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Error Control System for Parallel Multichannel Using Selective Repeat ARQ

M.Amal Rajan[1], M.Maria Alex[2]

[1]*Assistant Prof in CSE-Dept, Jayamatha Engineering College, Aralvaimozhi, India,*

[2]*Assistant Prof in CSE-Dept, Jayamatha Engineering College, Aralvaimozhi, India,*

[1]amalrajan25@gmail.com, [2]mariaalex.m@gmail.com

***Abstract*—In Wireless Parallel Multichannel data communication system using Selective Repeat Automatic Repeat Request protocol for Error Control Transmission. We assume the modified scheme for improve the performance of Data Transmission over Selective Repeat ARQ by adding SW ARQ protocol features. We evaluate the resequencing delay and the resequencing buffer occupancy, respectively. Under the assumption that all channels have the same transmission rate but possibly different time-invariant error rates, we derive the probability generating function of the resequencing buffer occupancy and the probability mass function of the resequencing delay. Then, by assuming the Markov error model for each channel, we extend our analysis to time-varying channels.**

***Keywords*— In-sequence Delivery, Multichannel Data communications, Resequencing buffer occupancy, Resequencing Delay, SW-ARQ, SR ARQ.**

I. INTRODUCTION

In a modern high-speed wireless data network, however, multiple parallel channels between adjacent transmitter–receiver pairs are often created using advanced wireless communication technologies (e.g., orthogonal frequency division multiplexing (OFDM) systems [1] and multiple-input–multiple-output (MIMO) systems [2]) to increase the data transmission rate. Unlike packet transmission over a single channel, in a multichannel communication system, multiple packets are sent at a time, one packet per channel, and packet transmission errors can occur across every channel. To implement error control through retransmission of packets in a multichannel communication system, an ARQ protocol has been generalized to allow concurrent transmission of multiple packets.

Automatic Repeat Request (ARQ) is a technique used to ensure that a data stream is delivered accurately to the user despite errors that occur during transmission. ARQ forms the basis for peer-to-peer protocols that provide for the reliable transfer of information. The idea of using ARQ strategies was first introduced after which three classical ARQ schemes have been developed: stop-and-wait (SW-ARQ), go-back-N (GBN-ARQ), and selective-repeat (SR-ARQ). In SW-ARQ, the transmitter sends a packet to the receiver and waits for its acknowledgment. Based on error-detection results, the receiver generates either a negative acknowledgment (NACK) or a positive acknowledgment (ACK) for each received packet and sends it over a feedback channel. If an ACK is received, the transmitter sends out a next packet; otherwise, if an NACK is received, retransmission of the same packet will be scheduled immediately, and this process continues until the packet is positively acknowledged. In GBN-ARQ, the transmitter sends packets to the receiver continuously and receives acknowledgments as well. When a NACK is received, the transmitter retransmits the negatively acknowledged packet immediately and all already-transmitted packets following it. In SR-ARQ, the transmitter sends packets continuously until a NACK arrives at the transmitter, in which case the transmitter retransmits the negatively acknowledged packet without resending the transmitted packets following it. To preserve the original arriving order of packets at the receiver, the system has a buffer, referred to as the resequencing buffer, to store the correctly received packets that have not been released.

The performance of the three classical ARQ protocols for multiple identical channels, the average number of packets successfully transmitted per unit of time, and the mean transmission delay, which is the average time between the instant when a packet is transmitted for the first time and the instant when it is successfully received, have been derived. The transmission-delay [1] distribution functions of GBN-ARQ for parallel channels that have the same transmission rate but possibly different time-invariant error rates. Recently, [2] the ARQ protocols for parallel channels in which each channel may have a unique transmission rate and error rate Expressions for the throughput and the mean transmission delay have been derived. In this a resequencing analysis for SR-ARQ over parallel channels, all of which have the same transmission rate but possibly different time-invariant error rates. All of the above mentioned studies on multichannel ARQ protocols have been based on the assumption of a time-invariant error rate for each channel. In a wireless communication system, however, the transmission condition of a wireless channel changes over time, and consequently, the channel is often severely affected by time-varying losses. Even though studies [3], [4] on ARQ protocols over a single channel of time-varying models have been conducted, there has been no study reported in the literature for analysis of multichannel ARQ protocols with time-varying channel models. In this paper, a multichannel SR-ARQ protocol for time-varying channel models. The performance of the resequencing buffer in terms of the resequencing buffer occupancy, which is the number of packets waiting in the resequencing buffer for delivery, and the resequencing delay, defined as the waiting time of a packet in the resequencing buffer, in steady state. First, under the assumption that all channels have the same transmission rate but possibly different time-invariant error rates, we derive the probability generating function of the resequencing buffer occupancy and the probability mass function of the resequencing delay. Then, a traditional time-varying channel model, the Gilbert–Elliott model [5], [6] is assumed, the pgf of the resequencing buffer occupancy and the mean resequencing delay. In addition, the mean resequencing buffer occupancy and the mean resequencing delay for channel models grow with the increase of either the number of channels or the average error rate of channels.

