ERROR CONTROL STRATEGIES FOR CUT-THROUGH SWITCHING NETWORK

Indexing terms: Optical switching, Errors

Error control strategies for cut-through switching networks are studied. It seems unnecessary to have link control functions at every node in the network because of the wide deployment of an optical transmission system which has qualities of high speed and low bit error rate. Error control performed only at the destination node (ECDN) is proposed. It will compare with error control performed at every node (ECEN) from the viewpoint of transfer delay. It is shown through numerical example that the ECDN performs better than the ECEN if the increment of traffic intensity caused by the error control functions performed at every node is significant. A simulation is also provided to support the validity of the analysis.

Introduction: The cut-through switching technique can reduce the end-to-end network transfer delay required for conventional packet switching techniques. If it were applied in packet-switched integrated services digital networks, it would be more satisfactory to those services which need real-time delivery, such as voice and video.

The cut-through switching technique has been proposed for some years.[1-4] The virtual (or full) cut-through switching was proposed by Kermani and Kleinrock.[1] Another cut-through switching, called quasi cut-through switching, was studied by Ilyas and Mouftah.[2] A general cut-through switching was proposed by Abo-Taleb and Mouftah.[4] Under this general cut-through switching, a packet can cut through a node as long as the selected outgoing channel becomes idle before it is received completely regardless of the number of packets before it. Intuitively, the general cut-through switching can reduce more end-to-end transfer delay than any other cut-through switching.

This switching will have widespread use in high speed and low bit error rate optical transmission systems in network. This will result in the functions of communication protocol adopted in the network being changed accordingly; and the function of layer-two protocol is the first that should be considered.

In Reference 3, the transfer delay of quasi cut-through switching network was analysed by Shin and Un under two error checking schemes: error checking performed at every node and error checking performed at a store-and-forward node. As previously mentioned, because the wide deployment of optical transmission systems, it seems unnecessary to perform error control functions at every node in the network. Thus the error control performed only at the destination node (ECDN) is proposed and a comparison with the error control performed at every node (ECEN) will be considered in this letter. The result shows that the two error control strategies have almost the same transfer delay if the bit error rate of the channel in the network is small. If the increment of overhead caused by the error functions perfomed at every node increases relative to the effective traffic intensity and is significant, the ECDN will perform better than the ECEN.

Performance analysis: An n-node tandem network with a noisy channel, shown in Fig. 1, is considered in this letter. It is a general cut-through switching network that adopts ECDN or ECEN strategy. Before the analysis, the following assumptions are made: (a) the arrival process for every node is Poisson, (b) the service time distribution of packet is general, (c) the buffer in each node is infinite, (d) the service discipline of the network is first-come–first-serve (FCFS), (e) the network is homogeneously loaded, (f) the channels are noisy, and (g) the effective arrival of a packet is defined as whenever the header of the packet is received and the destination is recognised, (h) each node in the network will send an ACK to acknowledge a successful transmission or an NAK to request a retransmission. Hence, each node can be assumed to be a M/G/1 model.

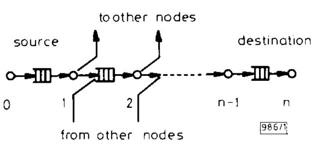

Fig. 1 *n-node tandem network*

We denote e as the bit error rate in all channels, C as the channel capacity, X as the mean packet service time, X_h as the service time of packet header, P_e as the error probability of a packet, P_{fc} and P_{gc} as the probabilities that a packet will make a full-cut and a general-cut through a node, respectively, W_c and W_{nc} as the average waiting times given that the packet can cut and cannot cut through a node, respectively. Then we have

$$P_e = 1 - (1 - e)^{cx} \tag{1a}$$

$$P_{fc} = W_q(0) \tag{1b}$$

$$P_{gc} = W_q(X - X_h) \tag{1c}$$

$$W_c = \int_0^{X - X_h} t \, dW_q(t) \,.\, [W_q(X - X_h)]^{-1} \tag{1d}$$

$$W_{nc} = \int_{X - X_h}^{\infty} t \, dW_q(t) \,.\, [1 - W_q(X - X_h)]^{-1} \tag{1e}$$

where $W_q(t)$ is the waiting time distribution of packet for the M/G/1 model.[5] In the following, the transfer delays for both strategies will be derived.

ECDN strategy: The probability that a packet is received correctly at the destination node can be expressed as $P_c = (1 - P_e)^n$. The average number of hops traversed by the packet as it successfully arrives at the destination is $N_d(n) = n/P_c$. The effective traffic intensity ρ'_d can thus be obtained by $\rho'_d = \rho[N_d(n)/n] = \rho/P_c$, where ρ is the actual traffic intensity. The ρ'_d is greater than ρ for the retransmissions of erroneous packets in the network. Notice that $W_q(t)$ is a function of the effective traffic intensity. P_{fc}, P_{gc}, W_c and W_{nc} will be altered accordingly.

Define the transfer delay of a packet as the time spent when it starts to leave from source node until it has been received correctly at destination node. In error free channels, the transfer delay through n nodes, denoted by $T_f(n)$, can be expressed as

$$T_f(n) = (n - 1)[\tau + P_{gc}(X_h + W_c) + (1 - P_{gc})(X_h + W_{nc})] + X + \tau \tag{2}$$

where τ is the propagation delay per hop. In a noisy network, we can obtain the transfer delay, denoted by $T_d(n)$, as

$$T_d(n) = \frac{T_f(n)}{P_c} + \frac{1 - P_c}{P_c} \times [n(\tau + T_a) + (n - 1)W_r + 2W_R] \tag{3}$$

where the T_a is the transmission time of a NAK at each node as it is sent from destination node to source node, W_r is the mean delay time at each of the $(n - 1)$ intermediate nodes from receiving the NAK to repeating it to the previous node, and W_R is the mean response time that the destination node takes to start sending an NAK after receiving an erroneous packet or the source node takes to start a retransmission after receiving a NAK.

