An Improved Point-to-Multipoint GB(N) ARQ Scheme for High Speed Satellite Communications

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ABSTRACT

This paper proposes and evaluates a point-to-multipoint GB(N) scheme with memory at receivers, suitable for high speed satellite communications. Its key idea is to store errorless messages received during an error recovery procedure It avoids buffer overflow, reduces the round trip delay effect, is easy to implement and presents a good performance under a wide range of conditions. It is shown that the proposed protocol throughput efficiency is better than the best known multipoint GB(N) scheme results. In addition, in environments with a large number of receivers, it outperforms a known multipoint selective repeat protocol, under a wide range of bit error rate.

INTRODUCTION

Satellite communication provides high bandwidth and is of most advantage for distributed systems over difficult terrain such as mountains, large forests or oceans, or where terrestrial communication facilities are not available or too expensive. Moreover, satellite links have an inherent ability to provide a point-to-multipoint connection, in which a single transmission from a source station may be received simultaneously by several geographically dispersed destination ones. This facility, not available in many terrestrial networks, make economical use of the satellite channel when it is required to convey the same information to several sites.

In high speed environments, as the transmission speed increases the message processing time becomes a performance bottleneck. An approach to overcome this problem comprises the design of new protocols with mechanism specifically conceived for high bandwidth communications and a simple error recovery procedures.

Automatic-repeat-request (ARQ) is the most common method for handling transmission errors in computer networks since it offers a simpler implementation and performs well on many types of real channels. There are three basic ARQ protocols: stop-and-wait (SW), go-back-N (GB(N)) and selective-repeat (SR). SW protocol is the simplest ARQ scheme, but it is very inefficient for long round trip delay. GB(N) scheme presents a middle both implementation complexity and performance and SR one is the more efficient ARQ protocol at the expense of a high complexity implementation which requires extensive buffer (theoretically infinite) and high processing capacity at the stations. Because of the inefficiency of the SW and the complexity of the SR schemes, the requirement for simple error recovery procedures leads to GB(N) ones. Some authors have proposed to provide buffering memory at the GB(N) receivers aims at storing the messages sent in advance and received without errors after an erroneous one detection, over point-to-point links[1-4].

This paper presents and evaluates a point-to-multipoint GB(N) protocol with buffering memory at the receivers, for high speed satellite communications. The proposed strategy only uses accumulative acknowledgments and performs very well under a wide range of data and bit error rates and round trip delays.

Firstly, the analytical model based on discrete-time semi-Markov process are presented. The two following sections describe the proposed recovery strategy and analyse its throughput efficiency. Numerical results are provided and compared with other ARQ schemes. Finally, the conclusions are presented.

ANALYTICAL MODEL

A message is said transfered to a receiver when it and all earlier ones (smaller sequence number) are correctly received by this receiver. Moreover, a message is said communicated, or communicated to the set of receivers, when it is transfered to all receivers.

The protocol throughput efficiency is defined as the ratio between the number of information bits communicated to the set of receivers and the total number of transmitted and retransmitted bits (including overhead bits). It will be obtained by assigning states to the set of receivers according to the recovery process conditions in at least one receiver and modeling the set of receivers behavior as a discrete-time semi-Markov process, whose state $X(n), n = 0, 1, 2, \ldots$, denotes the state of the set of receivers after the reception of the n^{th} message.

Throughout this paper it is assumed an environment consisting in one transmitter that transmits data over a broadcast channel to M receivers. All the data is transmitted in form of *messages*. If a message numbered N(R) is detected in error, the receiver sends the control message (REJ N(R) *reject*) requesting the retransmission of this message and of all ones sent in advance. Through the positive acknowledgment (RR N(R) *receiver ready*), receivers informs that information messages with sequence number smaller than N(R) have been correctly received (*accumulative acknowledgment*).

The probability of an information message arriving with at least one bit error at a given receiver is denoted by P_{be} (additionally, $P_{bc} = 1 - P_{be}$). Is is assumed that P_{be} and P_{bc} are independent from message to message and from receiver to receiver and that the round trip delay, measured in time units, is constant and equal to S for all receivers, where the time unit is defined as the time required to transmit one information message. Finally, it is also assumed that all information messages have the same length: L total bits and K information ones.