II. SYSTEM MODEL

In terms of the open system interconnection (OSI) reference model for layered network architectures [7], an ARQ protocol is usually located at the Data link layer (i.e., layer 2). Below and above it are the physical layer (layer 1) and the network layer (layer 3), respectively. In the ARQ protocol point of view, the physical layer provides forward channels (for data packets from the transmitter to the receiver) and feedback channels (for acknowledgment messages from the receiver to the transmitter), and the network layer provides data packets for transmission

A. Multichannel System with ARQ

A multichannel data communication system, in which a transmitter-receiver pair communicates data packets for one communication (e.g., a large-size video file transfer).

The communication link connecting the transmitter and the receiver consists of M ($M \geq 2$) parallel channels numbered from 1 to M, each of which is characterized by a data transmission rate and a channel model. The transmission rate of a channel is measured by the maximum number of packets that can be transmitted over that channel during a specified time period, while the channel model, or the model of packet errors, describes the statistical property of transmission errors of packets when they are transmitted over the channel.

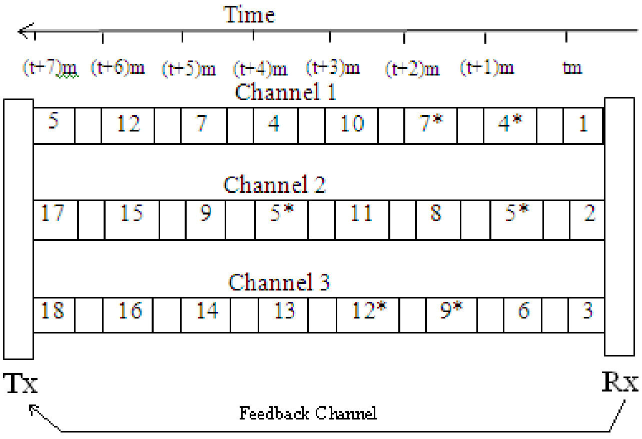
A feedback channel is also provided in the system Fig. 1. We assume that an erroneous packet can always be detected through CRC coding and that the feedback channel is error-free for transmitting acknowledgement packets.

Each packet to be transmitted is identified by a unique integer number, referred to as the sequence number. We assume that there is a buffer in the transmitter, referred to as the transmission queue, in which infinitely many packets are waiting according to their sequence numbers for first-in-first-out transmission and retransmission. That is, there are always packets in the system to be transmitted, which in related studies is referred to as the heavy traffic condition.

We also assume that all channels have the same transmission rate, and that the M channels are time-slotted with one unit (or slot) equal to the transmission time of a packet over a channel. Therefore, the transmission rate of each channel is one packet per slot. All packets, when transmitted from the transmitter to the receiver, have a fixed round trip time (RRT) equal to $(m - 1)$ slots, which is assumed to be an even number of slots. (Therefore, m slots represent the sum of the transmission time and RTT of a packet.) A packet experiences the same propagation delay in forward and feedback channels, which is $(m-1)/2$ slots. Once packet transmission starts, the transmitter sends multiple packets at a time, one per channel. All channels share the same set of sequence numbers of the packets in packet-to-channel scheduling.

B. Multichannel Selective Repeat ARQ over SW ARQ

In this paper, we assume the modified scheme for data transmission in multichannel for increasing the performance of the ARQ protocol. We combine the features of both SW ARQ[10] and SR ARQ. Every data transmitting between channels, transmitter waits particular time period by the time slot on transmitter. The transmitter sends packets continuously until a NACK arrives at the transmitter. The transmitter only retransmits erroneously received packets but the receiver delivers packets in the order of their sequence numbers (i.e., in-sequence delivery), is illustrated in Fig. 1.



