Performance Analysis of Channel Error Probability using Markov Model for SCTP Protocol

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***Abstract*—**In this paper, we propose an analysis model for the performance of channel error probability in Stream Control Transmission Protocol (SCTP) using Markov model. In this model it is assumed that the compressor and decompressor work in Unidirectional Mode. And the average throughput of SCTP protocol is obtained by finding the throughputs of when the initial channel state is good or bad.

***Index Terms*—**Channel Error Probability, SCTP, Markov Model.

I. INTRODUCTION

TCP [1] has provided for long time the primary means of reliable data transfer in IP networks. As the number of application increases recently, it is found that the role of TCP is limited and they have incorporated their own reliable data transfer protocol on top of UDP. Such a trend in application directly motivated the development of SCTP.

However, the encapsulation process of SCTP/IP layers produces packets whose payload size, for particular services, is of a little percentage of the whole packet size, but the header sizes are relatively of a large percentage (high overhead services), so that, a significant part of radio channel bandwidth, which is the most expensive and limited resource of the whole wireless system, should be used for header transmission. For these reasons it is of primary importance that the adoption of a header compression scheme can be able to reduce the protocol overhead with the aim to make the economically feasible and physically realizable implementation of such high overhead-services.

The header compression work has been studied from 1984 and several header compression protocols such as Thin-wire I and II, CTCP (Compressed TCP) [3], IPHC (IP Header Compression) [4] and CRTP (Compressed RTP) [5] etc have been proposed. However, none of them can work well over the wireless link due to error propagation. To solve the problem, the header compression working group in IETF proposed a new header compression framework, named as Robust Header compression (ROHC). The most significant feature of the protocol is its robustness. ROHC successfully reduces the error propagation by a special encoding mechanism, known as Windows-based Least Significant Bits (W-LSB) encoding method.

The paper is organized as follows: Following this introduction, we will briefly describe the SCTP and ROHC in section II; and the analysis model is described in section III; the results of performance analysis are presented in section IV. Finally, the conclusion of this paper is discussed in section V.

II. ANALYSIS MODEL

In order to analyze the effect of channel error probability over the throughput of SCTP protocol, the analysis model based on Markov model is developed and it will be discussed in this section.

A. Assumptions

Some assumptions are made in the analysis model as follows:

1) *Mode*
The compressor and decompressor can work in three modes. They are named as unidirectional (U), optimization (O) and reliable (R) mode. In U-mode, the communication between compressor and decompressor is allowed only in one direction. In O- and R-mode, the communication property between compressor and decompressor is bidirectional.
2) In order to simplify the model, we assume that the compressor and decompressor work only in U-mode.
3) *State*
There are 3 states such as initialization and refreshment (IR), first order (FO) and second order (SO) states. It is assumed that the compressor works only in IR and SO states.
4) *Packet types*
Assume that there are only two types of packet in our defined packet stream: IR is for context refreshment and uncompressed header, CH is for the packet with compressed header.
5) *Channel*
Assume the corruptions of packets through the channel are independent of each other. And the parameter for bit error probability through the channel is set to be b_1 or b_2. It is assumed that the

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time is divided into a series of time slots and that the packet data is transmitted in one slot time.

B. Analysis Model

We define a SCTP packet stream as shown in Fig. 1 and there are N packets in the stream including I R and CH packets.

