An Effective Selective Repeat ARQ Strategy for High Speed Point-to-Multipoint Communications

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Abstract

In high speed environments, the protocol processing overhead at the stations and network nodes becomes a performance bottleneck as the transmission rate increases. Selective repeat (SR) protocols are the most efficient of the automatic repeat request (ARQ) strategies, but present the highest implementation complexity. Techniques such as repeated retransmission, adaptive optimization, forward error correction (FEC) and hybrid error recoveries have the drawback of increasing even more the processing load of selective repeat ARQ schemes. This paper proposes and analyses the performance of a point-to-multipoint selective repeat pure ARQ protocol with finite receiver buffer. It is simple to implement and well suited for high speed communications. Only messages negatively acknowledged or discarded due to buffer overflows are just single copy retransmitted. Analysis uses a semi-Markov process model to derive a lower bound on the throughput of the proposed scheme. The results show that it outperforms all existing similar ARQ schemes. Furthermore, its throughput efficiency remains in a usable range even for very high error rate conditions where it is higher than a known multicopy retransmission SR scheme one.

1 Introduction

Recent advances in data transmission and VLSI (*Very Large Scale Integrated Circuit*) technologies make it possible to provide communication systems offering raw bandwidth that are orders of magnitude higher than the current systems. At the same time, the availability of high speed networks with multiple destination features, opens up the possibility of a new range of point-to-multipoint applications, such as multimedia conference

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systems, broadcasting of information, document distribution and communication for distributed systems. When required to convey the same information to several sites, point-to-multipoint channels use the network more efficiently than multiple single destination links, decrease the delays and make them more uniform. Although new technologies have permitted to reduce considerably the transmission errors, they continue to exist in communication systems due to message loss, congestion or flow control, statistics multiplexing and resource (CPU and memory) starvation. Therefore, end-to-end error control is still required for a great number of applications.

Automatic-repeat-request (ARQ) is the most common method for handling transmission errors in computer networks since it offers a simpler implementation, performs well on many types of real channels and adapts itself in a satisfactory way to different behaviors on the transmission channel. There are three basic ARQ protocols: stop-and-wait (SW), go-back-N (GB(N)) and selective-repeat (SR). SW protocol is the simplest of the ARQ schemes and presents a very simple implementation, but it is inherently inefficient due to the idle time spent in waiting for the receiver acknowledgment after each transmission. In GB(N) protocol, the transmitter sends messages continuously, thereby reducing the idle time and the effect of the round trip delay on the throughput efficiency. When a negative acknowledgment is received, the erroneous message is retransmitted along with the messages sent before reception of the negative acknowledgment (*sent in advance*). At the receiver end, all messages following an erroneous one are discarded, regardless of whether they contain errors or not. This becomes rapidly inefficient because of the high message loss rates (due to either bit errors or congestion losses) rates and/or long round trip delays.

In the SR scheme the message transmission is also continuous. Nevertheless, the transmitter only repeats those messages that are detected in error. Hence, SR is the most efficient ARQ protocol at the expense of a high complexity implementation that requires extensive buffer (theoretically infinite) and high processing capacity at the stations.

In point-to-multipoint communications, besides processing acknowledgment messages of various receivers, the transmitter needs to maintain several lists (or control variables), to ensure that every message is correctly received by each receiver [1]. Thus, the transmitter processing overhead increases with the number of receivers, due to the increasing of both acknowledgment messages and control variables required to be processed. In high speed environments, as the transmission rate increases, the protocol processing overhead at the stations and network nodes becomes a performance bottleneck. An idea to overcome this performance bottleneck comprises the design of new low processing load protocols with mechanism specifically conceived for high bandwidth communications, such as fixed header length, reduced number of control protocol data units and simple error recovery procedures [2]-[6].

The most of the early works on finite receiver buffer selective repeat ARQ for point-to-multipoint communications involves multicopy retransmission [7]-[10] or the use of hybrid error recovery [9]. These techniques improve the throughput efficiency at the expense of increasing even more the high implementation complexity of the selective repeat schemes. Mainly when the number of copies is dynamic and adaptively adjusted, since it requires the transmitter computes the number of receivers that are lacking correctly to receive each message. In addition, in many of the previous works the receivers send an acknowledgment (positive or negative) for each received message.

