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A Survey on Multi-Stage Interconnection Networks

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ABSTRACT

In this paper variety of fault tolerant multistage interconnection networks that have been proposed in literature are surveyed .Fault tolerant networks are capable of handling requests even in presence of faults although at reduced performance. Various networks which we have surveyed include Augmented Baseline Network (ABN) , Irregular Augmented Baseline Network (IABN), Modified Augmented Baseline Network (MABN), Augmented Shuffle Exchange Network (ASEN-2), Irregular Augmented Shuffle Exchange Network (IASEN), Irregular Augmented Shuffle Network (IASN),Improved Irregular Augmented Shuffle Network(IIASN), New Irregular Augmented Shuffle Network(NIASN), Modified Augmented Shuffle Exchange Network (MASEN), Irregular Augmented Shuffle Exchange Network–3 (IASEN-3), Modified Alpha Network (MALN), Advance Irregular Alpha Multistage Interconnection Network (AIAMIN2), Irregular Advance Omega Network (IAON).

***Keywords*: -** Multistage interconnection networks, fault-tolerance, cost- effectiveness, path length, reliability and performance.

I. INTRODUCTION

Multistage interconnection networks are a class of high speed computer network usually composed of processing elements (PEs) on one end of the network and memory elements (MEs) on the other end, connected by switching elements (SEs). The switching elements themselves are usually connected to each other in stages. This paper surveys a number of multistage interconnection networks which are capable of serving requests even in presence of faults. Various networks which are surveyed include Augmented Baseline Network (ABN), Irregular Augmented Baseline Network (IABN), Modified Augmented Baseline Network (MABN), Augmented Shuffle Exchange Network (ASEN-2), Irregular Augmented Shuffle Exchange Network (IASEN), Irregular Augmented Shuffle Network (IASN), Improved Irregular Augmented Shuffle Network (IIASN), New Irregular Augmented Shuffle Network(NIASN), Modified Augmented Shuffle Exchange Network (MASEN), Irregular Augmented Shuffle Exchange Network–3 (IASEN-3), Modified Alpha Network (MALN), Advance Irregular Alpha Multistage Interconnection Network (AIAMIN-2), Irregular Advance Omega Network (IAON).

II. STRUCTURE AND DESIGN OF VARIOUS MINs

A. ABN

An Augmented Baseline Network (ABN)[2] of size N x N consists of, two identical groups of N/2 sources and N/2 destinations. The switches in the last stage are of size 2 x 2 and the remaining switches in stages 1 through n-3 ($n=\log_2 N$) are of size 3 x 3. In each stage, the switches can be grouped into conjugate subsets, where a conjugate subset is composed of all switches in a particular stage that lead to the same subset of destinations. The switches, which communicate through the auxiliary links, form a conjugate loop. Each source is linked to both the groups via multiplexers and destinations via de-multiplexers. An ABN[2] of size 16 x 16 is illustrated in Fig. 1.

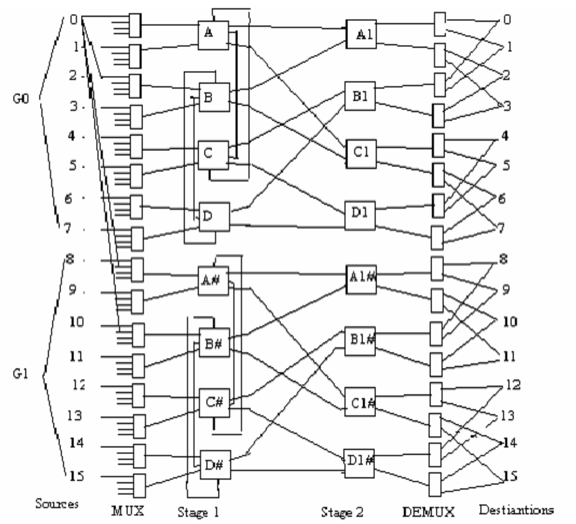
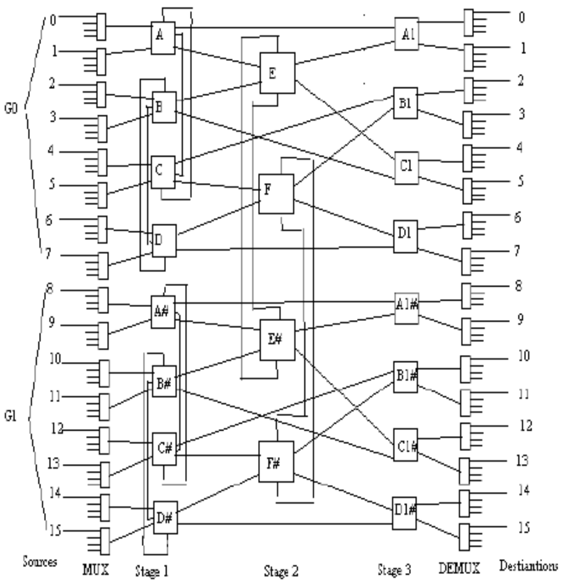


