IEICE TRANS. COMMUN., VOL. E80–B, NO. 12 DECEMBER 1997

LETTER

Hybrid Dilated Banyan Network with Bypasses at the Stage of 4×2 Re-Arrangeable Output Switch

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SUMMARY Many switching networks are currently designed to support ATM architectures. In this letter, we propose the performance improvement of a network called hybrid dilated banyan network with bypasses at the stage of 4×2 re-arrangeable output switch. Our letter also includes the performance analysis of the improved hybrid dilated banyan network.

key words: *ATM, switching elements, input rate, output rate*

1. Introduction

Banyan networks are self-routing networks [1] which are used in multiprocessor computer applications for ATM switching [2]. A hybrid dilated banyan network [3] is a kind of banyan networks which can remove blocking in first n-stages. The hybrid dilated banyan network is constructed with 2×4 re-arrangeable input switches in the first stage, the 2-dilated banyan networks of first n-stages, 4×2 re-arrangeable output switches and the ordinary banyan network. At the stage of 4×2 re-arrangeable output switch, only one request can select a particular output port and is forwarded to a single output link. When more than one request arrive at the same time and select the same output port, link debation will be occurred. One request per link can be forwarded. At most the number of links, which has the same number as that of the requested output ports, can be randomly selected at most and the requests will be forwarded. The others will be blocked and discarded. Therefore, we add additional links to forward the blocked requests to the upper switching element. These links are called bypasses [4]. In this letter, we propose the improvement of hybrid dilated banyan network using bypasses at the stage of 4×2 re-arrangeable output switch and analyse the performance of the improved network.

2. Using Bypasses

The output rate of a hybrid dilated banyan network suddenly decreases when the 4×2 re-arrangeable output switches are used. To improve the output rate of the network, we use the bypass links into the 4×2 re-arrangeable output switches as shown in Fig. 1.

Two bypasses are put between switching elements in the same stage, namely the upper and lower switching elements. Under the condition of all bypasses connecting switching elements, the requests are assumed to be correctly forwarded to the requested output ports. When the requests arrive at the 4×2 re-arrangeable lower output switch at the same time and select the same output port, one request is randomly selected and is forwarded to the lower switching element, the others (not more than two) are forwarded through the two bypasses to the upper switching element. In this way, the output rate at the lower switching elements is not different from the former but the output rate at the upper switching elements is increased because the arriving requests are increased. Therefore, the overall performance of hybrid dilated banyan network is increased. A sample of hybrid dilated banyan network including two bypasses at the stage of 4×2 re-arrangeable output switch is shown in Fig. 2.

3. Analysis of Input Rate and Output Rate in the Cases of One and Two Bypasses

We consider the proposed network under the following assumptions: 1) Every processor in this network gener-

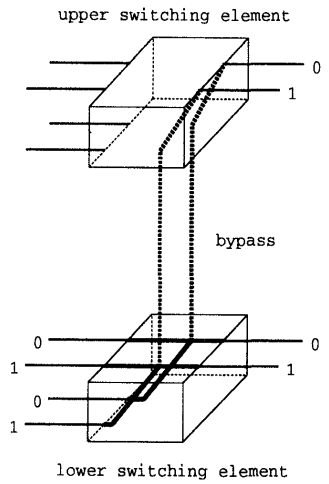

Fig. 1 4×2 re-arrangeable upper switch and lower output switch with two bypasses.

Manuscript received June 27, 1997.
Manuscript revised September 9, 1997.

