Irregular Augmented Four Tree Network

[1]Dr.Harsh Sadawarti, [2]Pawandeep Kaur, [3]Kanwarpreet Kaur
[1,2,3] Computer Science Dept., RIMT-IET, Mandi Gobindgarh, Punjab, INDIA

Abstract
Parallel processing is an efficient form of information processing system, which emphasizes the exploitation of concurrent events in the computing process. To achieve parallel processing it's required to develop more capable and cost-effective systems. In order to operate more efficiently a network is required to handle large amount of traffic. Multi-stage Interconnection Network plays a vital role on the performance of these multiprocessor systems. In this paper an attempt has been made to analyze the characteristics of a new class of irregular fault-tolerant multistage interconnection network named as irregular augmented four tree network (IAFT). Performance measures show that IAFT achieve a significant improvement over other popular existing irregular MINs like FT and NFT.

Keywords
Interconnection networks; Multistage Interconnection Network; Four Tree Network ;New Four Tree Network; Permutation Passable.

I. Introduction
With the present state of technology building multiprocessor system with hundreds of processors is feasible. A vital component of these systems is the interconnection network (IN) that enables the processors to communicate among themselves or with the memory units. Multipath nature of multistage interconnection networks become more popular. A multistage Interconnection network is capable of connecting an arbitrary input terminal to an arbitrary output terminal [6]. Many ways of providing fault-tolerance to multistage interconnection networks (MINs) have been proposed. The basic idea for fault-tolerance is to provide multiple paths between source-destination pair so that alternate paths can been used in case of faults. Sufficient work has been done on the regular type of MINs, but little attention has been paid to the irregular type of MIN.

In this paper, a new class of irregular fault-tolerant multistage interconnection network named as Irregular Augmented Four Tree network (IAFT) is proposed. The paper is organized as follows: Section II describes the construction procedure of FT network. Construction procedure of New Four Tree Network is describes in Section III. Section IV describes the construction procedure of IAFT network. Section V describes the Redundancy Graph of IAFT Network. Section VI describes the analysis of permutation passable of existing and proposed networks. The cost effectiveness of IAFT network is analyzed in Section VII. Finally conclusions are given in Section VIII.

II FT Network
The FT network [5] of size 2^n X2^n contains two identical groups G0 and G1 each consisting of a MDOT network of size 2^{n-1} X 2^{n-1} ,which are organized one above the other. The two groups are formed based on the most significant bit (MSB) of the source-destination terminals. Thus, half of the source destination terminals with MSB 0 fall into group G0 and others having MSB 1 fall into the group G1.The FT network of size 2^n X 2^n has (2m-1) stages and total of (2^{m+2} -6) switches with 2^{n-1} of size 2X2 and rest of size 3X3. There are 2^n multiplexers and an equal no of demultiplexers of 2X1 and 1X2 sizes respectively. Both the stages i and 2m-i in the group have 2^{n-i-1} switches and are numbered as 1,2…..2n-i-1 (where i = 1,2…,m , m = log2 N/2 and N = 2^n). Every 3X3 SE in a stage forms a loop with the corresponding numbered 3X3 SE of other sub –network in the same stage. Every source and destination is connected to both the subgroups by means of multiplexers and demultiplexers. In case the primary path is busy or faulty, requests will be routed through secondary path in the sub-network. FT network is single switch fault-tolerant. If both switches in a loop are simultaneously faulty then clearly some sources are disconnected from some destinations. FT network of size 16X16 is shown in Fig. 1.