Fig. 1 AN ABN OF SIZE 16 X 16

B. IABN

An Irregular Augmented Baseline Network (IABN)[2] is an ABN[2] with one additional stage, additional auxiliary links and increased size of demultiplexers. An IABN[2] of size N x N consists of two identical groups of N/2 sources and N/2 destinations. Each group consists of a multiple path modified baseline network of size N/2. The switches in the last stage are of size 2 x 2 and the remaining switches in stages 1 through n-2 ($n=\log_2 N$) are of size 3 x 3. There is one 4 x 1 MUX for each input link of a switch in stage 1 and one 1 x 4 DEMUX for each output link of a switch in stage n-1. Each group consisting of a modified baseline network of size N/2 plus its associated MUXs and DEMUXs is called a sub network. Thus an IABN[2] consists of two identical sub-networks which are denoted by G^i. For example, in Fig. 2, switches A, B, C, D belonging to stage 1 of a subnetwork (G^i) form a conjugate subset, switches A and B form a conjugate pair, and switches A and C form a conjugate loop.



. Fig. 2 AN IABN OF SIZE 16 X 16

C. MABN

An Modified Augmented Baseline Network (MABN)[3] of size NXN i.e. N sources and N destinations has two identical groups of N/2 sources and N/2 destinations. Each group consists of a multiple path modified baseline network of size N/2. Each source is linked to both the groups via multiplexers. There is one 4 x 1 MUX for each input link of a switch in stage 1 and one 1 x 4 DEMUX for each output link of a switch in stage n-2. Each group consisting of a modified baseline network of size N/2 plus its associated MUXs and DEMUXs is called a sub-network. Thus an MABN[3] consists of two identical sub-networks which are denoted by Gi.

