBN) for various values of parameters α and β.

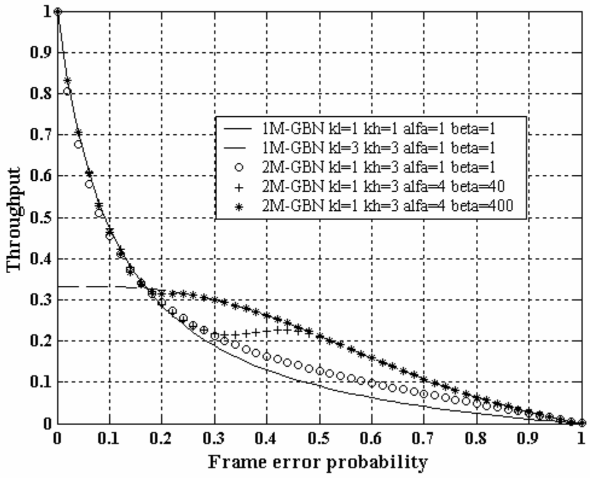

Figure 4. Throughput of single-copy and three-copy 1M-GBN scheme and 2M-GBN scheme for N=100

The values of parameters α and β were empirically determined in order to achieve as good as possible graph overlapping for a single-copy and three-copy single-mode mechanism and two-mode GBN mechanism. In this analysis α=4 and β=400 values were selected.

IV. CONCLUSSION

This paper presents an efficient method for throughput estimate of an adaptive GBN scheme in channels with two states based on retransmission cycles. The recommended method is not limited to slow time-varying channels and the condition that the transmission of any frame starts and ends in the same operation mode. We approved that reciprocal throughput value of adaptive GBN model with two groups of states is equal to a sum of the products of reciprocal throughput of one two-mode and one single-mode GBN model and corresponding conditional probabilities of occurrence of initial states.

Proposed adaptive model is suitable for error-control in satellite networks, due to dynamic condition of transmission data over satellite links.

ACKNOWLEDGEMENT

Authors wish to thank Dr. Grozdan Petrovic for helpful comments and suggestions.

REFERENCES

[1] Y. –D. Yao, “An effective Go-Back-N ARQ scheme for variable-error-rate channels”, *IEEE Trans. Commun*., vol. 43, pp.20-23, No.1, January 1995.

[2] S. S. Chakraborty and M. Liinaharja, “Exact analysis of adaptive go-back-N ARQ scheme,” *Electron. Lett.*, vol. 35, pp. 379-380, March 1999.

[3] H. Minn, M. Zeng, and V. K. Bhargava, “On ARQ scheme with adaptive error control,” *IEEE Trans. Veh. Technol.*, vol. 50, no. 6, pp.1426-1436, November 2001

[4] R.Vojinović, Z.Petrović:``A Novel Three-state ARQ scheme for variable error-rate channels,`` *AEUE – International Journal of Electronics and Communications,* Vol. 56, Issue 6, 2002, pp 389-395.

[5] R.Vojinovic, G. Petrovic, Z. Petrovic: “The analysis of the adaptive three-mode ARQ GBN scheme using retransmission cycles mechanism”, *AEÜ- – International Journal of Electronics and Communications,* , Vol. 60, Issue 2, 2006, pp *190-198*