Where, Tx, RX denote Transmitter and Receiver respectively

*And * denoted as transmission error.*

Fig. 1. Multichannel Selective Repeat -ARQ

- At the beginning of a slot tm (t=0,1,…)(see Fig. 1), the transmitter starts sending a block of M packets to the receiver, and completes its transmission at the end of the slot. The transmitter sends packets continuously, it does not waiting for the acknowledgments (ACKs/NACKs) for sending next slot. The time slot depending up on the system performance. Before the transmitter sends the next block of M packets in slot (t+1)m , it is idle.
- The receiver receives the block of packets at the end of slot (mt+(m-1)/2). Each M packet is received erroneously with some probability. The probability is pi for channel i, and for channels with time-varying error rates (or Markov channels), it is the state of the Markov chain at the instant when the packet is received. After the error detection, the receiver sends an acknowledgment packet, which contains exactly M acknowledgments (ACKs/NACKs) corresponding to the most recently received block of packets, to the transmitter.
- The receiver deletes all erroneously received packets, delivers all qualified packets, as will be defined below, from the resequencing buffer to the upper layer, and stores all unqualified packets for

future delivery. A qualified packet is a correctly received packet with a sequence number such that all packets with a smaller sequence number have been correctly received, and an unqualified packet is a correctly received nonqualified packet

- The transmitter sends packets continuously until a NACK arrives at the transmitter, in which case the transmitter retransmits the negatively acknowledged packet without resending the transmitted packets following it. To preserve the original arriving order of packets at the receiver, the system has a buffer, referred to as the resequencing buffer, to store the correctly received packets that have not been released.
- New packets chosen to be transmitted in the next block are those with the smallest sequence numbers waiting in the transmission queue.
- To transmit the next block of packets in slot (t+1)m , a packet-to-channel assignment rule needs to be specified. There are two assignment rules, the static assignment rule and the dynamic assignment rule, to be considered.

C. *Packet Scheduling Policy:*

Packet Scheduling Policy is a packet-to-channel assignment rule when transmitter simultaneously transmits M packets over M channels

1) *Static Rule:* In Static scheduling policy, An old packet is retransmitted over the same channel as originally assigned one

2) *Dynamic Rule:* In Dynamic scheduling policy, the packet with the k^{th} smallest sequence number is assigned to the channel having the k^{th} smallest error rate

D. *Markov Error Model*

The packet-error property is characterized by the Gilbert–Elliott model, in which a two-state Markov chain {E(k):k=0,1,...} , referred to as the error process, is defined. The state space of the Markov chain is

$$\{e_G, e_B\}, \quad (1)$$

where the two real numbers represent the packet error rates of the channel when it is in good and bad transmission conditions, respectively. The transition matrix of the Markov chain {E(t):t>=0} is,

$$\begin{bmatrix} \alpha & 1-\alpha \\ 1-\beta & \beta \end{bmatrix} \quad (2)$$

The Markov chain has the stationary distribution given by,

$$((1-\beta)/(2-\alpha-\beta),(1-\alpha)/(2-\alpha-\beta)). \quad (3)$$

The resequencing buffer occupancy for MSR-ARQ is defined as the number of packets that have been correctly received but not been delivered from the resequencing buffer to the upper layer at the beginning of a slot during which a block of M packets are received, and the resequencing delay of a packet is measured from the time epoch at which the packet is successfully received until the epoch of its in-sequence delivery (see Fig. 1 for an illustration of packet with sequence number 6).

III. RESEQUENCING ANALYSIS

In packet data networks, it often happens that packets (the data units transmitted) depart from the receiver in a different order of their arriving at the transmitter due to the randomness of packets' transmission time. In such a system, however, packets are often required to leave the receiver in the same order as they arrived at the transmitter, which is referred to as in-sequence delivery. This can be accomplished by providing a resequencing buffer at the receiver to control the departure of packets.