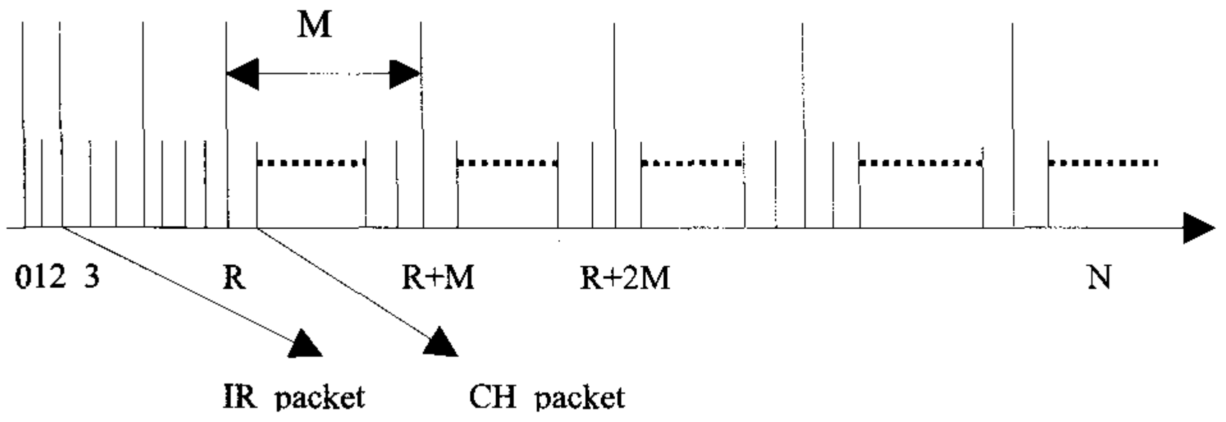

Fig. 1 The SCTP packet stream

As we know, the IR packet is larger than the CH packet because the header of CH packet is compressed but the IR packet is not compressed. So we use the long line to represent the IR packet, and use the short line to represent the CH packet as shown in Fig. 1.

We use a sequence number $\{n_i \mid n_i = 0,1,2,...,N\}$ to index the packets in the stream. And we use ir to index the IR packet, ch to index the CH packet.

The compressor starts to work from IR state, where the context refreshment period is exponentially increased. The output packets are seldom compressed until the sequence number reaches a predefined value, R. Then the compressor changes into the SO state, where the IR packet is transmitted at a fixed interval of M packets. The relation of R and M can be described as

$$R = \lfloor \log_2 M \rfloor \qquad (1)$$

As we know, the packet stream includes two types of packet, IR and CH packets. So we can represent the index of IR packets in IR and SO state.

$$n^{ir} = \begin{cases} 2^{ir} + ir - 1 & \mathit{IR\ state,}\ 0 \le ir < R+1 \\ (ir-R)*M + 2^{R+1} + R - 1 & \mathit{SO\ state,}\ R+1 \le ir < N \end{cases} \qquad (2)$$

For a given compressed packet stream, we use '$p(\ )$' to represent the probability of decompressing a given packet successfully. The successful decompression of a packet depends on two conditions. First, the packet itself should not contain any bit error that causes the decompression failure. We use '$e(\ )$' to represent the probability of fatal bit error (FBE). Second, the context should be valid. We use '$c(\ )$' to represent the possibility that the context is valid on CH packet.

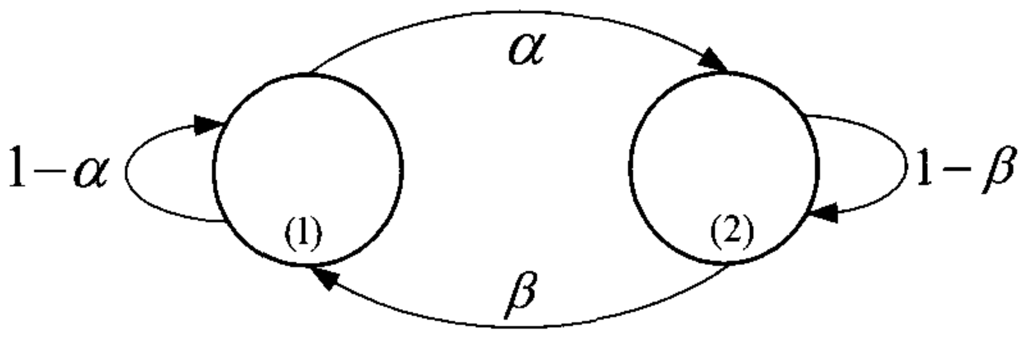

Fig.2 State transition model for channel error probability

Fig.2 is the state transition model for channel error probability. The wireless link used in this analysis is modeled as a two-state Markov process: good and bad states. α is the transition probability from good channel state to bad channel state, while β is the transition probability from bad to good channel state.

1) When Initial State is Good State.

The channel error of each state is considered to be passion distributed with average BER (Bit Error Rate). The BER is given by b_1 when the channel is in good state, and by b_2 when the channel is in bad state $b_1 < b_2$. The transition probabilities between the good and bad states are geometric distributions and are given by the transition matrix as in the following:

$$\begin{vmatrix} P_{11}(k) & P_{12}(k) \\ P_{21}(k) & P_{22}(k) \end{vmatrix} = \begin{vmatrix} 1-\alpha & \alpha \\ \beta & 1-\beta \end{vmatrix}^{k} \qquad (3)$$

where k represents the number of transitions. Through Eq.(2), we can get the position of IR packet in the SCTP packet stream as shown in Table 1:

Table 1 Channel error probability in each position of IR packets on the condition that the initial channel state is good state

number of IR packet	positions of IR packets	Prob(channel is in state 1)	Prob(channel is in state 2)
1	2	$P_{11}(2)$	$P_{12}(2)$
2	5	$P_{11}(5)$	$P_{12}(5)$
3	10	$P_{11}(10)$	$P_{12}(10)$
4	19	$P_{11}(19)$	$P_{12}(19)$
...	...	...	...