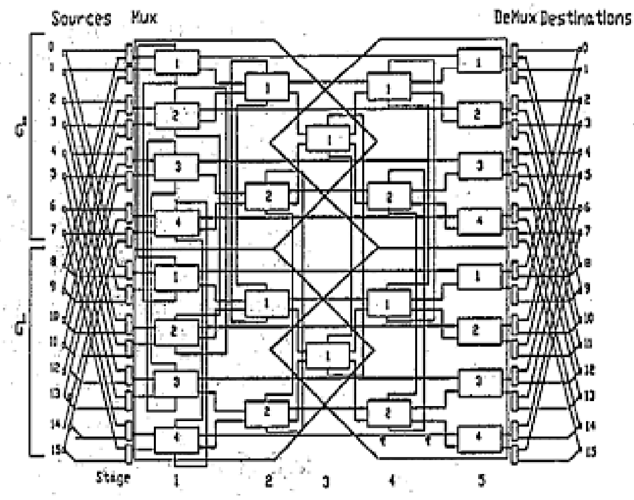

Fig:1 : Four Tree Network of Size 16X16

III. Construction of NFT Network
A New Four Tree (NFT) network [2] of size NxN has $2\log_2 N/2$ –1 stages. Both stage i and stage (2n-3) have exactly 2^{n-i} switches where i=1 and n=4. The stage i and 2n-4 have exactly 2^{n-3} switches where i=2. The middle stage has 2^{n-2} switches. A NFT network being an irregular network supports multiple paths of different path lengths. Every 3x3 SE in a stage forms a loop with the corresponding numbered 3x3 SE of other sub network in the same stage. Every source and destination is connected to both the subgroups by means of multiplexers and demultiplexers. The advantage of this network is that if both switches in a loop are simultaneously faulty then even some sources are connected to the destinations. NFT network of size 16x16 is illustrated in Fig. 2.

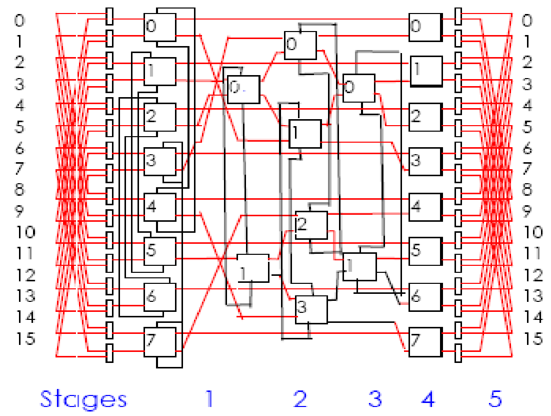

Fig. 2 : New Four Tree Network of Size 16X16

IV. Construction Procedure of IAFT Network

IAFT network of size 2^n x 2^n is constructed with the help of FT network as shown in Fig. 3. IAFT is constructed by removing the middle stage from FT network, which is a source of blocking. The first and last stage contain equal number of switching element. It consists of total (2_{m+2} -8) switches with 2^{n-1} of size 2 ×2 and rest of size 3 × 3.There are 2^n multiplexer of size 2 x 1 and 2^n demultiplexer of size 1 x 2. Every source and destination is connected to both the subgroups by means of multiplexers and demultiplexers. In case the primary path is busy or faulty, requests will be routed through secondary path in the sub-network. The advantage of this network is that if both switches in a loop are simultaneously faulty in any stage even then some sources are connected to the destinations. Following structural changes have been made in IAFT in comparison to FT network.

1) Removed the 3 stage (middle stage)

2) Loops and connections changed.

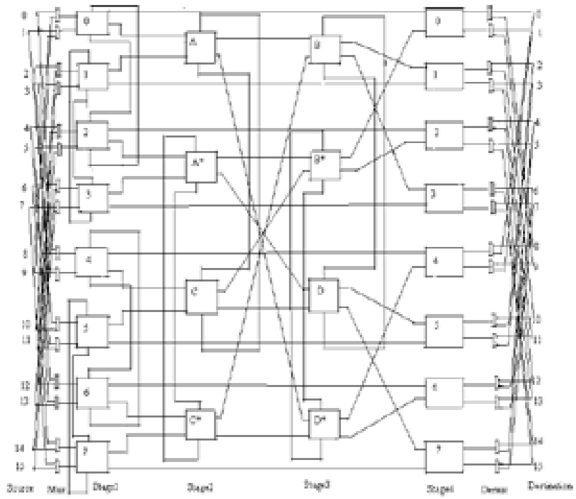

Fig. 3: Irregular Augmented Four Tree Network of Size 16X16

V. Redundancy Graph of IAFT Network

A redundancy graph offers a convenient way to study the properties of a multi-path MIN, such as the number of faults tolerated or the type of rerouting possible. A redundancy graph depicts all the available paths between a source and a destination in a MIN [1]. It consists of two distinguished nodes-the source S and the destination D-and the rest of the nodes correspond to the switches that lie along the paths between S and D. The redundancy graph of IAFT shows that there exist eight paths between any source and destination, as shown in Fig. 4.

