FAULT TOLERANT IRREGULAR AUGMENTED SHUFFLE NETWORK

HARSH SADAWARTI[1], P.K. BANSAL[2]

[1]Asstt. Prof. Deptt. of Computer Science & Engg., RIMT-Institute of Engineering & Technology, Mandi Gobindgarh, Punjab, India, Tel :+91-1765-241405
[2]Principal, GZCET, Bathinda, Punjab, India

ABSTRACT: The Performance of a system depends directly on the time required to perform an operation and number of these operations that can be performed concurrently. High performance computing systems can be designed using parallel processing. The effectiveness of these parallel systems rests primarily on the communication network linking processors and memory modules. Hence, an interconnection network that provides the desired connectivity and performance at minimum cost is required for communication in parallel processing systems. Multistage interconnection networks provide a compromise between shared bus and crossbar networks.

In this paper, a new class of Irregular, Fault-tolerant multistage interconnection network named as Irregular Augmented Shuffle Network (IASN) has been proposed. The network has less number of stages as compared to existing irregular networks. Various performance parameters have been analyzed which shows better performance of the proposed network than the existing networks. The reliability of a network is evaluated in terms of MTTF. It has been the IASN has a higher MTTF for upper and lower bound in comparison bound in comparison to networks such as ASEN-2 and ABN and is comparable to FT network.

Key-Words:- Parallel processing, , Fault-tolerant multistage interconnection network, Fault-tolerant routing.

1. INTRODUCTION.

A new class of irregular fault tolerant multistage interconnection network named Irregular Augmented Shuffle Network (IASN) has been proposed and analyzed in this paper. As the network is irregular, 50% of the requests pass through minimum path length of 2 in comparison to the regular networks, which have a constant path length. Thus, the irregular network IASN helps in reducing the latency or delay. Moreover, the network is fault tolerant i.e. it is capable of serving requests even in presence of certain faults. IASN has been designed in a way to improve the performance of the network.

IASN network is an irregular multistage interconnection network. An NxN (2^n x 2^n) network (where N is the number of sources and destinations, n = $\log_2 N$) consists of m stages (where m = $\log_2 N/2$). The first and the last stage of the network consist of equal number of switching elements (SEs) that is 2^{n-1} each whereas the intermediate stages consist of less number of switching elements equal to 2^{n-2} each. The switches in the last stage are of size 2x2 and the rest switches from stage 1 to m-1 are of size 3x3. Thus, the total number of switches are equal to $2^{n-2}(m+2)$ out of which 2^n number of switches are of size 2x2 and (m-2)x 2^{n-2} number of switches are of size 3x3. There is one 4x 1 multiplexer for each input link of a switch in first stage and one I x2 demultiplexer for each output link of switch in the last stage. Hence, there exists 2N multiplexers and demultiplexers of size 4x I and I x2 respectively.

2 CONSTRUCTION PROCEDURE OF IASN.

Irregular Augmented Shuffle Network (IASN) of size NxN is constructed of two identical subgroups consisting of N/2 sources and N/2 destinations, denoted as G^i (where i =0,1). The two groups are formed on the basis of most significant bit (MSB) of the source-destination pair. If the MSB of source-destination pair is 0, then it belongs to G^0 group otherwise if MSB is 1, then it belongs to G^1 group. Both the groups are connected to the N sources and N destinations with the help of multiplexers and demultiplexers.

The network being an irregular network supports ,multiple paths of varied path lengths. The network is regular in the first and last stage as it consists of same number of switching elements but it is irregular in the intermediate stages, which consist of less number of switching elements. Multiple paths are available for passing requests from a particular source to a particular destination. This makes the network fault-tolerant as requests route through alternate paths available.

At each stage except the last, there exists a fork at every point so that routing from source to destination can take place from an alternate path in presence of faults or when a particular output link if busy. At each stage except the last, the switching elements are linked by auxiliary links to form a loop. These SEs hence form a conjugate loop. So, if a particular switching element is faulty or a particular output link is busy, routing takes place through the .use of auxiliary links, which helps in

maturing of the requests through the other fault-free SE present in the loop.