THE PROTOCOL

The proposed strategy, based on the Extended REJ[3] and the ARQ1[4] point-to-point protocols, is a GB(N) scheme supposed to be used in a point-to-multipoint satellite environment. Thus, the scheme is a conventional GB(N) with a modified recovery procedure in the receivers, in order to achieve an improved throughput performance in the high bit error rate region. In addition to the classical $(S+1)$-messages retransmission buffer, the scheme requires an equal size receiving buffer. The transmitter operates as the conventional point-to-multipoint GB(N) scheme. The GB(N) retransmission reduces the the processing overhead. At the same time, the buffering memories allow the receivers to process, acknowledge and store errorless messages received after a detection of an erroneous one, eliminating the need for successful retransmission of messages already stored at all receivers. In addition to reducing the number of acknowledgment messages, the accumulative feature also reduces the number of processed control variables for each transmitted information message.

The transmitter sends sequenced messages and stores them in a retransmission buffer while waiting for their positive acknowledgement from all receivers. In order to ensure that every message is correctly received by all receivers, the transmitter maintains a state variable $V_i(R)$ for each receiver, indicating the number of the last positively acknowledged message. Hence, $V_i(R) = N(R)$ indicates the receiver i has been correctly received all messages with sequence number smaller than N(R). Besides these variables, the transmitter maintains two global state variables: $VG(S)$ indicating the number of the next message to be transmitted and $VG(R) = \min_i\{V_i(R)\}$ indicating last message communicated to all receivers. Thus, messages with sequence number smaller than $VG(R)$ can be removed from retransmission buffer.

When a receiver detects an erroneous message, it sends a repeat request, beginning an error recovery procedure, reserves a slot in its buffer and continues to receive, process and acknowledge the messages sent in advance. The errorless messages are stored while a buffer slot is reserved for each erroneous one. Henceforth, messages corresponding to buffer slots will be called messages B_{e_i} and corresponding repeat requests, REJ B_{e_i}, where $0 \leq i \leq S$ (in this case $N(R) = B_{e_i}$). After REJ B_{e_0} sending, the first message out of those sent in advance detected in error by one or more receivers will be called message B_{e_1}, regardless which and how many receivers have received it in error. The second will be called message B_{e_2}. And so on. An *exception condition* exists in the set of receivers from the time REJ B_{e_0} is sent to the time all messages $B_{e_0}, \ldots, B_{e_0} + S$ are communicated to all receivers.

Performance Analysis

The proposed strategy defines two states to the set of receivers: normal and exceptional states. In normal state there is no exception condition in the set of receivers and there are no messages stored in any receiver buffer. The receivers accept the sequenced received messages and deliver them to their users.

The set of receivers goes to exceptional state when at least one receiver detects an erroneous message (message B_{e_0}) and sends the REJ B_{e_0}, beginning an error recovery procedure and establishing an exception condition at the set of receivers. (it is defined the transition occurs at the beginning of erroneous message reception). This condition will be classified in cycles, corresponding to exceptional state ones. It has one *transmission cycle* and one or more *retransmission cycles*. Transmission cycle corresponds to the processing and storing of messages sent in advance. In this cycle each receiver may store up to $S+1$ messages (including slots reserved for messages B_{e_i}). The number of retransmission cycles corresponds to number of GB(N) retransmissions needed to recover all messages $B_{e_i}, 0 \leq i < S$. Each retransmission cycle ends after the reception of the message $B_{e_0}+S$ retransmission. During this state, the set of receivers only stores messages with sequence number between B_{e_0} and $B_{e_0} + S$). After sending the REJ B_{e_0}, processing and storing messages sent in advance, the set of receivers waits for the retransmissions, asks for new retransmissions and goes to the normal state when all messages B_{e_i} are recovered. Fig. 1 shows the

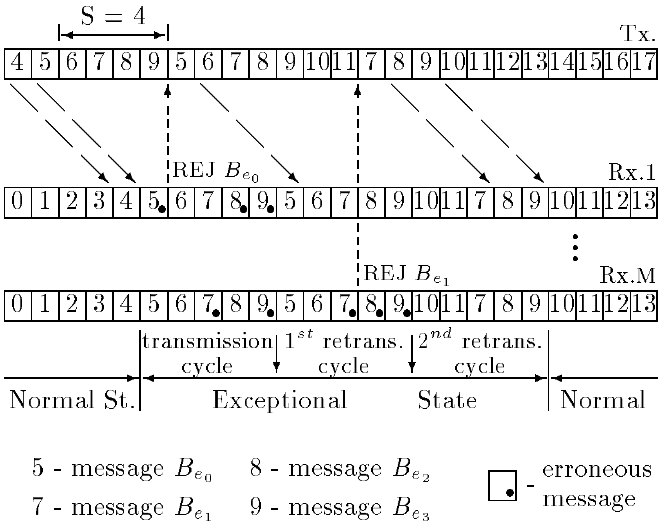

Fig. 1 - The analyzed strategy

scheme behavior.