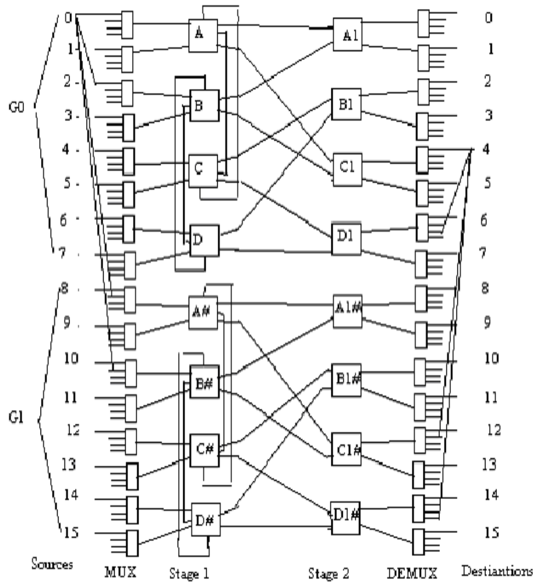


Fig. 3 AN MABN OF SIZE 16 X 16

D. ASEN-2

Augmented Shuffle Exchange Network (ASEN-2)[4] is a regular network, having equal number of switches in each of the stage. ASEN-2[4] network is constructed from Shuffle Exchange Network by adding a stage of 2×1 multiplexers at the initial stage and 1×2 demultiplexers at last stage. It provides multiple paths between a source and a destination. ASEN-2[4] of size N × N with N number of sources and N number of destination consists of log2N -1 stages where the initial stage consists of N/2 switches of size 3×3 and the last stage consist of N/2 switches of size 2×2. ASEN-2[4] provides fault tolerance using links between the conjugate pairs of switches. A 16×16 ASEN- 2[4] network is shown in Fig. 4.

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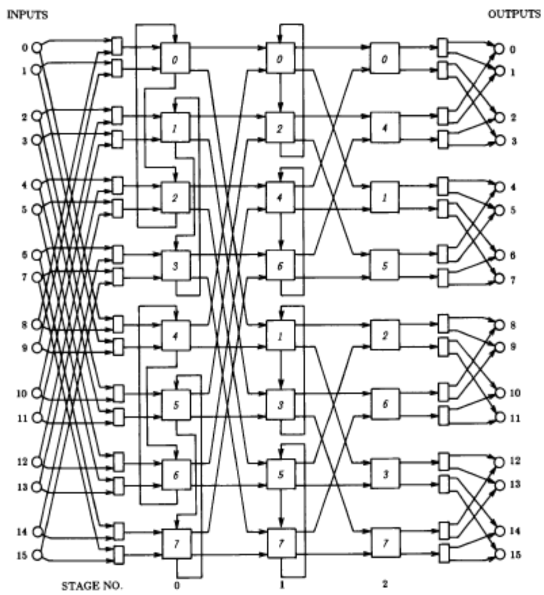

Fig. 4 AN ASEN-2 OF SIZE 16X16

E. IASEN

Irregular Augmented Shuffle Exchange Network (IASEN)[4] shown in Fig. 5 is derived from ASEN-2[4] multistage interconnection network. The switches in the first stage form a loop to provide multiple paths if a fault occur in the next stage. Each source is connected to two different switches in each group with the help of multiplexer and each destination is connected with demultiplexers. Following structural changes have been made in IASEN[4] in comparison to ASEN-2[4].

1) Four switches removed from the stage 1 (Intermediate Stage)
2) Use of 1 x 4 DEMUX in place of 1 x 2 DEMUX
3) Loops and connections changed

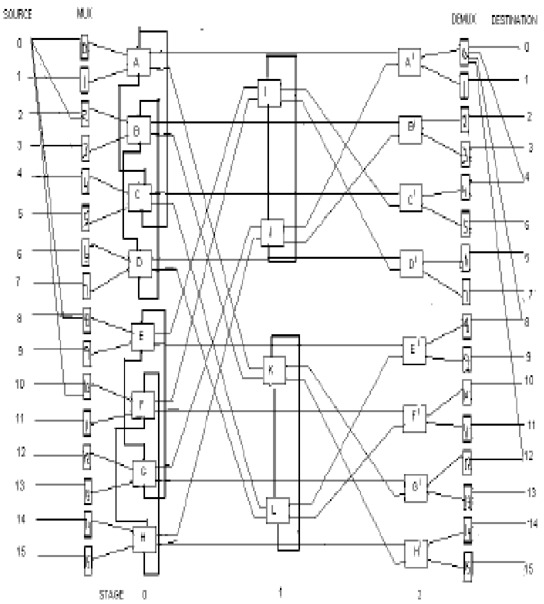

Fig. 5 AN IASEN OF SIZE 16X16

F. IASN

Irregular Augmented Shuffle Network (IASN)[5] 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. 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. 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. 6 shows the construction of IASN[5] for size N= 16 .