Fig 1.1 and Fig 1.2 shows the construction of IASN for size N= 16 and its corresponding redundancy graph respectively.

Redundancy graph is a method of showing all possible paths between source and destination pairs. It depicts the various paths available for routing so that if a particular path is faulty, routing can take place through alternate paths available. Redundancy graph of IASN network as shown in Fig 1.2 depicts the various possible paths available in the network..
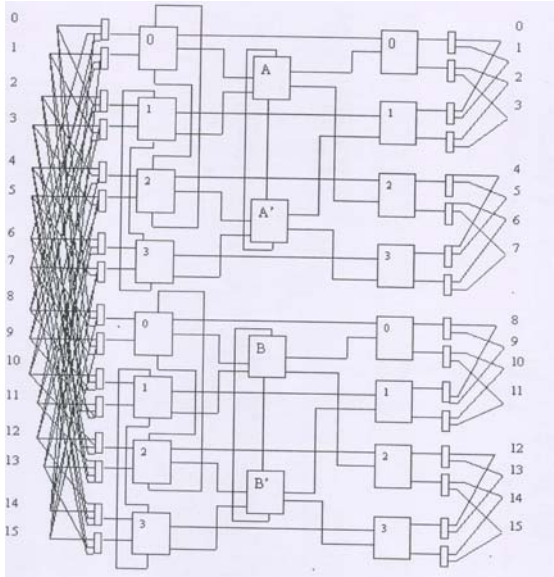
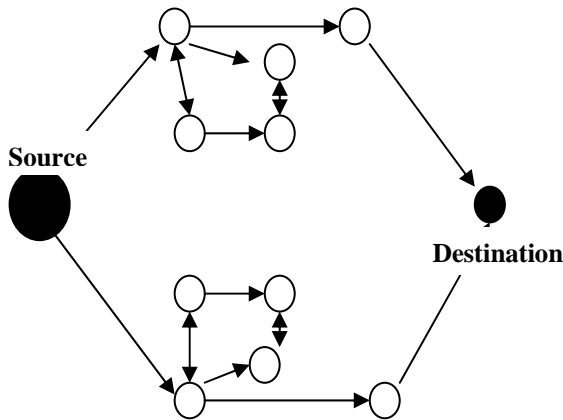

Fig. 1.1 Irregular augmented shuffle network (IASN)

Fig. 1.2 Redundancy Graph of IASN

3 ROUTING PROCEDURE FOR IASN

Routing tag consists of binary digits that control the connection through different stages of the path from input ,to the output.

Let the source S and destination D be represented in binary as:

$$S= S_{n-1} ....S_1S_0$$
$$D= d_{n-1}.................d_1d_0$$

The routing scheme for IASN is described as follows:
Algorithm: Fault Tolerant Routing for IASN
PROCEDURE

i. One of the networks G^i is selected on the basis of most significant bit (MSB) of the destination address for routing the request to a particular destination.

ii. For each source-destination pair, there exist two paths called primary and secondary path. Firstly, the request tries to enter through the primary path. If the primary path is faulty, then the secondary path is chosen. And if secondary path is also faulty, then the network fails.

iii. The routing tag bit is the destination address with its MSB removed. This tag bit determines the path that is chosen for routing a request from source to destination.

iv. If a particular output link is faulty or the switch in the next stage is faulty, then the request is passed to another switch in the same stage through a third I ink called auxiliary or express link. If this auxiliary link is also faulty, then the request is dropped.

v. At the end, for routing the request through the demultiplexer, bit d_0 of the routing tag is used.

Example: Let the data be routed from S=0000 to various destinations of a 2^4 X 2^4 IASN network. The path lengths calculated for set of destinations are as summarized in the Table 1.1.