As we know, we defined two types of packets in the SCTP packet stream. So, except IR packets, the remaining are CH packets. We can use Table 2 to represent the positions of CH packets in the SCTP packet stream.

Table 2 Channel error probability in each position of CH packets on the condition that initial channel state is good state

number of CH packet	position of CH packet	Prob(channel in state 1)	Prob(channel in state 2)
1	1	$P_{11}(1)$	$P_{12}(1)$
2	3	$P_{11}(3)$	$P_{12}(3)$
3	4	$P_{11}(4)$	$P_{12}(4)$
4	6	$P_{11}(6)$	$P_{12}(6)$
...	...	...	...

We make the assumptions as follows:

①The initially state is good state, which we represent as state 1.

②At the first position of IR packet, the probability to state 1 (good state) or state 2 (bad state) is given by the first row in the matrix below:

$$\begin{vmatrix} P_{11}(1) & P_{12}(1) \\ P_{21}(1) & P_{22}(1) \end{vmatrix} = \begin{vmatrix} 1-\alpha & \alpha \\ \beta & 1-\beta \end{vmatrix} \quad (4)$$

③At the second IR packet position, the probability to stay in state 1 or state 2 is given respectively by the first row in the matrix below:

$$\begin{vmatrix} P_{11}(2) & P_{12}(2) \\ P_{21}(2) & P_{22}(2) \end{vmatrix} = \begin{vmatrix} 1-\alpha & \alpha \\ \beta & 1-\beta \end{vmatrix}^2 = \begin{vmatrix} (1-\alpha)^2+\alpha\beta & \alpha(1-\alpha)+\alpha(1-\beta) \\ \beta(1-\alpha)+\beta(1-\beta) & (1-\beta)^2+\alpha\beta \end{vmatrix} \quad (5)$$

So, we can get the equations for correct decompression probability for IR and CH packets taking the channel error probability into consideration.

For IR packet

IR packet is independent from the context and can be decompressed if no FBE happens. So we can get the probability of decompressing an IR packet successfully through Eq. (6):

$$p(ir) = \begin{pmatrix} P_1(ir) \\ P_2(ir) \end{pmatrix} = \begin{pmatrix} 1-e_1(ir) \\ 1-e_2(ir) \end{pmatrix}. \qquad ir \in \{n_{ir}\} \quad (6)$$

where $e_1(ir)$ and $e_2(ir)$ are the packet error probabilities through the channel. The throughput of IR packets can be calculated as in Eq. (7) and the unit is [packets].

$$T_{ir,g} = \sum_{ir=0}^{N-1} p(ir) = \sum_{ir=o}^{N-1} \{[1-e_1(ir)]P_{11}(ir)+[1-e_2(ir)]P_{12}(ir)\}.$$
$$ir = 2,5,10,19....(7)$$

In the equation above, $T_{ir,g}$ represents the throughput of IR packet when the initial state is good state. $P_{11}(ir)$ represents the probability of state changes for IR packet from good to good state after ir times of transition. $P_{12}(ir)$ represents the probability that the system changes from good to bad state after ir times of transition.

For CH packet

The probability of correct decompression, *p*, depends not only on FBE, but also on its context. So the probability p of CH packet can be calculated as:

$p(ch)=p(i^{th}$ *packet is not corrupted*$)*p($*context is valid*$)$

And we can get the equation as in Eq. (8).

$$p(ch) = \begin{pmatrix} P_1(ch) \\ P_2(ch) \end{pmatrix} = \begin{pmatrix} 1-e_1(ch) \\ 1-e_2(ch) \end{pmatrix} .c(ch) \qquad ch \in \{n_{ch}\} \quad (8)$$

where $e(ch)$ is the error probability during the transmission. The throughput of CH packets when the initial channel state is bad state can be calculated as in Eq. (9) and the unit is [packets].