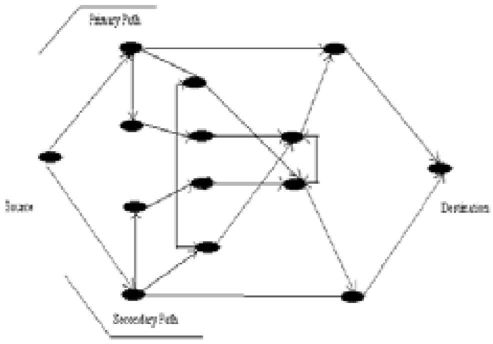

Fig. 4: Redundancy Graph of IAFT Network

VI. Permutation Passable Analysis

Permutation [8] is the one to one association between source to destination pair. Path length and the routing tags parameters are the major backbone to evaluate the permutation. There are two ways to evaluate the permutation:

A. Identity Permutations

A one-to-one correspondence between same source and destination number is called Identity Permutation. For example correspondence between 0..0 , 1..1 and so on .In terms of source and destination this can be expressed by: Where i = 0,1…….N-1

For example: connectivity between source to destination for identity is represented by: S0 - D0 , S1 – D1 ,----------------------- S15 - D15

Incremental Permutations

A source is connected in a circular chain to the destination in incremental permutation as shown below:

S0 – D4 , S1 – D5 ,----------------------- S15 – D3

We are considering the best possible cases to find out the permutations

- Non-Critical Case : If a single switch is faulty in any stage
- Critical Case : If the switches are faulty in a loop in any stage (if it exists)

Permutation evaluation requires the path length of given source to destination (path length can be more than one, from a given source to destination if multiple paths exists) and the routing tags. The analysis of some popular network from given source to destination to evaluate incremental (S0 to D4, S1-D5...) permutations along with proposed network is as following:

Table 1 : Incremental Permutation Of IAFT Network

Switch/faults	Total Path Length	Total no. Of Passes	Average Path Length	% Passable
Without	60	16	3.75	100
Mux	56	15	3.73	93
S1 A	53	14	3.78	87
S1 B	45	12	3.75	75
S2 A	52	14	3.7	87
S2 B	44	12	3.66	75
S3 A	51	14	3.64	87
S3 B	42	12	3.5	75
Demux	57	15	3.8	93

A : Non-Critical Case B : Critical case

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Table 2 : Incremental Permutation Of FT Network

Fault	Total Path Length	Total number of request passes	Average Path Length	% passable of Requests
Without	40	8	5	50
Mux	40	8	5	50
S1 A	35	7	5	43
S1 B	30	6	5	37
S2 A	30	6	5	37
S2 B	20	4	5	25
S3 A	30	6	5	37
S3 B	20	4	5	25
S4 A	30	6	5	37
S4 B	20	4	5	25
S5 A	35	7	5	43
Demux	40	8	5	50

A : Non-Critical Case B : Critical case

Table 3 : Incremental Permutation of NFT Network
A* : Non-Critical Case B*: Critical case

Fault	Total path length	Total no of request passes	Average path length	% Passable of requests
Without	32	8	4	50
Mux	32	8	4	50
S0 A*	32	8	4	50
S0 B*	16	4	4	25
S1 A*	24	6	4	37
S1 B*	16	4	4	25
S2 A*	24	6	4	37
S2 B*	16	4	4	25
S3 A*	32	8	4	50
S3 B*	16	4	4	25
S4	32	8	4	50
Demux	32	8	4	50