This paper proposes a point-to-multipoint selective repeat pure ARQ protocol with finite receiver buffer in which the sender retransmits just the negatively acknowledged messages and those ones discarded due to buffer overflow. When buffer overflow occurs at one or more receivers, the transmitter is capable of detecting it and identifying the discarded messages, which need be retransmitted. To reduce the processing overhead, only the erroneous messages need be acknowledged as they arrive. The control messages contain a special field to accumulatively acknowledge the sequenced correctly received messages. This allows the transmitter to maintain an acknowledgment list (control variable) for each receiver instead of one for each message-receiver pair, simplifying the acknowledgment procedure and providing an additional reduction on the transmitter processing overhead. This is especially useful in communication where the transmitter needs to process and to control acknowledgments from various receivers.

The proposed strategy outperforms all previous point-to-multipoint single copy retransmission ARQ protocols with the same receiver buffer size. Its throughput efficiency remains in a usable range even for very high error rate conditions where it outperforms a known finite buffer multicopy retransmission selective repeat ARQ scheme. In addition, its single destination version (when the number of receivers is set to one) also outperforms all existing similar point-to-point ARQ schemes [11]-[14] at high bit error rates.

First the proposed scheme is described. The following section describes the analytical model, which is based on a discrete-time semi-Markov process, and derives the performance analysis of the proposed scheme. Section 4 provides numerical results and compares it to other ARQ scheme results. Finally, conclusions are presented.

2 The Proposed Scheme

This paper assumes an environment consisting in one transmitter and M receivers, where the communication between the transmitter and receivers is over a point-to-multipoint channel. All the data are transmitted in form of fixed length (L total bits and K information ones) *information messages* whose transmission time is defined as the time unit.

The probability of an information message arriving without bit errors at a given receiver is denoted by P_{bc}. On the other hand, the probability of an information message arriving with at least one bit error at a given receiver is denoted by P_{be} (i.e., $P_{be} = 1 - P_{bc}$). These probabilities are independent from message to message and from receiver to receiver. Moreover, the round trip delay, measured in time units, is constant and equal to S for all receivers. It is also assumed that there is always an information message waiting to be transmitted at the transmitter.

The proposed strategy is a point-to-multipoint selective repeat ARQ scheme with finite receiver buffer suited for high speed communication channels. The transmitter retransmits only the negatively acknowledged messages and those ones discarded due to buffer overflow at one or more receivers. It is assumed that a continuous supply of messages is available. For simplicity, this work considers the case in which the size of the receiver buffers is $S+1$ where S is the number of information messages that can be transmitted during a round trip delay. The proposed strategy can be modified in a similar way for any buffer size $q.S+1,\ q = 1, 2, \ldots$. When an information message is ready for transmission, it is stored in the input queue of the transmitter. After the transmission of a message, the transmitter stores them in a retransmission buffer while waiting for confirmation that they have been correctly received by all receivers. After transmitting a message, the transmitter picks the next one from the input queue and transmits it too. 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 delivered to user by this receiver. Here, $V_i(R) = N(R)$ indicates the receiver i has correctly received all messages with sequence number smaller than N(R). Besides these variables, the transmitter maintains two global state variables: $VG(S)$ indicates the number of next message to be transmitted and $VG(R) = \min_i\{V_i(R)\}$ indicates the last message delivered to users by all receivers. Thus, $VG(R) = N(R)$ indicates all messages with sequence number smaller than N(R) have been received correctly by all receivers and may be removed from retransmission buffer.

On the receipt of a message, each receiver performs a parity checking. If no errors are detected, the message is either delivered to the user or stored in this receiver until it is ready to be delivered to the user in the correct order. Otherwise that receiver discards the message, reserves a space in its buffer and sends a control message (negative acknowledgment - NACK) to the transmitter requesting retransmission of that message detected in error. A receiver does not deliver any of the subsequently received messages, until the earliest erroneously received one is recovered. The control messages have a special field N(R) indicating correct reception of all information messages with sequence number smaller than N(R). It is assumed that the return channel is error free and all the NACKs sent by various receivers for a particular information message arrive at the transmitter at the same time.

When the first negative acknowledgment for a message in the retransmission buffer is received from one or more receivers, the transmitter performs a retransmission of that message and marks it as NACKed. Then it continues to transmit new messages from the input queue. Until receiving a negative acknowledgment for a NACKed message, the transmitter just retransmits the messages negatively acknowledged. When a negative acknowledgment for a message marked as NACKed is received, the transmitter identifies it as the message B_{e_0} and initiates the retransmission of that and those messages with sequence number greater than $B_{e0} + S$. The receivers that have sent the second NACK for B_{e0}, have also discarded all messages with sequence number greater than $B_{e0} + S$. Hereafter, the NACKed messages with sequence number between $B_{e0}+1$ and $B_{e0}+S$ will be called messages B_{ei}, $1 \leq i \leq S$. An unsuccessful retransmission of a message B_{ei} causes only its retransmission, because the messages retransmitted due to B_{e_0} include the ones discarded due to the unsuccessful retransmission of B_{ei}. A negative acknowledgment for a NACKed message only may cause retransmission of other messages if the acknowledged message is the earliest NACKed one.