$$T_{ch,g} = \sum_{ch=0}^{N-1} p(ch) = \sum_{ch=o}^{N-1} \{[1-e_1(ch)]P_{11}(ch)+[1-e_2(ch)]P_{12}(ch)\}c(ch).$$
$$ch = 1,3,4,6,7,8,9....(9)$$

where the probability that the context is valid, $c(ch)$, can be calculated as follows [12]:

$$c(ch) = 1 - \prod_{h\in\left\{n_k^{o,ch-1}\right\}} e(h) - \sum_{j=o}^{ch-w-1} \left(p(j) * \prod_{m=j+1}^{j+w} e(m) \right) (10)$$

2) When Initial State is Bad State.

If the initial channel is in bad state or state 2, we can get the equations for throughput, T_{ir} and T_{ch}, as follows:

$$T_{ir,b} = \sum_{ir=0}^{N-1} p(ir) = \sum_{ir=o}^{N-1} \{[1-e_1(ir)]P_{21}(ir)+[1-e_2(ir)]P_{22}(ir)\}.$$
$$ir = 2,5,10,19.... \text{ ,}(11)$$

where $T_{ir,b}$ represents the throughput of IR packet when the initial channel state is bad state. $P_{21}(ir)$ represents the probability that the channel changes from bad state to good state after ir times of transitions. $P_{22}(ir)$ represents the probability that the channel goes from bad state to bad state after ir times of transitions. Likewise, the throughput of CH packet when the initial channel state is bad state is given by

$$T_{ch,b} = \sum_{ch=0}^{N-1} p(ch) = \sum_{ch=o}^{N-1} \{[1-e_1(ch)]P_{21}(ch)+[1-e_2(ch)]P_{22}(ch)\}c(ch).$$
$$ch = 1,3,4,6,7,8,9....(12)$$

As we mentioned previously, the channel error probability of each state is considered to be Bernoulli distributed with average BER (Bit Error Rate). So the FEP (Frame Error Probability) can be calculated in two cases.

Case 1: FEP in good channel state is given by

$$\begin{aligned} e_1(ir) &= 1-(1-b_1)^{(L_{ir}+L_p+L_{link})} \\ e_1(ch) &= 1-(1-b_1)^{(L_{ch}+L_p+L_{link})} \end{aligned} \tag{13}$$

where b_1 is the BER, L_p is the data length, L_{ir} is length of the uncompressed header, L_{ch} is length of the compressed header and L_{link} is length of the link layer header.

Case 2: FEP in bad channel state is given by

$$\begin{aligned} e_2(ir) &= 1-(1-b_2)^{(L_{ir}+L_p+L_{link})} \\ e_2(ch) &= 1-(1-b_2)^{(L_{ch}+L_p+L_{link})} \end{aligned} \tag{14}$$

where b_2 is BER and the others are already defined above.

3) The Average Throughput of SCTP Packet Stream

We define a parameter, T_{avg}, to represent the average throughput of SCTP packet stream. The value of T_{avg} then can be obtained as follows:

T_{avg} =(The *Probability that Initial state is Good State*) □$(T_{ir,g}+T_{ch,g})$+ (The *Probability that Initial state is Bad State*)□$(T_{ir,b}+T_{ch,b})$

$$= \frac{\beta}{\alpha+\beta}\left(T_{ir,g}+T_{ch,g}\right)+\frac{\alpha}{\alpha+\beta}\left(T_{ir,b}+T_{ch,b}\right)$$

III. PERFORMANCE ANALYSIS

In this section, we present some performance results based on the analytical model 2 specified by equation (1) to (15). And the performance results will be divided into two parts: First, we analyze the throughput of IR packet under different average bit error rates which is introduced when we consider the channel to be of a Markov Process. Then we describe the throughput of CH packet under different bit error rate taking the channel state into consideration