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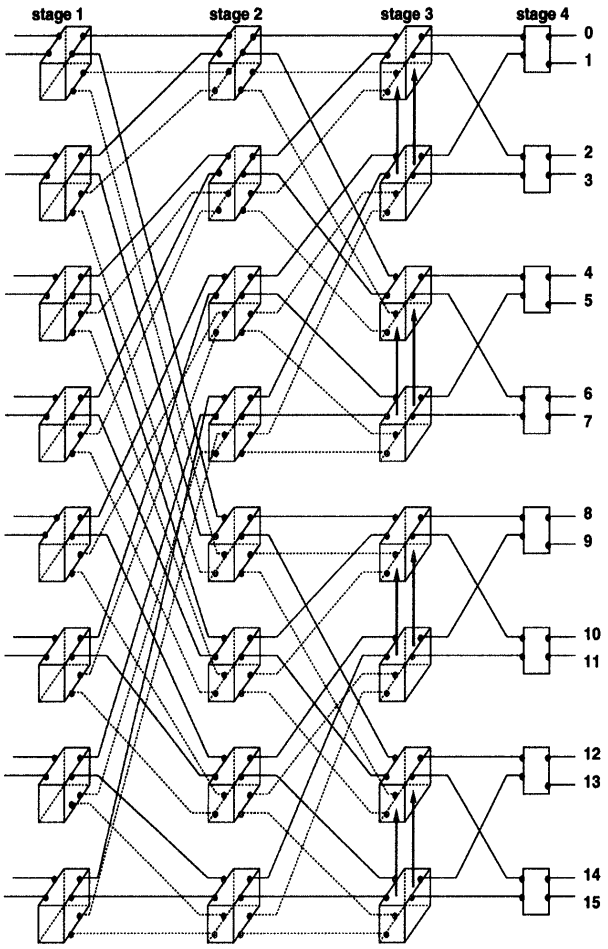

Fig. 2 16 × 16 hybrid dilated banyan network including two bypasses at the stage of 4 × 2 re-arrangeable switch.

ates random and independent requests. 2) At the beginning of each time cycle, each processor generates a new request with some probability of input rate to the next processor. 3) The blocked requests are neglected. Then, the requests issued at the next cycle are independent of the former ones. 4) The requests that are forwarded through the bypass are independent of the former ones and may have link debation at the next time cycle. 5) The input rate and output rate before the stage of 4×2 re-arrangeable output switch are used based on the results [3] because the proposed network of first n-stages has the same switching structure as that of hybrid dilated banyan network.

Based on the previous condition, the output rate at the stage of 4×2 re-arrangeable output switch is analyzed for two cases.

1. If the output ports are in the lower 4×2 re-arrangeable output switch, the output rate of this switch can be calculated to be,

$$p_{out} = 2p_{in} - \frac{3}{2}p_{in}^2 + \frac{1}{2}p_{in}^3 - \frac{1}{16}p_{in}^4 \qquad (1)$$

where p_{in} is the input rate at the input port of switching element and p_{out} is the output rate at the output port of switching element.

2. If the output ports are in the upper 4×2 re-arrangeable output switch and only one bypass is used, the output rate can be described by the following equation,

$$p_{out} = 2p_{in} - \frac{7}{2}p_{in}^3 + \frac{67}{16}p_{in}^4 - \frac{9}{4}p_{in}^5 + \frac{19}{32}p_{in}^6 - \frac{1}{16}p_{in}^7 \qquad (2)$$

and if two bypasses are used, the output rate is given by,

$$p_{out} = 2p_{in} - 3p_{in}^3 + \frac{21}{8}p_{in}^4 - \frac{21}{16}p_{in}^6 + \frac{15}{16}p_{in}^7 - \frac{81}{256}p_{in}^8 + \frac{7}{128}p_{in}^9 - \frac{1}{256}p_{in}^{10} \qquad (3)$$

where p_{in} is the input rate at the input port of switching element and p_{out} is the output rate at the output port of switching element (according to the above assumption that p_{in} of upper output switches are equal to the lower output switches).

Applying all of the above equations, the output rate at the output port of 4×2 re-arrangeable output switch can be calculated. There are two flows of the output rate, one comes from the lower output switching element (p_{low}) and the other comes from the upper output switching element (p_{up}). When 4×2 re-arrangeable output switches are connected with the ordinary banyan switches at the last stage of hybrid dilated banyan network, the output rate (p_{low}) and (p_{up}) can be used. Therefore, the output rate of the hybrid dilated banyan network can be calculated by using the following equation,

$$p_{out} = \frac{1}{2}p_{low} + \frac{1}{2}p_{up} - \frac{1}{4}p_{low}p_{up}, \qquad (4)$$

where p_{out} is the output rate of the hybrid dilated banyan network.

Using the equations presented above and the equations from the paper [3], the comparisons among three types of hybrid dilated banyan network: hybrid dilated banyan network without bypass, hybrid dilated banyan network with a bypass at the stage of 4×2 re-arrangeable output switch and hybrid dilated banyan network with two bypasses at the stage of 4×2 re-arrangeable output switch, are shown for the arrival rate (input rate) of 1.0 in Fig. 3. The x axis shows the number of the stages and the y axis denotes the output rate.