Table 1.1: Routing Information for IASN

S	D	Path Lengths available
	0000	
	0001	
	0010	
	0011	2,3
	1000	
	1001	
	1010	
	1011	
0000		
	0100	
	0101	
	0110	
	0111	3
	1100	
	1101	
	1110	
	1111	

4 FAULT-TOLERANCE OF IASN

Fault tolerance in an interconnection network is very important for continuous operation over relatively long period of time. Fault tolerance is the ability of the system to continue operating in the presence of faults although at a degraded performance [6]. These faults can be either permanent or transient in nature [22]. It is criteria that must be met for a network to operate even in presence of certain faults.

The network should be able to satisfy the criteria of full access that is ability of the network to transfer data from any input terminal to any output terminal. In case of fault-free conditions, one to one connection is maintained and in presence of faults alternate paths are chosen for routing. So, under the criteria of full access a

network is assumed to be faulty if there is any input-output pair that cannot be connected with each other due to the presence of faulty components in the network.

A network is single fault tolerant if it can function as specified by its fault tolerance criteria despite any single faults conforming to its fault models. A network is said to be k fault tolerant if it can still provide a connection for any source destination pair in the presence of any instance of up to k faults in the network [26].

The proposed IASN network satisfies the fault tolerance criteria as it can operate even in presence of certain faults. Fault tolerance has been achieved by providing a primary as well as secondary path from source to destination so that if the primary path is faulty, then secondary path can be chosen. Every source-destination pair has a fork available at every stage except at the last one.

A network is robust in the presence of k faults if it can tolerate some instance of k faults. The maximum number of faults it can tolerate comes from the case that only one of the groups is fault-free [26].

The presence of the auxiliary links available in the network provides an alternate path for routing, except at the last stage. But if the switches in the same loop are simultaneously faulty, then it disconnects certain source-destination pairs. Such a fault is termed as 'critical fault'. So as long as the fault is not critical, the network continues to operate even though at degraded performance. Hence, strictly speaking IASN network is single switch fault tolerant.

The multiple paths between S = 0000 and D = 0110 and between S = 0000 and D = 1010 are as shown in Fig 1.3.
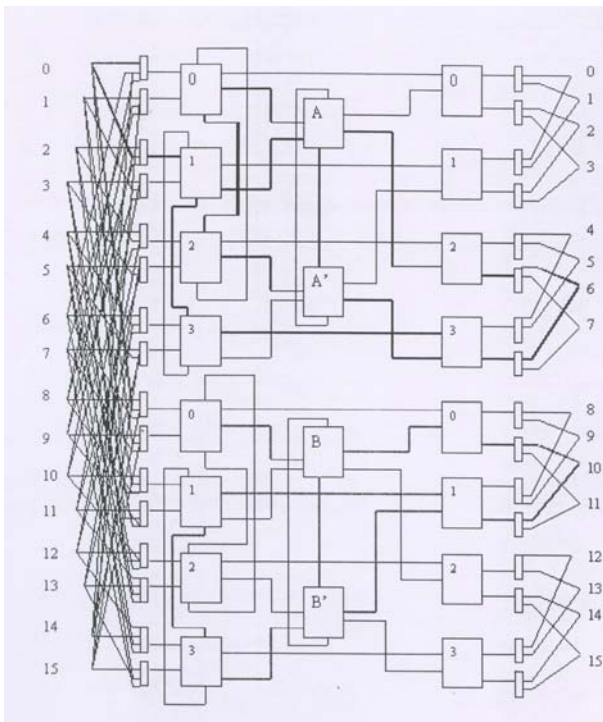

Fig. 1.3 IASN highlighting multiple paths between S-D pairs

The following theorems characterize the faults that can be tolerated in the IASN network.

Theorem1: In IASN network, if the faults occur such that at most one switch is affected in every pair of switches in a loop (that is conjugate switches), then there exists at least one fault-free path from any source to any destination.