A* : Non-Critical Case B*: Critical case

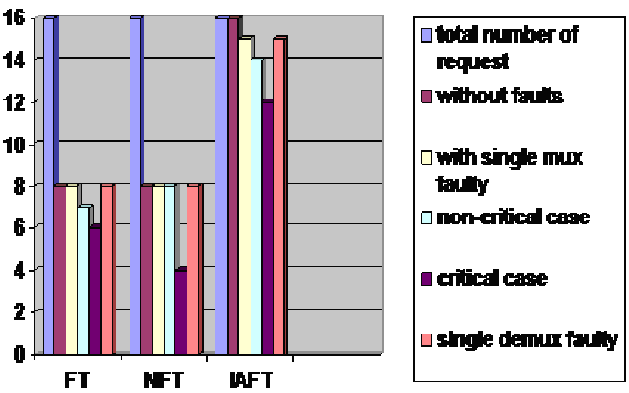

Fig. 5 : Comparison of requests matured

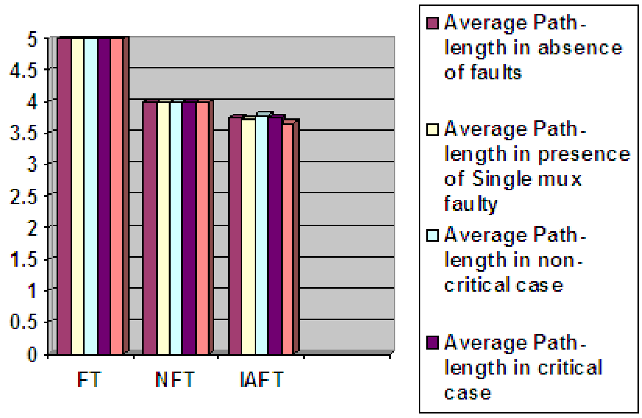

Fig.6 :Comparison of Average Path-length

From the data given above, it can be concluded that average path length of proposed network IAFT is smaller than FT and NFT. There is significant improvement in number of requests successfully maturing at the destination side in case of IAFT. Main consideration in permutation possibility is how many requests get matured in presence of faults, the proposed irregular network IAFT gives better performance in this respect.

VII. Cost-Effectiveness Analysis

A common method is used to estimate the cost of a network that is to calculate the switch complexity with the assumption that the cost of a switch is proportional to the number of gates involved, which is roughly proportional to the number of 'cross points ' within a switch [2,3]. So in this way the cost of n x n switch comes out to n2. For an interconnection network that contains multiplexers and demultiplexers, it is roughly assumed that each Mx1 multiplexers or 1xM demultiplexers has M units.

The cost of IAFT network is evaluated as:

- Total no of 3×3 switches = 16
- Total no of 2×2 switches = 8
- Total no of mux and demux (2:1, 1:2) = 32
- Hence Cost of the IAFT network is = 240

Table 4 : Cost Comparison of Various networks

Network	Cost
IAFT	240
FT	258
NFT	240

VIII. Conclusion

An irregular class of Fault Tolerant Multistage Interconnection Network called Irregular Augmented Four Tree Network has been proposed and analyzed. It has been observed from table 1 that the permutation passable of IAFT is much better that existing FT network and NFT network. It has also been observed from the analysis that IAFT and NFT network has same cost but IAFT network has lesser cost in comparison to existing irregular Four Tree network and New Four Tree network.

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Pawandeep Kaur received her Bachelor of Technology in Information Technology from Punjab Technical University, Jalandhar in 2009 and pursuing Masters in Computer Science and Engineering from Punjab Technical University, Jalandhar.

Kanwarpreet Kaur received her Bachelor of Technology in Information Technology from Punjab Technical University, Jalandhar in 2009 and pursuing Masters in Computer Science and Engineering from Punjab Technical University, Jalandhar.

Dr. Harsh Sadawarti, Ph.D., is Professor cum Director at RIMT- IET, Mandi Gobindgarh and DEAN (Faculty of Computer Science & Applications) Punjab Technical University Jalandhar. He has rich experience of 16.5 years in Teaching & Administration in Educational Institutes and in Industry. He has Published/ communicated 22 research papers in International Journals/ Conferences, National Conferences.