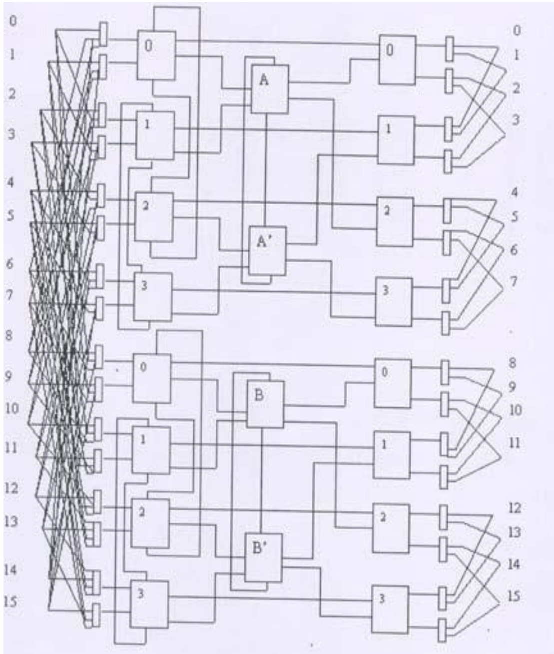

Fig. 6 IASN OF SIZE 16X16

G. IIASN

A typical IIASN[6] is an Improved Irregular Augmented Shuffle Multistage Network of size 2n x 2n is constructed with the help of two similar groups; lower and upper, each group consisting of a sub network of 2n-1 x 2n-1 size and has 2n-2–1 stages, both stages at log 2 N –3 and log 2 N –1 have 2n-1 switches (where N=2n of N x N network). The centre stage has exactly 2n-3 switches. The switches in the first stage form a loop to provide multiple paths if a fault occur in the next stage. Each source is connected to two different switches in each group with the help of multiplexer and each destination is connected with demultiplexer. In case the main route is busy or faulty, requests will be routed through alternate path in the same 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. IIASN[6] network of size 16x16 is illustrated in Fig. 7.

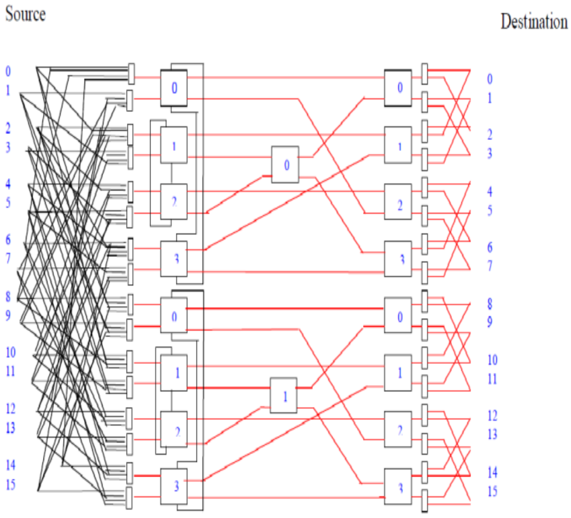

Fig. 7 IIASN MIN of size N=16

H. NIASN

New Irregular Augmented Shuffle Network (NIASN)[7] network is 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}+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. There are 2^n multiplexers of size 2 x 1 and 2^n demultiplexers of size 1 x 2. NIASN[7] network of size 16x16 is illustrated in Fig. 8.