A. Throughput of IR packet

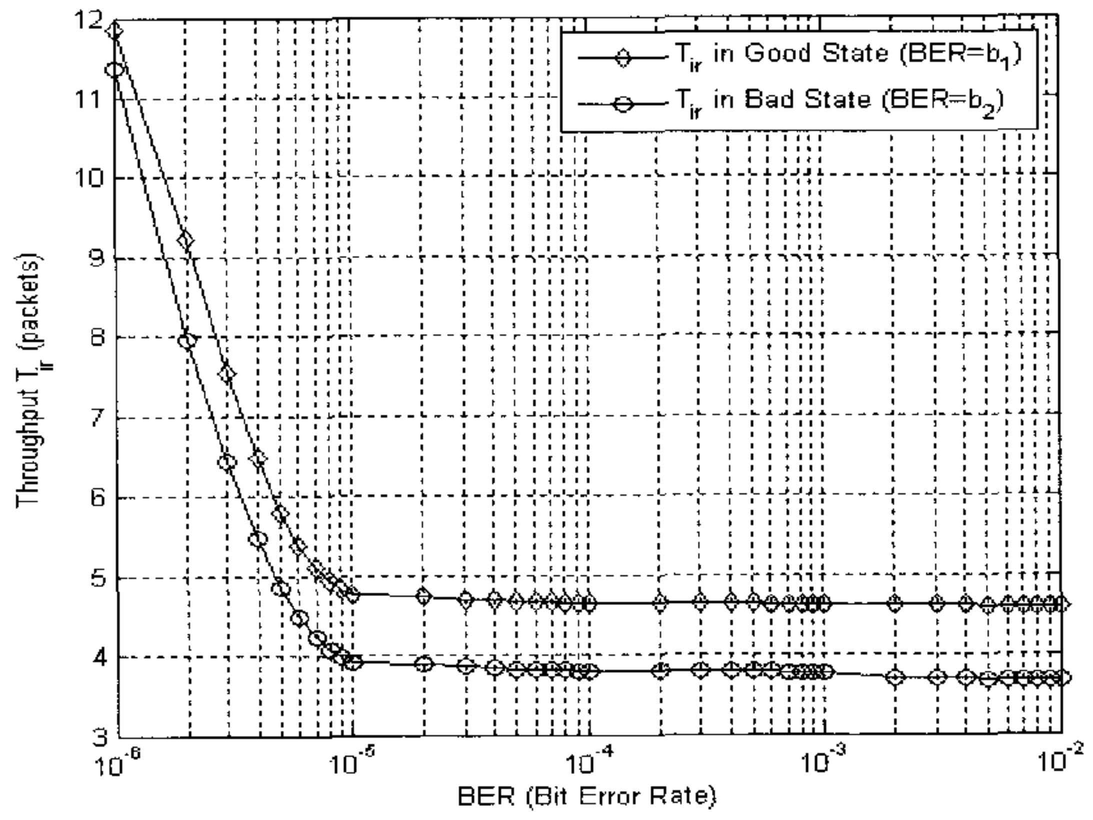

Fig.3 Throughput of IR packet as a function of BER as a parameter

We can calculate the result from equations (1) to (14) as shown in Fig. 3. In equation (7), we set the value of N as 1000. $P_{11}(ir)$, $P_{12}(ir)$, $P_{21}(ir)$, $P_{22}(ir)$ can be calculated from equation (3). For example, from equation (5), we can have

$$\begin{aligned} P_{11}(ir) &= P_{11}(2) = (1-\alpha)^2+\alpha\beta, \\ P_{12}(ir) &= P_{12}(2) = \alpha(1-\alpha)+\alpha(1-\beta), \\ P_{21}(ir) &= P_{21}(2) = \beta(1-\alpha)+\beta(1-\beta), \\ P_{22}(ir) &= P_{22}(2) = (1-\beta)^2+\alpha\beta \end{aligned}$$

when $ir=2$, which are presented in equation (7). In equation (11), we assume $\alpha=0.95$, $\beta=0.8$. Then $e_1(ir)$, $e_2(ir)$ can be calculated from equation (13) and (14). Where, we set $b_2=100b_1$, and the BER in good state, b_1, is changing over 10^{-6} to 10^{-4}, $b_1\in\left[10^{-6},10^{-4}\right]$, $b_2\in\left[10^{-4},10^{-2}\right]$. For example, when b_1 is given by $b_1=10^{-6}$, then b_2 is given by $b_2=10^{-4}$. The parameters such as L_{ir} and L_p are given by $L_{ir}=18$, $L_p=20$. It is assumed that PPP protocol is used in link layer, thus L_{link} is set to be $L_{link}=7$.

Fig. 3 shows the throughput of IR packet with channel state comparison. It is obvious that the throughput in good state is better than which in bad state. And the throughput decreases as the BER increasing. In this case, the throughput is affected from channel state. Both good channel state and bad channel state will reduce the throughput. However, the bad channel state will reduce the throughput more as Fig. 3 shows.