The network includes three components: disordering network, resequencing buffer, and queueing network. Packets arriving at the disordering network are numbered in a numerical sequence. For instance, the sequence C_1, C_2, C_3, · · · represents a sequence of arriving packets, where C_n is the nth packet arriving at the disordering network. Because of the random nature of sojourn times of packets in the disordering network, packet C_n may leave the disordering network before some packet C_k with $k < n$. In this case, C_n is an out-of-sequence packet. A packet C_n is deliverable if it is correctly received and all packets C_k, for $k < n$, have also been correctly received. In order to make packets enter the queueing network in the same order as they arrived at the disordering network, the resequencing buffer sends only deliverable packets to the queueing network. For resequencing analysis in the context of the resequencing network, delay in the resequencing buffer (referred to as the resequencing delay) and a number of packets waiting in the resequencing buffer.

In this paper, a Markov chain $\{Y_n\}n\geq1$, in which Y_n is the packet delay of packet C_n, has been constructed, and, under some condition, its stationary distribution function has been obtained. Yum and Ngai [8] derived the distribution function of the resequencing delay for the servers in an M/M/m queue having different service rates. An incoming class i packet joins the first queue with a probability pi or the second queue otherwise, and packets only with the same class are re-ordered in the resequencing buffer. In [9], a priority queueing model is used to analyze the mean resequencing delay for SR-ARQ with a Bernoulli arrival process.

we analyze the resequencing buffer occupancy for Markov channels. That is, the packet-error property of channel i, for i=1,…M, is characterized by the error process {Ei(k):k≥0}, which is a two-state discrete-time Markov chain represents the very beginning of slot km. The M error processes are mutually independent and have the same state space and transition matrix given by $\{e_G, e_B\}$, We assume that before the transmission of a block of M packets that occurs during k^{th} step (or in slot km),

The transmitter knows the realizations of the random variables

$$Ei(k), \text{ for } i=1….M. \quad (4)$$

The dynamic assignment rule works as follows. The transmitter counts the number, referred to as L, of channels whose states at step t+1 are e_G . If L is either zero or

M(i.e., all channels are in a same error state), each packet of the M packets for transmitting at step t+1 is randomly (i.e., with probability) assigned to a channel; otherwise (i.e., L is between 0 and M), the transmitter assigns each of the packets with sequence numbers being the first smallest in the block of packets to a channel, whose state is e_G, and assigns the rest (M-L) packets to the channels with states being e_B .

We let C_o be the packet that has the smallest sequence number in the block of M packets to be received at the end of the slot of observing the resequencing buffer.

If A_0 is true, the resequencing buffer is empty at the observation instant. When A_n is true for n≥1, we denote by nm the slot at whose end C_0 is received for (n-1)st time, and by $B_{r,n}$ the resequencing buffer occupancy. For each, t=0,…n, we define X(t) as the number of packets in the block of M packets received at the end of slot tm that have a sequence number smaller than that for C_0 , and Y(t) as the number of channels whose error processes are in state e_B at step t . X(t) is a {0,1,….M-1}-valued random variable and Y(t) is a {0,1…M} -valued random variable. Furthermore, the process {X(t),Y(t)):t=0,1,…n} is a Markov chain with the state space ϴ=(0,1…M-1},

where

i={(i,0),(i,1),….,(i,M)},i=0,1,….M-1 (5)

is a vector. In the following, we use $\binom{x}{y}$ to represent the binomial coefficient of x choosing y, and

$$\bar{h} = M - h \tag{6}$$

$$\bar{e}_G = 1 - e_G, \tag{7}$$

and.

$$\bar{e}_B = 1 - e_B \tag{9}$$

The transition probability matrix of the Markov chain {(X(t),Y(t)):t=0,1...n} is given by

$$P = \begin{bmatrix} P_{0,0} & O & O & \cdots & O \\ P_{1,0} & P_{1,1} & O & \cdots & O \\ P_{2,0} & P_{2,1} & P_{2,2} & \cdots & O \\ \vdots & \vdots & \vdots & \ddots & O \\ P_{M-1,0} & P_{M-1,1} & P_{M-1,2} & \cdots & P_{M-1,M-1} \end{bmatrix} \tag{10}$$

where 0 represents the zero matrix.