- 3 shows the output rate of a network connected with 2×4 re-arrangeable input switches at the first stage, the 4×2 re-arrangeable output switches at the second stage and the ordinary banyan switches at the third stage.
- 3-1 shows the output rate of a network connected with 2×4 re-arrangeable input switches at the

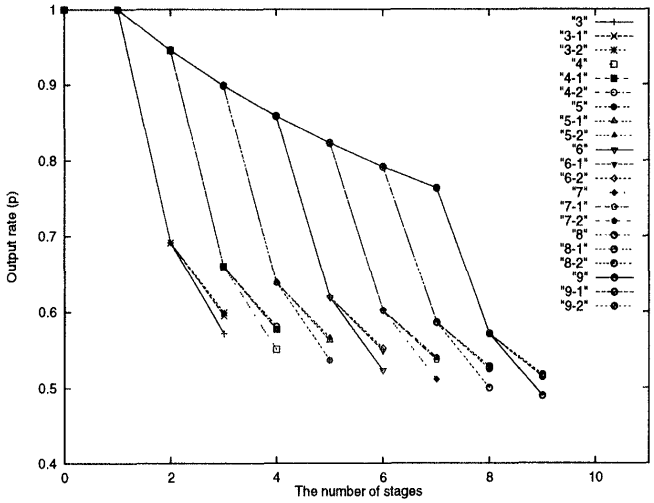

Fig. 3 Comparison of output rate for various hybrid dilated banyan networks depending on whether bypasses are used or not.

first stage, the 4×2 re-arrangeable output switches with a bypass at the second stage and the ordinary banyan switches at the third stage.

- 3-2 shows the output rate of a network connected with 2×4 re-arrangeable input switches at the first stage, the 4×2 re-arrangeable output switches with two bypasses at the second stage and the ordinary banyan switches at the third stage.
- 4–9 show the output rate of a hybrid dilated banyan network with 2×4 re-arrangeable input switches at the first stage, the 2-dilated banyan networks, the 4×2 re-arrangeable output switches at the stage before the last stage and the ordinary banyan switches at the last stage of the network.
- 4-1–9-1 show the output rate of a hybrid dilated banyan network with 2×4 re-arrangeable input switches at the first stage, the 2-dilated banyan networks, the 4×2 re-arrangeable output switches with a bypass at the stage before the last stage and the ordinary banyan switches at the last stage of the network.
- 4-2–9-2 show the output rate of a hybrid dilated banyan network with 2×4 re-arrangeable input switches at the first stage, the 2-dilated banyan networks, the 4×2 re-arrangeable output switches with two bypass at the stage before the last stage and the ordinary banyan switches at the last stage of the network.

From Fig. 3, the comparisons can be mentioned as follows.

- A hybrid dilated banyan network which the bypass is used at the stage of 4×2 re-arrangeable output switches has a higher output rate than a hybrid dilated banyan network where the bypass is not used. The output rate of networks with bypass facility is approximately 5 percent higher than the output rate of networks with no bypass. The throughput 0.5 is improved to 0.525 at the 9 stage case. The maximum ATM transfer speed defined by ATM-Forum is 622 Mbps. Since a cell has header information (5 bytes) and payload (48 bytes), which is total 424 bits, this transfer speed is equal to 1.46 Mcells/s. Therefore, 5 percent performance improvement corresponds to 0.0365 Mcells/s. This means more 9.35 MPEG1 (1.5 Mbps) channels or 3.5 MPEG2 (NTSC, 4 Mbps) channels is improved than the hybrid dilated banyan network without bypasses.
- Comparing the performance of a bypass and two bypasses at the stage of 4×2 re-arrangeable output switches, the one bypass networks almost have the same output rate as the two bypasses networks. Thus one bypass network has a better cost-performance than two bypasses network if the connecting cost per bypass is the same.

4. Conclusion

We have improved the performance of the hybrid dilated banyan networks by adding the bypasses in the stage of 4×2 re-arrangeable output switch. And we have compared the performance of one bypass and two bypasses at the stage of 4×2 re-arrangeable output switch. The results are useful in designing networks without blocking.

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