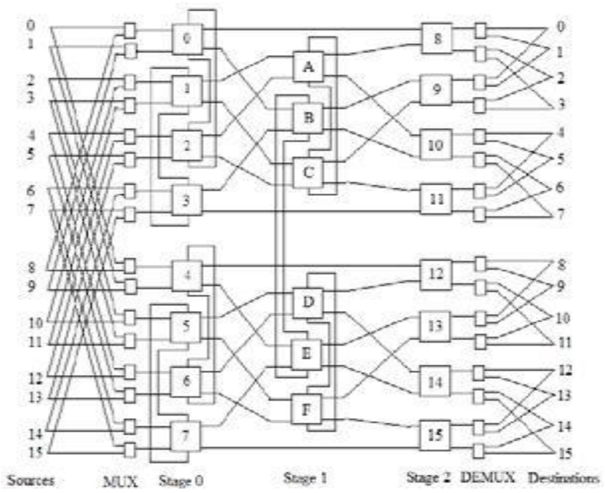

Fig. 8 NIASN of size 16 X16

I. MASEN

Modified Augmented Shuffle Exchange Network (MASEN)[8] is an irregular multistage interconnection network, derived from ASEN-2[4] network [4]. An N × N (2^n × 2^n) network consists of m stages (where m = $\log_2$ N/2). The first and the last stage of network contain equal number of switching elements that is 2^{n-1}, 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 2 × 2 whereas stages from 1 to m-1 are having switches of size 3 × 3. 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 2 × 2 and (m-2) × 2^{n-2} number of switches are of size 3 × 3 . There is one 4 × 1 multiplexer for each input link of a switch in first stage and one 1 × 2 demultiplexer for each output link of switch in the last stage. Hence, there exist 2N multiplexers and demultiplexers of size 4 × 1 and 1 × 2 respectively .Following structural changes have been made in ASEN-2[4]:

1. Use of 4 × 1 MUX in place of 2 × 1 MUX.
2. Four switches removed from stage 1 (Intermediate Stage).
3. Change in loops and connections.

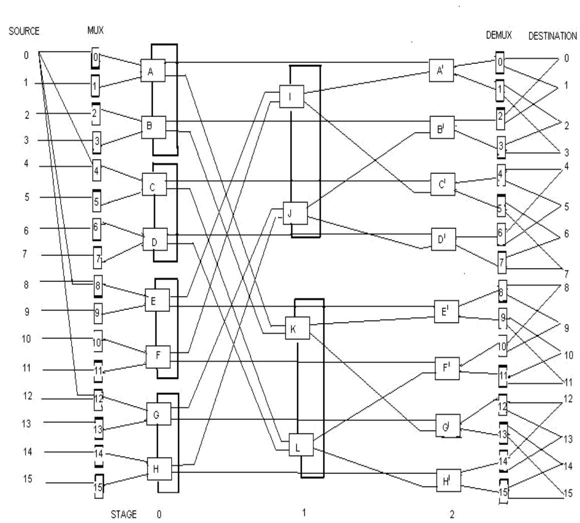

Fig. 9 MASEN of size 16 x 16

J. IASEN-3

The structure of Irregular Augmented Shuffle Exchange Network–3 (IASEN-3)[9] is a 3–stage MIN. In first and last stage, each source or each destination is connected with three switching elements (SEs) of that particular stage e.g. source 11 is connected with SE *f*, *a* and *d* and therefore *f*, *a* and *d* are the primary, first alternate and second alternate SEs for source 11. Similarly, we can find out the primary, first alternate and second alternate SEs for other sources and destinations. The size of each SE in first and third stage is 2×3 and 3×2 respectively. In stage 2, the size of each SE is 8×8.

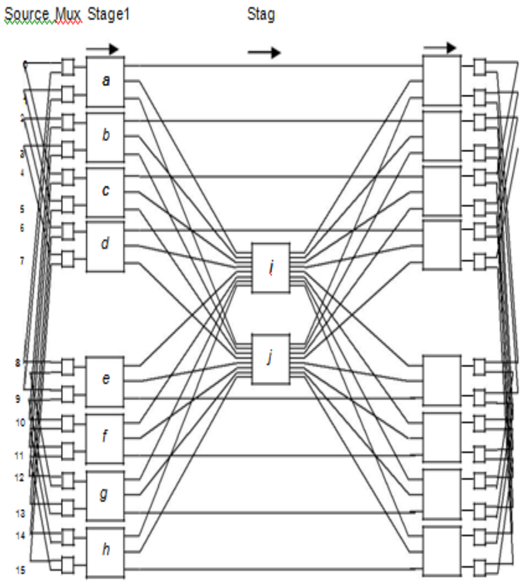

Figure 10 IASEN-3 OF SIZE 16X16

K. MALN

Modified Alpha Network (MALN)[10] is an Irregular Multistage Interconnection Network, of size N*N. It has N sources and N destinations. The MIN consists of n stages (n=log2 N).