3 Performance Analysis

A message is said to be transferred to a receiver when it is correctly received by this receiver and may be immediately delivered to the user. Moreover, a message is said to be communicated, or communicated to the set of receivers, when it is transferred 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.

The analytical model defines three states to the set of receivers: normal (N), selective repeat (SR) and exceptional (E). In the normal state, the receivers accept the sequenced correctly received messages and deliver them to their users. There is no outstanding error recovery in this state and there are no messages stored in any receiver buffer. The set of receiver turns to the SR state when an erroneous message is detected by one or more receivers. In this state the protocol works just as the basic point-to-multipoint selective repeat scheme. It returns to the normal state if all NACKed messages are recovered by their first retransmission attempt, that is, no message is received twice with error by the same receiver. On the other hand, the set of receivers passes from the SR to the exceptional state when a message (message B_{e_0}) is received twice with error by the same receiver. Therefore, the exceptional state, which is classified in cycles, begins after the erroneous reception of the first trial of retransmitting the message B_{e_0} and only ends after recovering all messages B_{e_i}. During this state, the set of receivers delivers $S+1$ messages to the users: the messages numbered from B_{e_0} to $B_{e_0} + S$.

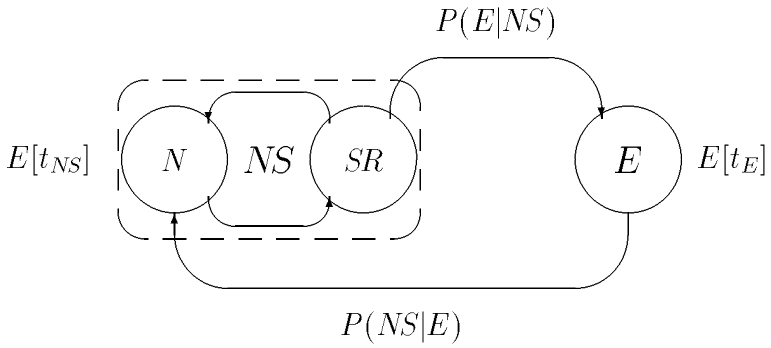

Fig.1 - Semi-Markov process that models the new protocol.

This performance analysis considers a semi-Markov process with two states: the NS state that is formed by the junction of the N and SR ones and the exceptional state. The protocol throughput efficiency is given by the weighted mean value of the efficiency in each state, where the weight is the probability of the set of receivers is in each state. The Fig. 1 shows the state diagram that models the proposed scheme.

Then:

$$\eta = \frac{K}{L}\left(P(NS)\frac{A_{NS}}{E[t_{NS}]} + P(E)\frac{S+1}{E[t_E]}\right), \tag{1}$$

where $P(NS)$ and $P(E)$ are the probabilities of the set of receivers is in the NS and E states, respectively, and A_{NS} is the average number of messages delivered to the users during the NS state. The expressions $E[t_{NS}]$ and $E[t_E]$ denote the mean holding time in the mentioned states.

Since the set of receivers always switches back and forth between the NS and the exceptional states (there are no virtual transitions), the conditional transition probabilities are:

$$P(E\,|\,NS) = P(NS\,|\,E) = 1. \tag{2}$$

Using equation 2 and applying the semi-Markov process properties, $P(NS)$ and $P(E)$ can be expressed as:

$$P(NS) = \frac{E[t_{NS}]}{E[t_{NS}] + E[t_E]} \tag{3}$$

and

$$P(E) = \frac{E[t_E]}{E[t_{NS}] + E[t_E]}. \tag{4}$$

Combining equations 3 and 4 with equation 1, the throughput efficiency can be given by:

$$\eta = \frac{K}{L}\frac{E[t_{NS}] + A_N S + 1}{E[t_{NS}] + E[t_E]}. \tag{5}$$

In the following, the mean holding time and the average number of messages delivered to user during the NS state will be derived. When the first message transmitted in this state is twice erroneously received by at least a receiver, the holding time in this state is $S+2$. This time is $S+3$ if the first message is communicated within the first two attempts, but the second one is twice received with error by the same receiver. And so on. The probability of the NS state holding time being equal to $q(S+1)+k, q \geq 1$ and $k = 1, 2, \ldots, S+1$ is given by:

- $Pr\{t_{NS} < S+1+1\} = 0;$
- $Pr\{t_{NS} = S+1+1\} = 1-(1-P_{be}^2)^M;$
- $Pr\{t_{NS} = S+1+2\} = [(1-P_{be}^2)^M][1-(1-P_{be}^2)^M];$
- $Pr\{t_{NS} = S+1+3\} = [(1-P_{be}^2)^M]^2[1-(1-P_{be}^2)^M];$

  $\vdots$
- $Pr\{t_{NS} = S+1+S+1\} = [(1-P_{be}^2)^M]^S[1-(1-P_{be}^2)^M];$
- $Pr\{t_{NS} = 2S+2+1\} = P_{bc}^M[(1-P_{be}^2)^M]^S[1-(1-P_{be}^2)^M];$
- $Pr\{t_{NS} = 2S+2+2\} = p_k(2)[(1-P_{be}^2)^M]^{S-1}P_{bc}^M[1-(1-P_{be}^2)^M];$
- $Pr\{t_{NS} = 2S+2+3\} = p_k(2)^2[(1-P_{be}^2)^M]^{S-2}P_{bc}^M[1-(1-P_{be}^2)^M];$

  $\vdots$
- $Pr\{t_{NS} = 2S+2+S+1\} = p_k(2)^S P_{bc}^M[1-(1-P_{be}^2)^M].$

  $\vdots$
- $Pr\{t_{NS} = qS+q+k\} = p_k(q)^{k-1}p_k(q-1)^{S+1-k}p_q(q)\ q \geq 1, 1 \leq k \leq S{+}1.$

where

$$p_k(j) = \begin{cases} 1, & j = 0; \\ (1-P_{be}^2)^M, & j = 1; \\ P_{bc}^M p_k(j-1) + \left((1-P_{be}^2)^M - P_{bc}^M\right) p_k(j-2), & j \geq 2; \end{cases} \tag{6}$$

$$p_q(i) = \begin{cases} 0, \quad i = 0; \\ 1 - (1 - P_{be}^2)^M, \quad i = 1; \\ P_{bc}^M p_q(i-1) + \left((1-P_{be}^2)^M - P_{bc}^M\right) p_q(i-2), \quad i \geq 2. \end{cases} \tag{7}$$

From these probabilities, the mean holding time in the NS state is calculated:

$$\begin{aligned} E[t_{NS}] &= \sum_{i=0}^{\infty} i Pr\{t_{NS} = i\} \\ &= \sum_{q=1}^{\infty} \sum_{k=1}^{S+1} (qS+q+k) p_k(q)^{k-1} p_k(q-1)^{S+1-k} p_q(q). \end{aligned} \tag{8}$$

The derivation of the average number of messages delivered to the users during the NS state will be divided in two cases, as below:

a. the holding time is lesser than or equal to $2S + 3$;

b. the holding time is greater than $2S + 3$.

In the first case, the average number of messages delivered to the users is given by:

$$A_{NS}(a) = E[t_{NS} \mid t_{NS} \leq 2S + 3] - S - 2. \tag{9}$$

In this case, the mean holding time in the NS state is given by:

$$\begin{aligned} E[t_{NS} \mid (a)] &= S + 2 + \frac{(S+1) P_{bc}^M [(1 - P_{be}^2)^M]^S + \sum_{k=1}^{S} k[(1 - P_{be}^2)^M]^k}{P_{bc}^M [(1 - P_{be}^2)^M]^S + \sum_{k=1}^{S} [(1 - P_{be}^2)^M]^k} \\ &= S + 2 + \\ & \frac{(1-P_{be}^2)^M - [(1-P_{be}^2)^M]^{S+1} (S+1-S(1-P_{be}^2)^M)}{(1-(1-P_{be}^2)^M) \{1-[(1-P_{be}^2)^M]^S ((1-P_{be}^2)^M - P_{bc}^M)\}} + \\ & \frac{(S+1)[(1 - P_{be}^2)^M]^S P_{bc}^M}{1-[(1-P_{be}^2)^M]^S ((1-P_{be}^2)^M - P_{bc}^M)}. \end{aligned} \tag{10}$$

That is,

$$A_{NS}(a) = \frac{(1-P_{be}^2)^M - [(1-P_{be}^2)^M]^{S+1}(S+1-S(1-P_{be}^2)^M)}{(1-(1-P_{be}^2)^M)\{1-[(1-P_{be}^2)^M]^{S+1} + [(1-P_{be}^2)^M]^S P_{bc}^M\}} + \frac{(S+1)[(1-P_{be}^2)^M]^S P_{bc}^M}{1-[(1-P_{be}^2)^M]^{S+1} + [(1-P_{be}^2)^M]^S P_{bc}^M}. \tag{11}$$

In the case (b), the NS state holding time until the reception of the message B_{e_0} first transmission is composed by the following message reception times:

- first transmissions of messages received in this state with sequence number lesser than B_{e_0};
- first retransmissions of messages with sequence number lesser than $B_{e_0} - S$ (retransmissions of messages with sequence number between $B_{e_0} - S$ and $B_{e_0} - 1$ reach the receivers after the first transmission of message B_{e_0} does).