In the following, the throughput efficiency of this scheme will be derived. As the set of receivers passes from normal to exceptional state at the beginning of the erroneous message reception, only error-free messages are received in normal state. Then, in this state, the partial throughput efficiency is K/L and mean waiting time is:

$$E[t_N] = \sum_{i=0}^{\infty} i.(1-P_{bc}^M).(P_{bc}^M)^i = \frac{P_{bc}^M}{1-P_{bc}^M} \ . \qquad (1)$$

On the other hand, $S+1$ messages are always communicated during exceptional state. Thus, the partial throughput efficiency in this state is $(K/L).(S+1)/E[t_E]$. Using the normal state mean waiting time, above partial throughput efficiencies, conditional transition probabilities and applying the semi-Markov process properties, the protocol throughput efficiency can be expressed as:

$$\eta = \frac{K}{L} \frac{P_{bc}^M + (1-P_{bc}^M).(S+1)}{P_{bc}^M + (1-P_{bc}^M).E[t_E]} \ . \qquad (2)$$

The mean waiting time in exceptional state is given by:

$$E[t_E] = (1 + E[n_e]).(S+1) \ , \qquad (3)$$

where $E[n_e]$ is the expected number of retransmission cycles and given by:

$$E[n_e] = \sum_{j=1}^{\infty} j.Pr\{n_i = j\}. \qquad (4)$$

The expression $Pr\{n_i = j\}$ is the probability that all $S+1$ messages corresponding to the transmission cycle are successfully communicated to all M receivers during the j^{th} retransmission cycle, but not all recovered within the $(j-1)^{th}$ retransmission cycle. It is given by

$$Pr\{n_i = j\} = Pr\{n_i \leq j\} - Pr\{n_i \leq j-1\}. \qquad (5)$$

where $Pr\{n_i \leq j\}$ is the probability that in n_i^{th} retransmission cycle the $S+1$ transmission cycle messages have been communicated to all M receivers and is given by:

$$Pr\{n_i \leq j\} = \frac{(1-P_{be}^{n_i+1})^M - P_{bc}^M}{1-P_{bc}^M} \left(1-P_{be}^{n_i+1}\right)^{M.S} . \qquad (6)$$

NUMERICAL RESULTS

This section discusses numerical results of the model presented and compares them with other published results. Throughput efficiency of proposed and *full memory* GB(N)[5] are shown in Fig. 2, for $M = 1, 3, 9$ and27, over a satellite channel at 10 Mbps with message length of 6832 bits ($L = 6832$ and $S = 1024$). It can be observed that the proposed scheme efficiency presents a considerably smaller reduction as the bit error rate increases. It can be said that receiver buffering improves the throughput efficiency for a large range of bit error rates (BER).

Fig. 3 compares, for point-to-multipoint satellite communication at 10 Mbps with $M = 100, S = 1024$ and $L = 6832$ bits, the throughput efficiency of the following schemes: proposed one, Towsley&Mithal's SR[6] with $q = 1$ and one copy retransmission ($n_1 = 1$); Towsley's GB(N)[7] with blocks of 512 and 1024 messages ($F = 512$ and $F = 1024$) and two Gopal&Jaffe's GB(N)[5]. Towsley&Mithal's SR requires buffer capacities of $2.S+1$ messages at transmitter and $S+1$ ones at receivers while the Towsley's GB(N) requires $F+S$ and F in transmitter and receivers, respectively. It is a block oriented GB(N) with selective retransmission. The proposed protocol outperforms other GB(N) schemes for all bit error rates. Moreover, for middle and high error rates, it performs better than Towsley&Mithal's SR. The Towsley's and Gopal&Jaffe's full memory schemes are the best previous known GB(N) results for point-to-multipoint communications.