The network Comprises of two identical groups of switching elements (SEs), named as G0 and G1.Each group incorporates N/2 sources and N/2 destinations. Both the groups are connected to the N inputs through N multiplexers, and to the N outputs through N no. of multiplexers. The switches in all the stages are of size 3*3 except the last one. The switches in the stages n-3,n-2 and n-have been connected to each other through links called as auxiliary links. The MALN[10] of size 2n * 2n consists of (2m-2) stages where m=log2(N/2).This network has 2n no. of switches of size 3*3 and 2n-1 no. of switches of size 2*2.Each source is connected to one switching element in each group with the help of multiplexers. The network of size 16*16 is depicted in following fig. 11.

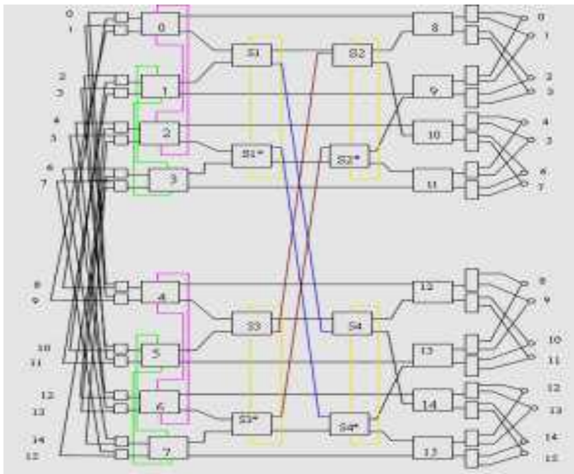

Figure 11 MALN OF SIZE 16X16

L. AIAMIN-2

The structure of Advance Irregular Alpha Multistage Interconnection Network (AIAMIN-2)[11] is shown in Figure 12. This network has 16 sources and 16 destinations. In Fig. 12, the source, destination, multiplexers and demultiplexers are represented by S, D, Mux and Demux respectively. There are 16 Mux and 16 Demux in AIAMIN-2[11]. The size of each Mux and Demux is 2×1 and 1×2 respectively. Each stage consists of 8 switching elements (SEs) except the second stage. The size of each SE in first and last stage is 2×3 and 5×2 respectively. The second stage consists of 4 SEs and size of each SE is 4×8.

In AIAMIN-2[11], SEs are categorized in 3 category i.e. main SE, first alternate SE and second alternate SE as each source is connected with 3 SEs via Mux e.g. source 0 is connected with SE a, e and f. It shows a, e and f are the main SE, first alternate SE and second alternate SE respectively.

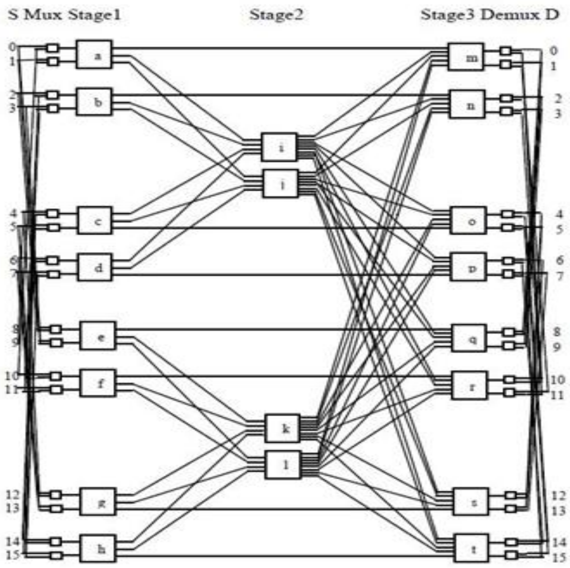

Fig. 12 AIAMIN-2 OF SIZE 16X16

M. IAON

The structure of Irregular Advance Omega Network (IAON)[12] has 3 stages for every network size. The sizes of Mux and Demux are 2×1and 1×2, respectively. Presently, there are 16 Mux and 16 Demux in this network. Each Mux connects the sources to SEs of first stage and each Demux connects SEs of third stage to destinations. In first and third stage, the network has 4 SEs in each, while second stage has 3 SEs.