B. Throughput of CH packet

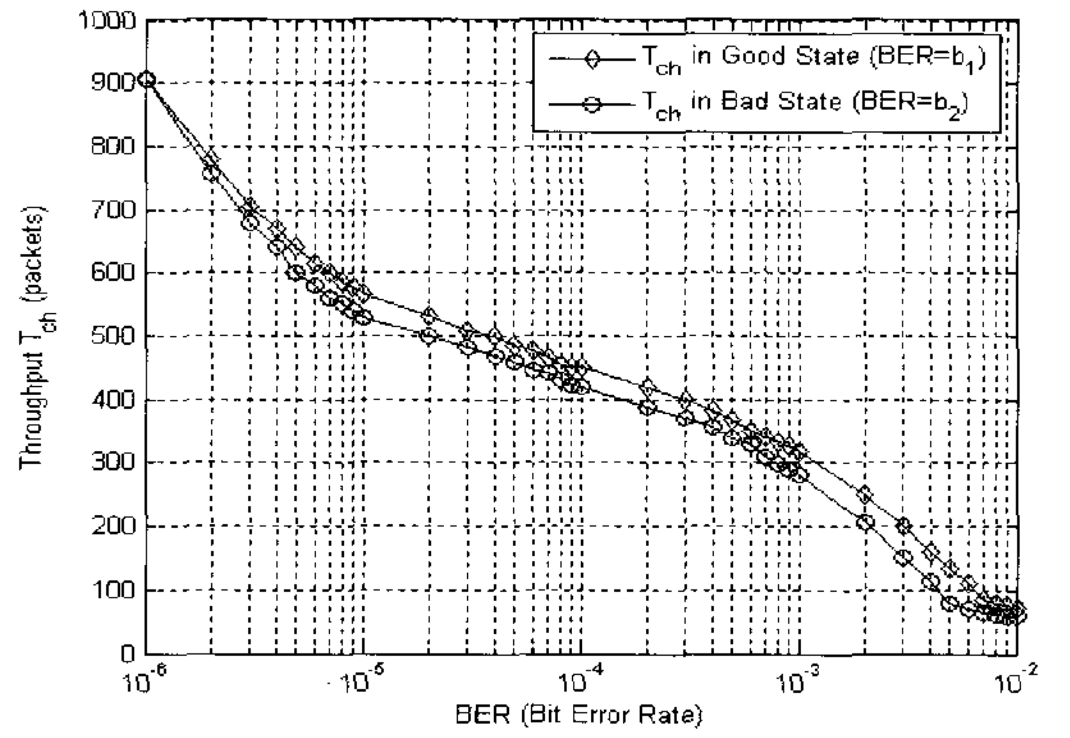

Fig.4 Throughput of CH packet as a function of BER with initial channel state as a parameter

The step of calculating the result shown in Fig.4 is similar to that mentioned above. In equations (9) and (12), $P_{11}(ch)$, $P_{12}(ch)$, $P_{21}(ch)$, and $P_{22}(ch)$ can be calculated from equation (3). For example, when $ch=1$, $P_{11}(ch)=P_{11}(1)=(1-\alpha)$, $P_{12}(ch)=P_{12}(1)=\alpha$, $P_{21}(ch)=P_{21}(1)=\beta$, $P_{22}(ch)=P_{22}(1)=1-\beta$ which are presented in equation (4). $e_1(ch)$, $e_2(ch)$ can also be calculated from equations (13) and (14) respectively. In equation (13) and (14), the parameter of header length for header compression is given by $L_{ch}=2$.

Fig.4 shows the throughput of CH packet with channel state as a parameter. The characteristic is similar to that of IR packet. The throughput from good channel state is better than that from bad channel state.