Proof: Since there is at most one switch affected in the loop of conjugate switches, the other switch is fault-free. Thus, through the auxiliary or express link, the other fault-free switch can be reached. As both the switches lead to the same destination, so requests instead of getting blocked pass through the fault-free switch in the same loop. Hence, there exists at least one fault-free path from any source to any destination.

Theorem2: In IASN, some source is disconnected from some destination if both the switches in a loop are simultaneously faulty.

Proof: Suppose that while routing from any source to any destination there exists a faulty switch in the route. The network will try to route the request through another switch in the same loop. But if both the switches are simultaneously faulty, then clearly some sources will be disconnected from certain destinations.

Lemma I: IASN is single switch fault tolerant in stages from 1 to m-1.

Proof: From stages 1 to m-1, there exists SEs that forms pair through the use of auxiliary links. Some sources will be disconnected from some destinations only if both the switches in the loop are simultaneously faulty. In case of single switch failures, sources are connected to destinations through the other fault-free switch available in the loop. Hence, IASN is single switch fault tolerant network..

5 RELIABILITY ANALYSIS OF IASN
There are three fault models adopted to the reliability analysis of the networks: ' stuck-at fault model', 'switch-fault model' and 'link-fault model'. In the stuck-at fault model, a failure causes a crossbar switch to remain in a particular state regardless of the control inputs given to it, thus affecting its capability to set up suitable connections. In switch fault model, a switch is considered to be totally unusable if it becomes faulty. In the link fault model, a failure affects an individual link of a switch leaving remaining part of the switch operational [4,8,22]. Any network fault that corrupts data on the information path is called a link fault. A link fault occurs in an information link when it becomes stuck at either logical "0" or "1", regardless of the actual input signal applied to it. In this thesis, switch fault model is used for the analysis of the network. It is

assumed that any of the switching component i.e. switching elements, multiplexers and demultiplexers can fail in the IASN network. All the faults are assumed to be independent of each other. The reliability is analyzed in terms of MTTF. The MTTF is analyzed by defining a set of critical components. A critical set of components is defined as set of switching components, each from different groups, such that a network failure will occur if all the components become faulty simultaneously [26].

Certain basic steps are used in the analysis of reliability [7]. These are:

I. First, the elements, subsystem and estimated individual reliability factors are identified.

II. Then a block diagram representing the logical manner in which these elements are connected is prepared to form a system.

III. Then the condition for the successful operation of the system is determined that is it is decided that how many units should function together.

IV. Finally the combinational rules of probability theory that is add, multiply and their combinations are applied to arrive at the system reliability factor.

The following assumptions are made during reliability analysis [8]:

Assumptions:

I. Switch failures occur independently in the network with the failure rate of $\lambda \left(= 10^{-6} \text{ per h} \right)$

II. Based on the gate count, failure rate of 2 x 2 SE is taken as $\lambda_2 = \lambda$; for a 3 x 3 SE it is $\lambda_3 = 2.5 \lambda$ and $\lambda_m = m\lambda/4$ for a m x I MUX or λ_d (=λm) for a I x m DEMUX.

III. 2 x 2 SEs in the last stage and their associated demultiplexers are taken as series system with a combined failure rate of $\lambda_{2d} = 2 \lambda$.

5.1 Upper Bound Analysis

This presents the optimistic value of the reliability. In this it is assumed that the network will be operational as long as one of the two multiplexers attached to the source is operational and as long as a conjugate pair of switch is not faulty [3]. The reliability block diagram for the upper bound is as shown in Fig 1.4 (a) and the corresponding. expression is:

$$R_{UB-IASN}(t) = \left[1 - \left(1 - e^{-\lambda_m t}\right)^2\right] \cdot \left[1 - \left(1 - e^{-\lambda_3 t}\right)^2\right]^{N/4+N/8*+...1} \cdot \left[1 - \left(1 - e^{-\lambda_{2d} t}\right)^2\right]^{N/4}$$