Fig. 4 plots, for point-to-multipoint satellite communication at 10 Mbps with $S = 1024$ and $L = 6832$ bits, the throughput efficiency of the above protocols as a function of the number of receivers for bit error rate of 10^{-5}. It is shown that new strategy outperforms all these protocols, for any number of receivers. For 100 receivers, its throughput efficiency is about 20% while the throughput efficiencies of the Towsley&Mithal's SR and Gopal&Jaffe schemes are lesser than 1%. The performance of the ideal SR scheme has been plot too. For a large number of receivers, the new scheme compares well with this ideal SR one.

The above protocols have been also compared for bit error rate of 10^{-6}. Besides outperforming all other GB(N) ones, the proposed scheme performs better than Towsley&Mithal's SR for $M > 37$.

CONCLUSION

This paper has presented and analysed a point-to-multipoint GB(N) scheme with buffers at the receivers easy to implement and suitable for high speed satellite environments. The proposed strategy avoids buffer overflows, reduces the effect of the round trip delay and performs well even under high error rate channel condition. The analytical results show that the new strategy presents a better performance than the best known point-to-multipoint GB(N) results. Furthermore, the proposed strategy outperforms a known finite buffer selective-repeat ARQ schemes for middle and high bit error rates and/or large number of receivers. At the same time, for certain condition of bit error rate and number of receivers its performance is close to the best possible one achievable by an ARQ protocol.

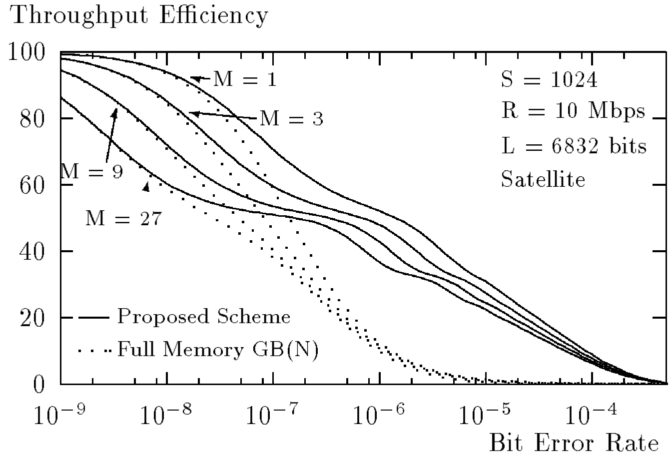

Fig. 2 - Full memory and proposed scheme efficiencies

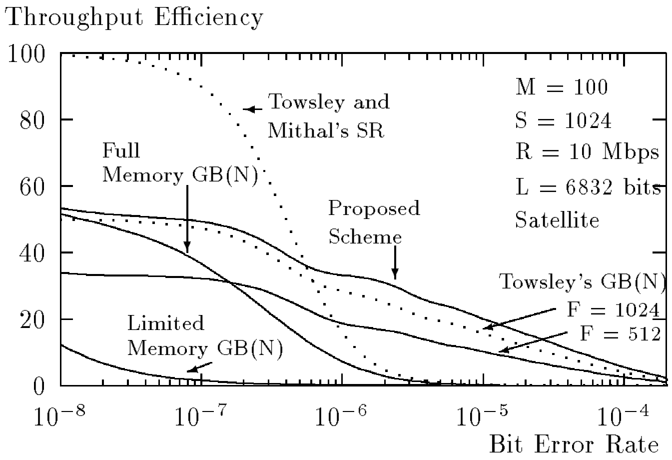

Fig. 3 - Comparison of the new scheme and other results

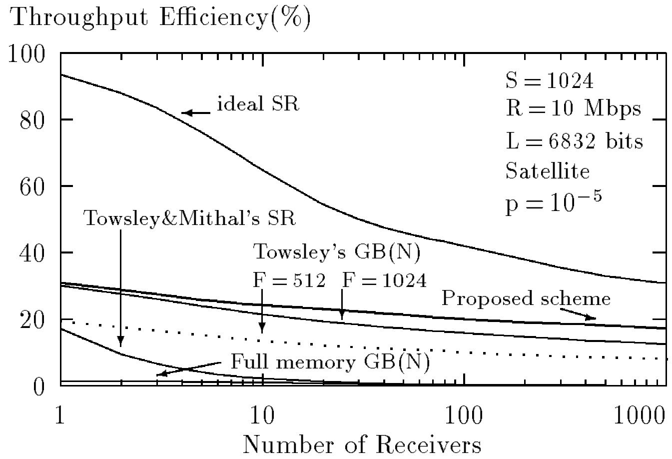

Fig. 4 - Comparison of the new scheme and other results

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