The average number of incorrect reception out of the S messages with sequence number between $B_{e_0} - S$ and $B_{e_0} - 1$ is given by $S(1-P_{bc}^M)$. On the other hand, the mean holding time until the reception of the first retransmission of B_{e_0} is given by: $E[t_{NS}] - S - 2$ (At each transition from the NS to the exceptional state instant, all the messages with sequence number lesser than B_{e_0} have been received by all receivers.) Therefore, the average number of messages delivered to the users during the NS state in the case (b) above is such that:

$$A_{NS}(b)P_{bc}^M + 2A_{NS}(b)(1-P_{bc}^M) = E[t_{NS} \,|\, t_{NS} > 2S+3] - S - 2 + S(1-P_{bc}^M). \tag{12}$$

In this case (b), the mean holding time in the NS state is given by:

$$E[t_{NS} \mid (b)] = S + 2 + \frac{\sum_{k=S+2}^{\infty} k Pr\{t_{NS} = S+2+k\}}{\sum_{k=S+2}^{\infty} Pr\{t_{NS} = S+2+k\}}. \tag{13}$$

The Combination of the equations (12) and (13) results in:

$$A_{NS}(b) = \frac{\sum_{k=S+2}^{\infty} k Pr\{t_{NS} = S+2+k\}}{(2-P_{bc}^M)\sum_{k=S+2}^{\infty} Pr\{t_{NS} = S+2+k\}} + \frac{S(1-P_{bc}^M)}{2-P_{bc}^M}. \tag{14}$$

Therefore, the final average number of messages delivered to the users during the NS state is given by:

$$\begin{aligned} A_{NS} &= A_{NS}(a)Pr\{t_{NS} \leq 2S+3\} + A_{NS}(b)Pr\{t_{NS} > 2S+3\} \\ &= \frac{(1-P_{be}^2)^M - [(1-P_{be}^2)^M]^{S+1}(S+1-S(1-P_{be}^2)^M)}{(1-(1-P_{be}^2)^M)} + \\ & \quad (S+1)[(1-P_{be}^2)^M]^S P_{bc}^M + \\ & \quad A_{NS}(b)[(1-P_{be}^2)^M]^S \left((1-P_{be}^2)^M - P_{bc}^M\right). \end{aligned} \tag{15}$$

Finally, mean holding time in the exceptional state will be derived. The first cycle of this state corresponds to the S messages received between the receptions of the first and second retransmissions of message B_{e_0} (the first retransmission is received with error). The last cycle ends after the recovery of all messages $B_{e_i}, 0 \leq i \leq S$. The intermediate cycles have duration of $S+1$. During the first cycle, the set of receivers may receive the following types of messages:

- transmission of messages with sequence number between $B_{e_0}+1$ and $B_{e_0}+S$;
- retransmission of messages with sequence number between $B_{e_0}+1$ and $B_{e_0}+S$;
- transmission of messages with sequence number greater than $B_{e_0}+S$. The lower the bit error rate the greater the number of these messages.

During the second cycle, that begins with the reception of the second message B_{e0}, the receivers may receive:

- retransmission of messages with sequence number between $B_{e_0}+1$ and $B_{e_0}+S$ (the messages $B_{e_i}, 0 \leq i \leq S$);
- transmissions/retransmissions of messages with sequence number greater than $B_{e_0}+S$.

When the set of receivers recovers all messages B_{e_i} in this second cycle, it does not discard those messages with sequence number greater than $B_{e_0}+S$ received during this cycle. They may be considered part of the next NS state. In this case the cycle duration corresponds to the message B_{e_i} reception times. Otherwise if the cycle is not a final one, its duration is $S+1$. Each additional cycle receives retransmissions of unrecovered messages B_{e_i} and transmissions/retransmissions of messages with sequence number greater than $B_{e_0}+S$. When the exceptional state has more than two cycles, the set of receivers also does not discard the messages with sequence number greater than $B_{e_0}+S$ received during the final cycle. So, these messages may be considered part of the next NS state and the final cycle duration corresponds to the reception times of the messages B_{e_i} recovered during this cycle. Therefore, the mean holding time in this state is given by:

$$\begin{aligned} E[t_E] \; = \; & S+\sum_{k=1}^{\infty}\left((k-1)(S+1)+\frac{1-(1-P_{be}^{k+1})^M}{1-(1-P_{be}^{2})^M}+\right. \\ & \left. S\left(P_{bc}^M[1-(1-P_{be}^{k+1})^M]+(1-P_{bc}^M)[1-(1-P_{be}^{k})^M]\right)\right) \\ & \left\{\left(P_{bc}^M(1-P_{be}^{k+2})^M+(1-P_{bc}^M)(1-P_{be}^{k+1})^M\right)^S\right. \\ & \frac{(1-P_{be}^{k+2})^M-(1-P_{be}^{2})^M}{1-(1-P_{be}^{2})^M}-\frac{(1-P_{be}^{k+1})^M-(1-P_{be}^{2})^M}{1-(1-P_{be}^{2})^M} \\ & \left.\left(P_{bc}^M(1-P_{be}^{k+1})^M+(1-P_{bc}^M)(1-P_{be}^{k})^M\right)^S\right\}. \end{aligned} \tag{16}$$

The term $(k-1)(S+1)$ corresponds to the non-final cycle duration, while that $[1-(1-P_{be}^{k+1})^M]/[1-(1-P_{be}^2)^M]$ and $S\{P_{bc}^M[1-(1-P_{be}^{k+1})^M]+(1-P_{bc}^M)[1-(1-P_{be}^k)^M]\}$ correspond to the reception time of the retransmissions of the messages B_{e_0} and $B_{e_i}(i\geq 1)$, respectively.

4 Numerical Results

This section discusses numerical results of the proposed scheme and compares them with other published point-to-multipoint results. Fig. 2 compares the proposed protocol with the Chandran&Lin's [7] and Towsley&Mithal's [8] (with $q=1$ and $n_1=1$) selective repeat schemes and with the Towsley's [15] and Gopal&Jaffe [16] GB(N) strategies. The

Towsley'GB(N) is called Broadcast GB(N) protocol (BGB(N)). Their throughput efficiencies were plotted considering parameters such as M = 10 (10 receivers), S = 1024 and L = 6800 bits, that correspond to either satellite links at 10 Mbps or terrestrial ones at 150 Mbps. The proposed scheme throughput efficiency is equal to or greater than all the other ones, for any bit error rates.

Considering a point-to-multipoint communication link with S=1024, L=6800 bits and bit error rate of 10^{-7} and 10^{-6}, respectively, Fig. 3 and 4 show that the new protocol outperforms all the above strategies, for any number of receivers.

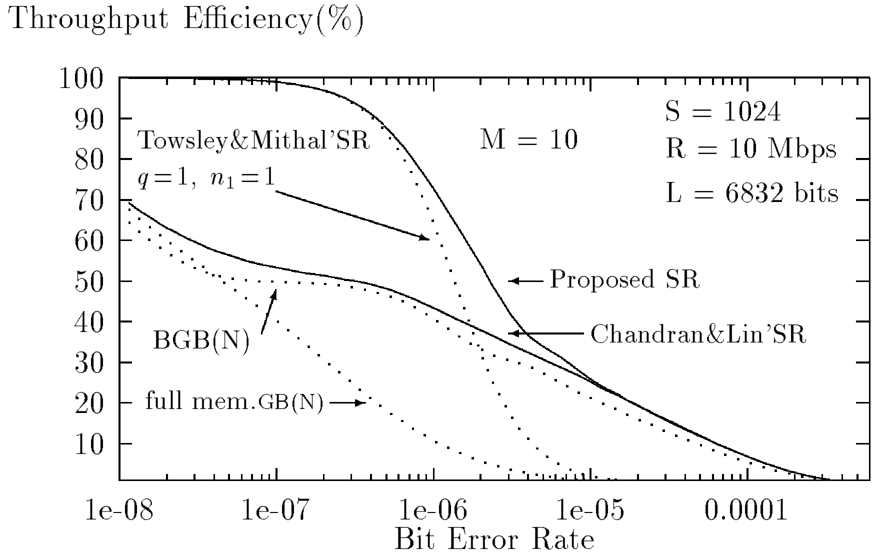

Fig. 2 - The proposed SR scheme compared with other ARQ protocols.