C. The Average Throughput of SCTP Packet Stream

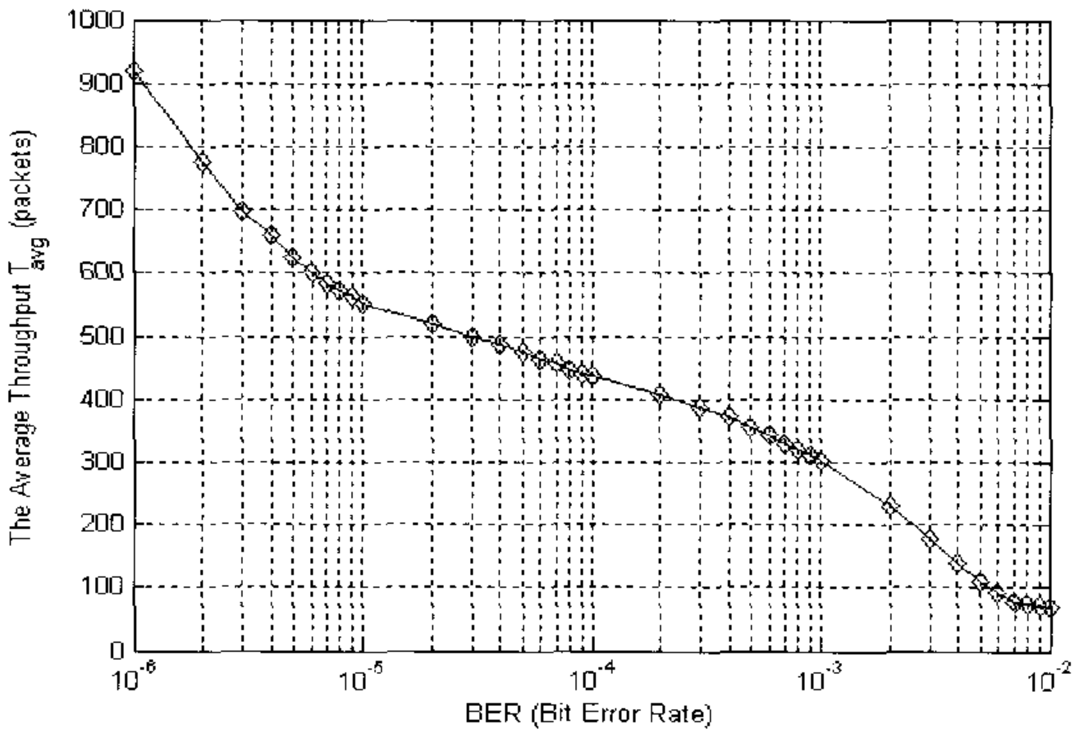

Fig.5 The average throughput of SCTP packet stream as a function of BER b_l for good channel

The numerical results in Fig. 5 can be obtained from Eq. (15). It shows the average throughput of total packets (including IR packet and CH packet) as a function of BER b_1 in good channel state. The throughput decreases as the BER b_1 increases. Note that the throughput decreases very rapidly over the two ranges, i.e. when the BER is less than 10^{-6} and larger than 10^{-3}. When the BER is over 10^{-6} to 10^{-3}, however, the throughput decreases slowly.

IV. CONCLUSIONS

In this paper, we proposed an analysis model for the performance of channel error probability in Stream Control Transmission Protocol (SCTP) using Markov model. In this model it is assumed that the compressor and decompressor work in Unidirectional Mode.

We analyzed the impact of channel state on throughput. It has been proved that ROHC method is also suitable for SCTP. We can use ROHC to reduce most of the SCTP header size, and to improve the throughput using W-LSB encoding method.

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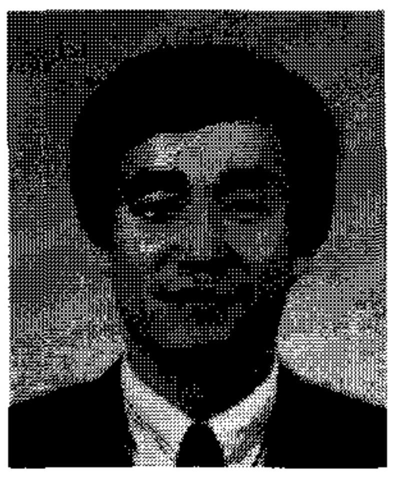

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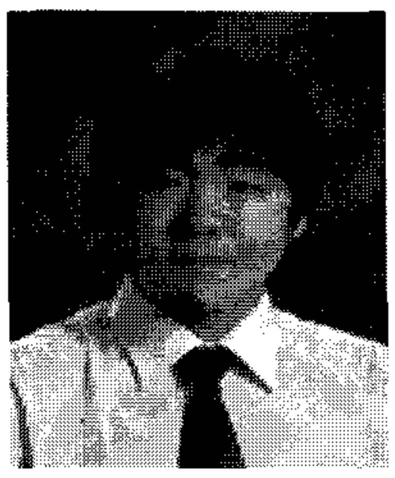

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