ECEN strategy: The average number of nodes visited by a packet can be given as[3]

$$N_e(n) = n + \frac{P_e}{1 - P_e}\left[\frac{n}{1 - P_{gc}} - \frac{P_{gc} - P_{gc}^{n+1}}{(1 - P_{gc})^2}\right] \tag{4}$$

Thus the effective traffic intensity is $\rho'_e = \rho[N_e(n)/n]$. If the workload of layer two functions indirectly increases the effective traffic intensity, the effective traffic intensity will turn to be $\rho''_e = \rho'_e(1 + r)$, where r is the increment ratio.

Denote the transfer delay in this case as $T_e(n)$. The $T_e(n)$ can be obtained from $T_e(n, k)$ which is defined as the transfer delay of a packet which is initially sent from the kth node to its successful reception at the destination node. Clearly, $T_e(n) = T_e(n, 0)$. The $T_e(n, k)$ can be obtained as

$$T_e(n, k) = P_e[X + 2\tau + T_a + 2W_R + T_e(n, k)] + (1 - P_e)[\tau + P_{gc}(X_h + W_c) + (1 - P_{gc})(X_h + W_{nc}) + T_e(n, k+1)] \qquad 0 \le k \le n-2 \quad (5a)$$

$$T_e(n, k) = P_e[X + 2\tau + T_a + 2W_R + T_e(n, k)] + (1 - P_e)[\tau + X] \qquad k = n-1 \quad (5b)$$

Using iterative manipulation

$$T_e(n) = \frac{nP_e}{1 - P_e}(X + 2\tau + T_a + 2W_R) + T_f(n) \qquad (6)$$

Numerical examples: In the following numerical example, the M/M/1 model is considered. Parameters used in this example are assumed as follows: $C = 64$ Kbit/s $X = 40$ ms, $X_h = 1$ ms, $n = 7$, $W_r = 1$ ms, $T_a = 1$ ms, $\tau = 25\,\mu$s, $W_R = 2$ ms, and $e = 10^{-7}$.

Fig. 2 shows the transfer delay against the actual traffic intensity ρ if $r = 0$. The transfer delay of the ECDN strategy is almost the same as that of the ECEN strategy. Although a packet can start retransmission earlier in the latter strategy than in the former one if it is ruined during transmission from source to destination, the probability is too small to count.

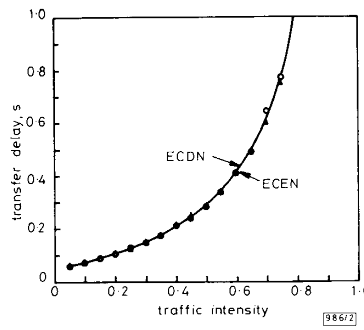

Fig. 2 *Transfer delay against actual traffic intensity*
$r = 0$
○ simulation for ECDN
▲ simulation for ECEN

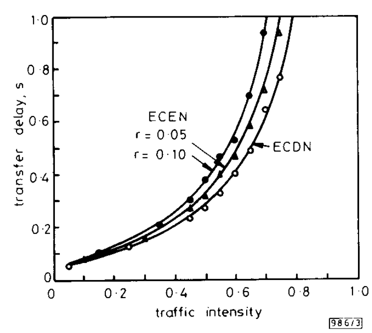

Fig. 3 *Transfer delay against actual traffic intensity*
$r \neq 0$
○ simulation for ECDN
△ simulation for ECEN; $r = 0.05$
● simulation for ECEN; $r = 0.10$

Fig. 3 shows the transfer delay when the increment ratio of traffic intensity r equals to 0·05 and 0·10. In this Figure, the ECDN strategy has less transfer delay than ECEN strategy in any value of actual traffic intensity. The agreement between the analysis and simulation is generally good. This helps verify the validity of our analysis.

Conclusions: It seems unnecessary to perform error control functions at every node because of the high speed and low bit error rate qualities of optical transmission system. The error control performed only at destination node (ECDN) strategy for an n-node tandem, cut-through switching network is proposed. The numerical example shows that the ECDN has almost the same transfer delay as the ECEN when the bit error rate is less than 10^{-7} and the indirect increment of traffic intensity caused by the extra error control functions in ECEN does not count. When this increment becomes significant, the ECDN will have less transfer delay than the ECEN.

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40 Gbit/s OPTIAL TIME-DIVISION CELL MULTIPLEXER FOR A PHOTONIC ATM SWITCH

Indexing terms: Optical switching, Multiplexers and multiplexing

A novel cell multiplexer for generating time-multiplexed ultrafast optical cells for the photonic ATM cell switch is presented. This multiplexer mainly consists of speed convertors which can compress the intervals of ultrashort optical pulses according to the binary multiplicative principle and make ultrafast optical cells of any length with minimal hardware. Generation of a four-bit 40 Gbit/s optical cell by the speed convertor is demonstrated.

Introduction: A high-speed optical cell switch for the photonic ATM (asynchronous transfer mode) system is considered to be a key technology for the future large-capacity communication systems. The optical cell switches proposed thus far include a wavelength-division cell switch[1] and a time-division cell switch.[2] The time-division switch needs minimal optical components such as switches and couplers to route the cells without contention. The wavelength-division switch requires sensitive wavelength tuners and complicated electrical controllers for the same task. Thus the time-division switch seems to be more promising.