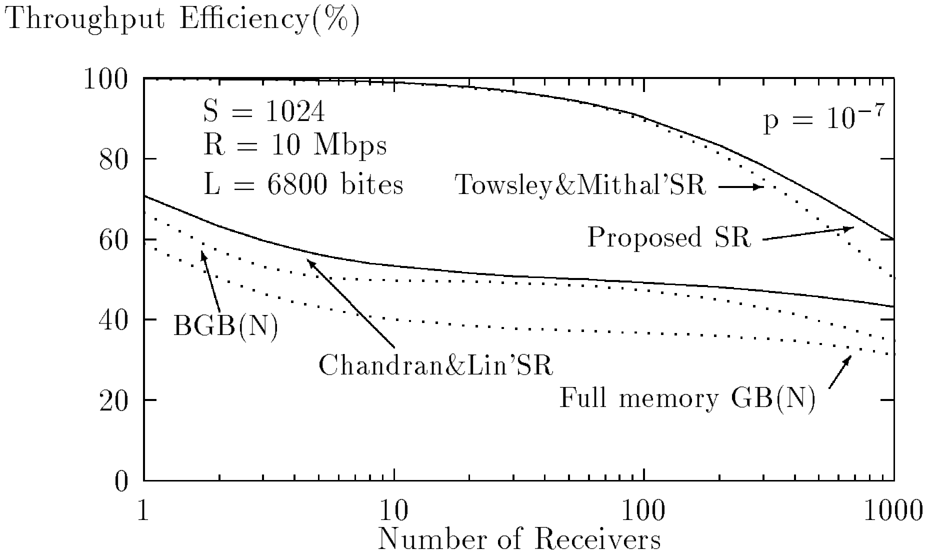

Fig. 3 - The proposed SR scheme compared with other protocols as a function of the number of receivers.

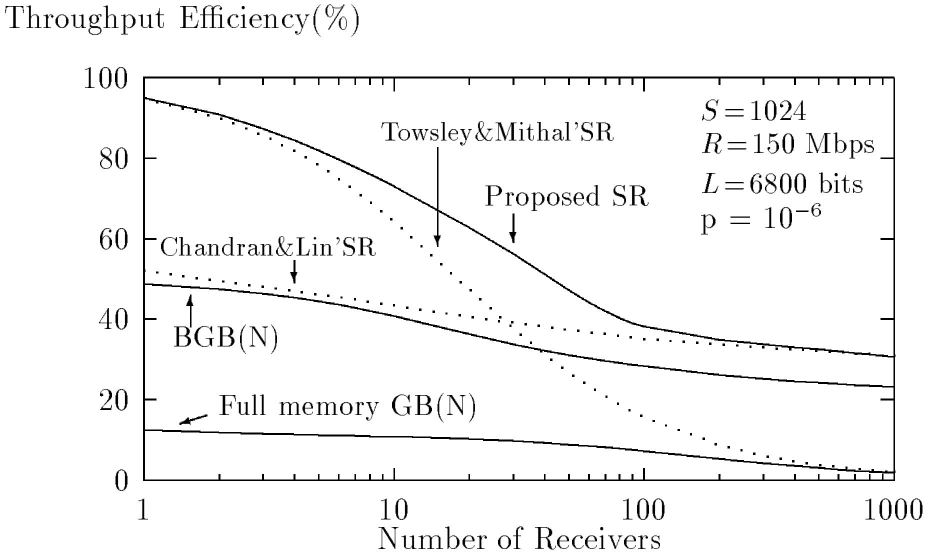

Fig. 4 - The proposed SR scheme compared with other protocols as a function of the number of receivers.

The Fig. 5 compares the proposed protocol, when the number of receivers is set to one, with some similar point-to-point SR schemes [12, 14]. The throughput efficiency of the extended REJ strategy [3] (with $m = 1$) is also plotted, for comparison purpose. The proposed scheme outperforms all the other protocols, including the best known result among the single-copy retransmission ARQ schemes [12].