$$P_{(0,h),(0,k)} = \sum_{l=0}^{h} \left(\binom{h}{l} \beta^{l} \bar{\beta}^{h-l} \binom{\bar{h}}{k-l} \bar{\alpha}^{k-l} \alpha^{\bar{h}+l-k} \right) \tag{11}$$

and

$$P_{(i,h),(j,k)} = f(i,j,h) P_{(0,h),(0,k)} \tag{12}$$

for which

$$f(i,j,h) = \begin{cases} \binom{i}{j} e_G^{j} \bar{e}_G^{i-j}, & \text{if } i \le \bar{h} \\ \sum_{l=0}^{j} \binom{\bar{h}}{l} e_G^{l} \bar{e}_G^{\bar{h}-l} \binom{i-\bar{h}}{j-l} e_B^{j-l} \bar{e}_B^{i-\bar{h}+l-j}, & \text{else} \end{cases}$$

for, 0≤h, k≤M, 1≤i≤M-1, and 0≤j≤i. (13)

The process {Y(t): t = 0, 1,...n} is an ergodic Markov chain, whose stationary probability distribution is denoted by

(л=л0,л1,….лM).

Through the sample path argument, the probability generating function GBr(z) of the resequencing buffer occupancy Br is given in the following theorem.

Theorem:

If C_0 has been (incorrectly) received for n times until the observation instant when n≥1, the probability generating function of $B_{r,n}$ is

$$\mathcal{G}_{B_{r,n}}(z) = \frac{1}{\mathbb{P}[A_n]} \sum_{(x_0,y_0)\in\Theta} \cdots \sum_{(x_{n-1},y_{n-1})\in\Theta} \sum_{y_n=0}^{M} \times \prod_{l=0}^{n-1} \mathcal{G}_{B_{r,n}^{(l)}}(z) \times \mathbb{P}[C(n, x_0, y_0, \ldots, x_{n-1}, y_{n-1}, 0, y_n)] \tag{12}$$

where,

$$\mathbb{P}[C(n, x_0, y_0, \ldots, x_{n-1}, y_{n-1}, 0, y_n)] = \left(\prod_{l=0}^{n-1} \delta_l \right) \left(\sum_{y=0}^{M} \pi_y \sum_{x=0}^{x_0} P_{(M,y),(x,y_0)} \right) \times P_{(x_0,y_0),(x_1,y_1)} \cdots P_{(x_{n-1},y_{n-1}),(0,y_n)}$$

in which

$$\delta_l = \begin{cases} e_B, & \text{if } x_l + y_l > M - 1 \\ e_G, & \text{else} \end{cases} \tag{13}$$

Where the event C(n,x0,y0,....xn-1,yn-1,0,yn)is equivalent to the intersection of the following independent events.

$A_n^{(1)}$: at most packets in the packets received in slot (i.e., slot before slot 0) are packets retransmitted in slot 0, which guarantees that is received for the first time in slot 0 with packets having a smaller sequence number.

$A_n^{(2)}$: the path of the Markov chain

$\{(X(t), Y(t))$:t=0,1,…,n}

from step 0 to step n is

$$\{X(0),Y(0))=(x_0,y_0),\ldots,(X(n-1),Y(n-1)) =$$

$$(x_{n-1},y_{n-1}),(X(n),Y(n)) = (0,y_n)\}$$

$A_n^{(s)}$: is received erroneously in slots 0,m,….(n-1)m.

For both packet scheduling policies, the average resequencing queue length grows with the increase of either the number of channels or the average error rate of channels. But, the dynamic scheduling outperforms the static scheduling policy in terms of the average resequencing queue length.

Moreover, as the absolute difference between the two error states becomes larger, the average resequencing queue length E[Br] increases when the static scheduling is applied, while it decreases when the dynamic scheduling is applied.

IV. CONCLUSION AND FUTURE WORK

We conducted performance analysis of the resequencing buffer for SR-ARQ over a generic number of parallel channels with time-varying. We combine the features of both SW ARQ and SR ARQ. With the dynamic assignment rule applied in the protocol. The distribution function of the resequencing delay for the model with time-invariant error rates and the mean resequencing delay for the model with time-varying error rates were also obtained. We discussed the impact of the packet-to-channel assignment rules, the variance in the error states, the average error rate, and the number of parallel channels on the mean resequencing buffer occupancy. For MSR-ARQ over parallel channels with Gilbert–Elliott model, the mean resequencing buffer occupancy increase with the average error rate and the number of parallel channels even though the mean resequencing buffer occupancy decreases with the variance in the error states. Possible future work is to evaluate the performance of ARQ protocols over multiple channels with both different transmission rates and different error rates.

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