$$\text{MTTF} = \int_0^\infty R_{UB-IASN}(t)dt$$

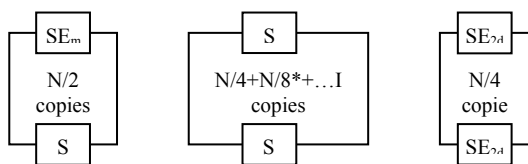| SE$_m$		S		SE$_{2d}$
N/2 copies		N/4+N/8*+...I copies		N/4 copie
S		S		SE$_{2d}$

Fig 1.4 (a) Upper Bound Reliability Block Diagram

The values for the Upper Bound MTTF for the IASN network are provided in Table 1.2.

Table 1.2 Upper Bound MTTF for IASN

Network Size → PL J.↓	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
2	155945	105456	72 190	49874	34686	24239	16996
3	139275						
4		94419					
5			64769				
6				44816			
7					31203		
8						21822	
9							15311

The values of upper bound MTTF for other networks like ASEN-2 [15], ABN [8] and FT [6] network are given in Table 1.3, 1.4 and 1.5 respectively.

Table 1.3 Upper Bound MTTF for ASEN-2

Network Size	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
UB	134935	77685	47339	29855	19255	12611	8353

Table 1.4 Upper Bound MTTF for ABN

Network Size'	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
UB	171627	91329	53434	32884	20867	13511	8872

Table 1.5 Upper Bound MTTF for FT

Network Size	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
UB	171627	115276	78546	54084	37525	26178	18334

5.2 Lower Bound Analysis

In the lower bound analysis each group is considered independently and it is assumed to be faulty if there is single fault in it. The input side SEs and their associated multiplexers are taken as series system and failure of

any component is assumed to be failure of all three. Hence, in this the results are pessimistic in nature.

The reliability block diagram for the lower bound is as shown in Fig 1.4 (b) and the corresponding expression is:

$$R_{LB\text{-}IASN}(t) = \left[1 - \left(1 - e^{-\lambda}3m^t\right)^2\right]^{N/4} \left[1 - \left(1 - e^{-\lambda}3^t\right)^2\right]^{N/4^* + N/8^* + \ldots 1} \left[1 - \left(1 - e^{-\lambda}2d^t\right)^2\right]^{N/4}$$

$$MTTF = \int_0^\infty R_{LB\text{-}IASN}(t)\,dt$$

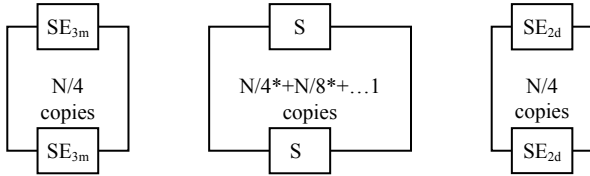| SE$_{3m}$ | | | S | | | SE$_{2d}$ |
| N/4 copies | | | N/4*+N/8*+…1 copies | | | N/4 copies |
| SE$_{3m}$ | | | S | | | SE$_{2d}$ |

Fig 1.4 (b) Lower Bound Reliability Block Diagram

The values for the Lower Bound MTTF for the IASN network are provided in Table 1.6.

Table 1.6 Lower Bound MTTF for A1SN

Network Size → PL ↓	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
2	117465	78067	52778	36133	24966	17364	12135
3	102088						
4		68559					
5			46704				
6				32150			
7					22301		
8						15554	
9							10891

The values of lower bound MTTF for other networks like ASEN-2 [15], ABN [8] and FT [6] network are given in Table 1.7,1.8 and 1.9 respectively.