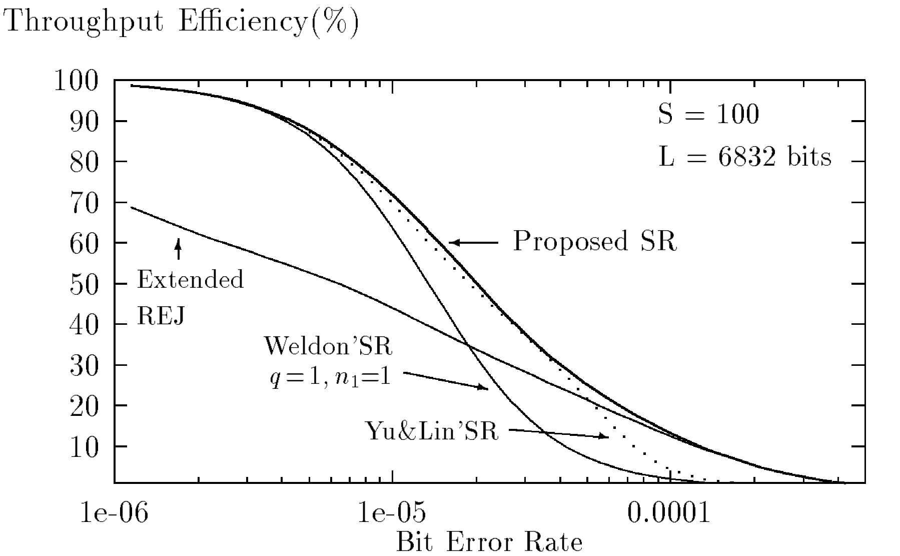

Fig. 5 - The proposed SR scheme compared with some point-to-point ARQ protocols.

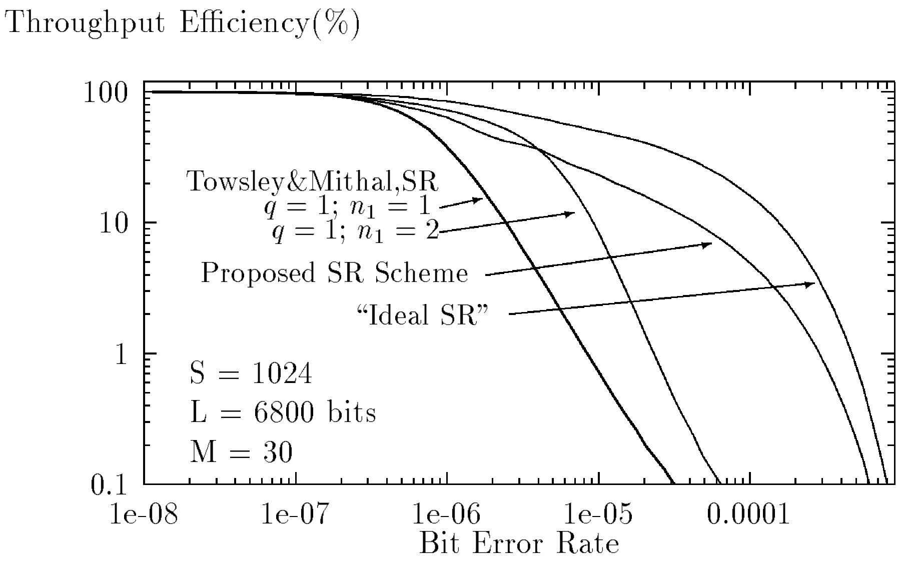

Fig. 6 - The proposed SR scheme compared with the point-to-multipoint "Ideal" SR and Towsley&Mithal'SR protocols.

Fig. 6 compares the performance of the proposed strategy, Towsley&Mithal's SR schemes ($n_1 = 1$ and $n_1 = 2$) and the infinity buffer "ideal" SR protocol which sets a limit on the throughput performance that any ARQ protocol can achieve in practice [16]. The proposed scheme outperforms even the multicopy retransmission ($n_1 = 2$) Towsley$Mithal'SR protocol at high bit error rates. Moreover, it can be seen that, for both low and high bit error rates, the proposed scheme compares well with the ideal SR protocols.

5 Conclusion

This paper has presented and analyzed a simple selective repeat scheme with finite receiver buffers for high speed point-to-multipoint communications. It presents both a low implementation complexity and a little processing overhead. Furthermore, it performs well even under high error rate condition.

The proposed protocol seems to be quite robust and numerical results suggest its utilization in end-to-end high speed communications where the performance bottleneck is the strategy processing overhead. In other words, the proposed scheme presents low implementation complexity, requires low processing and its throughput efficiency remains in a usable range even under very high bit error rate condition, where it outperforms a known multicopy retransmission SR scheme.

This paper has shown that the performance of the point-to-multipoint finite buffer SR ARQ schemes can be improved at high error rates without using techniques that increase the protocol processing overhead, such as multicopy retransmission, adaptive multicopy adjusting and hybrid error recovery. Moreover, the proposed scheme may use any above technique and achieve a higher throughput efficiency than the existing similar protocol, but such a combination is out this paper's scope.

The analytical results have shown that the proposed strategy outperforms all existing ARQ protocols of its category considering both any error rate and any number of receivers. At the same time, for ranges of both low and high bit error rates, its performance is close to the best achievable one by an ARQ protocol. Thus, the scheme proposed here extends the useful range of the single copy retransmission pure ARQ protocols.

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