The size of SEs in first and third stage is (N /4 ×4) and (4 × N/4), respectively. In the second stage, SE and have the size 5 ×5. The size of SE is 6 ×6. Each source is connected with two other SEs of first stage through auxiliary links. In the same way, each destination is connected with two other SEs of third stage through auxiliary links. In Fig. 13, auxiliary links of second stage are shown by green colour. In IAON[12], each source and each destination have one primary and two alternate SEs. If the SE is directly connected with any source or any destination then it will be primary SE of that particular source or destination. If it is indirectly (through auxiliary links) connected with any source or destination, then it will be first or second alternate SE of that particular source or destination. Hence, SEs *a*, *b*, and are the primary, first, and second alternate SEs for source 0, , respectively. Equally, we can see the primary, first alternate, and second alternate SEs of other sources and destinations in Fig. 13.

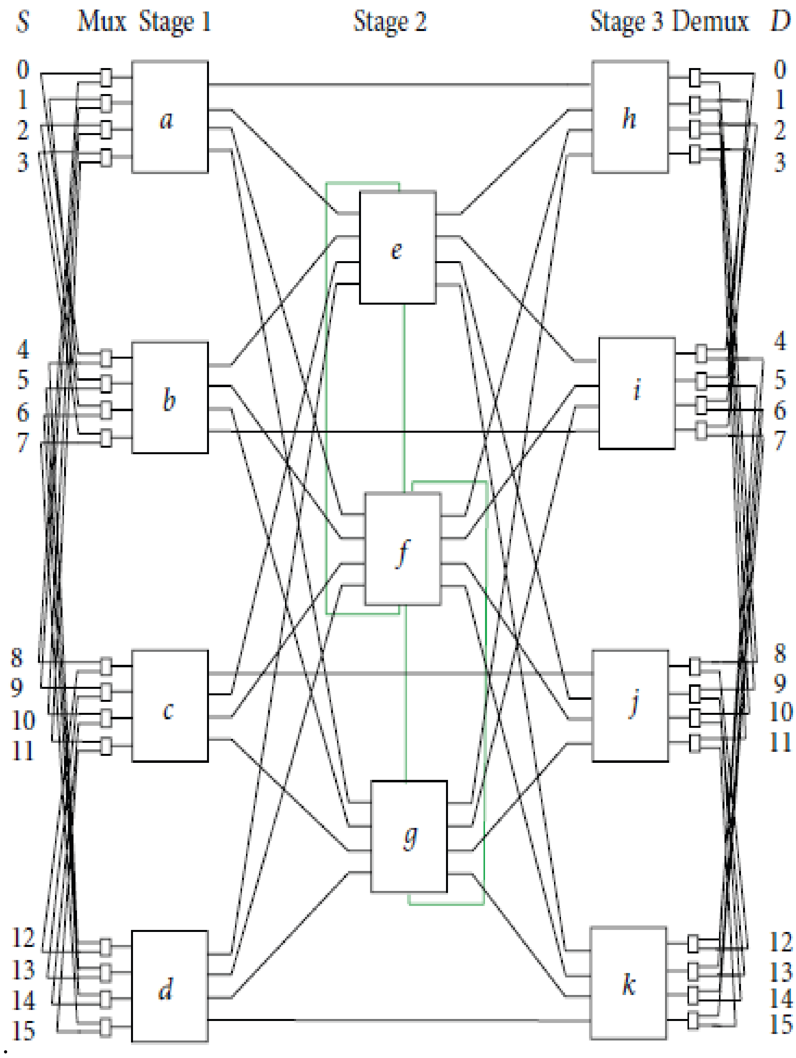

Fig. 13 AN IAON OF SIZE 16X16

III. COMPARISON OF MINs

In this paper MINs are compared on the basis of performance parameters. Comparisons are shown in table I.