Table 1.7 Lower Bound MTTF for ASEN-2

Network Size	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
UB	118383	69950	43375	27700	18035	11900	7928

Table 1.8 Lower Bound MTTF for ABN

Network Size	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
UB	94872	53944	32667	20546	13241	8676	5752

Table 1.9 Lower Bound MTTF for FT

Network Size	16x16	32x32	64x64	128x128	256x256	512x512	1024x1024
UB	142743	95166	64500	44244	30613	21315	14907

Fig 1.5(a) and Fig 1.5(b) shows the comparative Upper Bound MTTF and Lower Bound MTTF analysis of IASN with regular ASEN-2 and ABN networks respectively.

Fig 1.5(c) and Fig 1.5(d) shows the comparative Upper Bound MTTF and Lower Bound MTTF analysis of IASN with irregular FT network respectively.

From Fig 1.5(a) it can be seen that the Upper Bound MTTF of IASN is comparable to ASEN-2 and ABN for small network sizes but as the network size increases, the MTTF of IASN is better than ASEN-2 as well as ABN. Also from Fig 1.5(c) it can be seen that the Upper Bound MTTF of IASN slightly less than FT network for small network sizes but becomes comparable as the size increases. This implies that IASN is more reliable in comparison to ASEN-2 and ABN network and is comparable with the FT network.

From Fig 1.5(b) it can be seen that the Lower Bound MTTF of IASN is comparable to ASEN-2 but greater than ABN for small network sizes but as the network size increases, the MTTF of IASN is better than both ASEN-2 as well as ABN. Also from Fig 1.5(d) it can be seen that the Lower Bound MTTF of IASN is less than FT network for small network sizes but becomes comparable as large network sizes. This implies that IASN is more reliable in comparison to ASEN-2 and ABN network. IASN is less reliable than FT network for small network sizes and is comparable with FT network for very large network sizes.

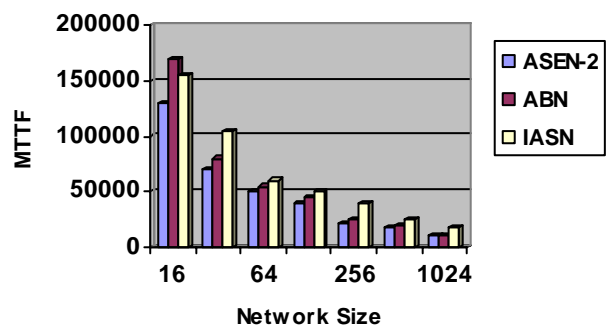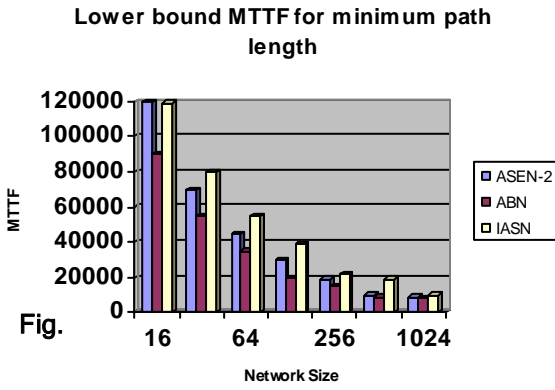**Upper bound MTTF for minimum path length**

Fig. 1.5 (a) Comparative Analysis of Upper Bound MTTF

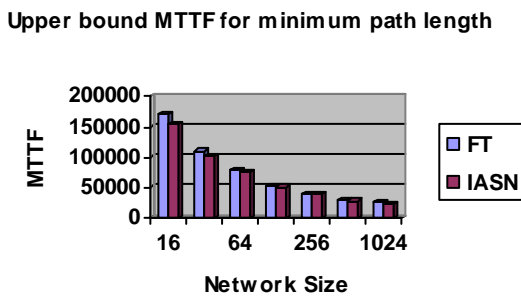**1.5 (b) Comparative Analysis of Lower Bound MTTF**