TABLE I
COMPARISON OF MINs

Characteristics\ Networks	Fault-Tolerant	Cost-Effectiveness	Path Length	Reliability & Performance
ABN	This network has limited fault-tolerance.	Its cost is $N/2(3\log_2 N+13)$ which is less than that of IABN.	The network has multiple paths of same lengths between a given source to destination pair.	It is less reliable than related fault-tolerant networks.
IABN	It is more fault-tolerant than ABN.	Cost of IABN is more than that of ABN. Its cost is $N/2(5\log_2 N+9)+9\log_2 N$	Provides multiple paths of varying lengths between a given source and destination pair.	The network has better performance than ABN for both upper and lower bounds.
MABN	It is also a fault-tolerant network.	It is more cost-efficient than ABN. Its cost is $N/2(5\log_2 N+9)$	Provides multiple paths between a given source and destination pair.	MABN has high reliability and good performance than other related fault-tolerant networks.
ASEN-2	ASEN-2 is less fault-tolerant than IASEN.	Its cost is $3N(1.5\log_2 N-1)$	The network has multiple paths of different lengths between a given source to destination pair.	It is less reliable than IASEN.
IASEN	It provides better fault tolerance than ASEN-2.	It is more cost-effective than ASEN-2.	Provides multiple paths of varying lengths between a given source and destination pair.	IASEN has better reliability than ASEN-2.
IASN	It is also a fault-tolerant network	It is more cost-effective than ASEN-2 and IASEN.	IASN has unique and better path length in comparison to IASEN.	IASN has better performance than IASEN, and ASEN-2 networks.
IIASN	It is also a fault-tolerant network.	It is more cost-effective than IASN.	IIASN has unique and better path length in comparison to IASN and other popular irregular networks.	IIASN has better performance than IASN.
NIASN	It is better fault- tolerant network than IASN.	It is more cost effective than IASN.	NIASN has better path length in comparison to IASN.	It has better performance than IASN.

MASEN	It is better fault- tolerant network than ASEN-2.	It is more cost effective than ASEN-2.	MASEN has better path length in comparison to ASEN-2.	It has better performance than ASEN-2.
IASEN-3	It is better fault tolerant network than other popular irregular networks.	It is less cost-effective than other irregular fault-tolerant networks.	Provides multiple paths between a given source and destination pair.	It has better performance than IASEN ,IASN , and NIASN .
MALN	It is also a fault tolerant network.	It is more cost effective than AIAMIN.	MALN has better path length.	It has better performance than MABN.
AIAMIN-2	It has better fault tolerant than MALN.	It is less cost effective than MALN.	Provides multiple paths between a given source and destination pair.	It has better performance than MALN.
IAON	It has better fault tolerance than IASEN , IASN and NIASN as it is double switch fault tolerant.	It is more cost effective than IASEN-3.	IAON has better path length in comparison to IASEN and IASN.	It has better performance than NIASN.

IV. CONCLUSION

In this paper fault-tolerant multistage interconnection networks named Augmented Baseline Network (ABN), Irregular Augmented Baseline Network (IABN), Modified ABN (MABN), Augmented Shuffle Exchange Network (ASEN-2), Irregular Augmented Shuffle Exchange Network (IASEN), Irregular Augmented Shuffle Network (IASN), Improved Irregular Augmented Shuffle Network (IIASN), New Irregular Augmented Shuffle Network (NIASN) , Modified Augmented Shuffle Exchange Network (MASEN) , Irregular Augmented Shuffle Exchange Network–3 (IASEN-3), Modified Alpha Network (MALN), Advanced Irregular Alpha Multi-Stage Interconnection Network-2 (AIAMIN-2) and Irregular Advanced Omega Network (IAON) are surveyed and compared. Further, these different multistage interconnection networks are compared in terms of different parameters like fault-tolerance, cost-effectiveness, path length, reliability.

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