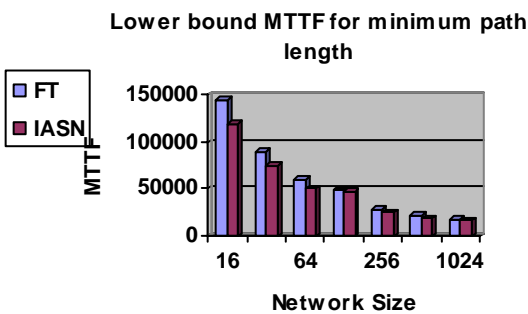**Fig. 1.5 (c) Comparative Analysis of Upper Bound MTTF**

Fig. 1.5 (d) Comparative Analysis of Lower Bound MTTF

6 CONCLUSION

A fault-tolerant, irregular multistage interconnection network named Irregular Augmented Shuffle Network (IASN) has been proposed. The network possesses fault tolerance capability and hence operates even under presence of faults. It has reduced number of stages thereby exhibiting reduced latency and better performance.

The reliability analysis, both in terms of upper bound as well as *lower* bound, shows that IASN is *more* reliable as compared to existing networks like ASEN-2 and ABN. Moreover, the reliability of IASN is comparable to the existing irregular FT network. The performance analysis also shows overall gain in performance *of* IASN as compared *to* various existing networks. Being irregular, IASN is very cost-effective too in comparison *to* various existing networks like ASEN-2, ABN, INDRA and ESC networks making it a suitable candidate *to* be used in parallel systems.

REFERENCES

[1] Adams G.B., Aggarwal D.P. and Siegel H.J., "A Survey of Fault-Tolerant Interconnection Networks", IEEE Computers, Vol.20, june 1987, pp.14-27.
[2] Adams III G.B. and Siegel H.J., " The Extra Stage Cube: A Fault Tolerant Interconnection Network for Supersystems", IEEE Transactions on computer, 1982, pp.443-454.
[3] Anderson G.A., Jensen E.D., "Computer Interconnection Networks: Taxonomy, Characteristics and Examples", ACM Computing Surveys, Vol.7, Dec. 1975, pp. 197-213
[4] Balaguruswamy. E., " Reliability Engineering", Tata Mc-Graw Hill, 1989.
[5] Bansal P.K., Singh K. and Joshi R.C., "Fault-Tolerant Double Tree network", Proc. Of International Conference IEEE INFOCOM 91, April,pp. 462-468
[6] Bansal P.K., Singh K. and Joshi R.C., "Routing and Path length for a Cost-Effective Four tree Multistage Interconnection Network", International Journal of Electronics and Electrical Engineering. Vol 73, No. 1, 1992, pp. 107-115.
[7] Bansal Savina and Bansal P.K., "Performance and Reliability Analysis for a Multistage Interconnection Network", presented in NSC-93 at IIT Kanpur, Dec. 1993.
[8] Bansal P.K., Singh K. and Joshi R.C., "On a Fault-Tolerant Multistage Interconnection Network", International journal of Electronics and Electrical Engineering, Vol 20, No.4, 1994,, pp. 335-345.
[9] Booting C., Rai S. and Aggarwal D.P., "Reliability Computation of Multistage Interconnection Networks", IEEE Transactions on Reliability, Vol. 38, No. 1, 1994, pp. 138-145.
[10] Duato J., Yalmanchili S. and Ni L.M.., "Interconnection Networks: An Engineering Approach", IEEE Computer Society, 1997.
[11] Feng T.Y., "Survey of Interconnection Networks", IEEE Computers, Vol. 4, Dec. 1981, pp 12-27.
[12] Howard J. Siegel, Wayne G. Nation, Cylde P. Kruskal and Leonard M. Napolitano, "Using the Multistage Cube Network Topology in Parallel Supercomputers", Proceedings of IEEE, Vol.77, No. 12, Dec. 1979, pp 1932-1953.
[13] Hwang Kai, "Advanced Parallel Processing with Super Computers", Proc. IEEE OC-75, Oct. 1987, pp. 127-137.