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A Fault-Tolerant Irregular Augmented Shuffle Exchange Network – 4

Sony Bansal[1], Dr. Harsh Sadawarti[2], Pawandeep Kaur [3]

[1]Research Scholar, Department of Computer Science & Engineering, PTU/RIMT-IET, Mandi Gobindgarh, Punjab, INDIA,

sonybansal12@gmail.com

[2]Director, PTU/RIMT-IET, Mandi Gobindgarh, Punjab, INDIA,

harshsada@yahoo.com

[3]Assistant Professor, Department of Computer Science & Engineering, PTU/RIMT-MAEC, Mandi Gobindgarh, Punjab, INDIA,

mangat_pawan27@yahoo.co.in

Abstract:

Inter-processors communication is one of the key issues of the system performance. The ability of networks to continue operating despite failures at minimum cost are major concerns in determining the overall system performance. In this paper, a new irregular multistage interconnection network is proposed named as Irregular Augmented Shuffle Exchange Network-4 (IASEN-4). The Performance of IASEN-4 is measured over some popular MINs in terms of permutation passable, fault-tolerance and cost effectiveness. It has been observed that IASEN-4 provides much better fault tolerance by providing more paths between any pair of source-destination at lesser cost as compared to other popular networks such as IASEN-3[12], IAON [8] and IASEN-2[11].

Key Words: Multistage Interconnection Networks, Irregular Augmented Shuffle Exchange Network, Irregular Advance Omega Network, Permutation Passable, Cost-Effectiveness.

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1. Introduction

Interconnection networks play a major role in the performance of modern parallel computers [5]. In this paper, an Irregular Augmented Shuffle Exchange Network (IASEN-4) has been designed and analyzed in terms of permutation passable, cost effectiveness and fault-tolerance. Permutation passable determines the data routing capability in the presence and absence of faults. This parameter is also analyzed in terms of Identity and Incremental Permutation. The proposed network is fault tolerant i.e. it provides service routing even under the presence of faults. Faults can be permanent or transient in nature. This proposed network (IASEN-4) is compared with the existing networks viz. IASEN-3[12], IAON[8] and IASEN-2[11] in terms of permutation passable and cost-effectiveness of network.

Section 1 Introduces the subject under study, Section 2 describes Proposed Interconnection network, Section 3 Routing Algorithm, Section 4 describes Cost Effectiveness Analysis, Section 5 describes Permutation Passable Analysis and Section V presents Conclusion.

2. PROPOSED INTERCONNECTION NETWORK:

IASEN-4 is an Irregular Augmented Shuffle Exchange Network -4. It 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). This proposed network consists of 2^n multiplexers of size 4x1 and 2^n de-multiplexers of size 1x4. The first and last stage of the network consist of equal number of switching elements (SEs) i.e. 2^{n-1} each whereas intermediate stage consist of less number of switching elements equal to 2^{n-2}. The switches in the first stage are of size 2x3, the switches in the last stage are of size 2x2 whereas the switches in the intermediate stage are of size 4x2. IASEN-4 is shown in **[Figure-1].**

In IASEN-4, SEs in first stage are categorized in 4 category i.e. main SE (MSE_1), first alternate SE(FAS_1), second alternate SE (SAS_1) and third alternate SE (TAS_1) as each source is connected with 4 SEs via multiplexer e.g. source 0 is connected with SE A, C, E, and G. It shows A, C, E and G are the main SE (MSE_1), first alternate SE (FAS_1), second alternate SE (SAS_1) and third alternate SE (TAS_1) respectively.

Similarly, the MSE_1, FAS_1, SAS_1 and TAS_1 for other sources can be obtained. In second stage, SE I and J are Primary SE (PSE_2) and Secondary SE (SSE_2) for the SEs A, B, C, and D. Similarly, SEs K and L are PSE_2 and SSE_2 for the SEs E, F, G and H. Further in third stage we have main SE (MSE_3), first alternate SE (FAS_3), second alternate SE (SAS_3) and third alternate SE (TAS_3). e.g. for destination 0, SEs A', B', E' and H' are MSE_3, FAS_3, SAS_3 and TAS_3 respectively.

Corresponding author: Sony Bansal

Similarly MSE_3, FAS_3, SAS_3 and TAS_3 for other destinations can be obtained.

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 [10] . Redundancy graph of IASEN-4 is shown in **[Figure-2]**. Graph depicts all the possible paths between a given source–destination pair within a MIN. In this figure, source S and destinations D are shown by black nodes. The rest of the nodes correspond to the switches that lie along the path between S and D. Following example describes all the possible paths from a particular source to a particular destination.

Example: Let source is 0 and destination is 3, all the possible paths are as follows:

Path 1: 0 →Mux (0) → A → A' → Demux(1) → 3
Path 2: 0 →Mux (0) → A → I → F'→ Demux(11) → 3
Path 3: 0 →Mux (4) → C → C' → Demux(5) → 3
Path 4: 0 →Mux (4) → C → I →F'→ Demux(11) → 3
Path 5: 0 →Mux (8) → E → K →A'→ Demux(1) → 3
Path 6: 0 →Mux (8) → E → K →B'→ Demux(3) → 3
Path 7: 0 →Mux (8) → E → L →C'→ Demux(5) → 3
Path 8: 0 →Mux (12) → G → K →A' → Demux(1) → 3
Path 9: 0 →Mux (12) → G → K → B' → Demux(3) → 3
Path 10: 0 →Mux (12) → G → L → C' → Demux(5) → 3

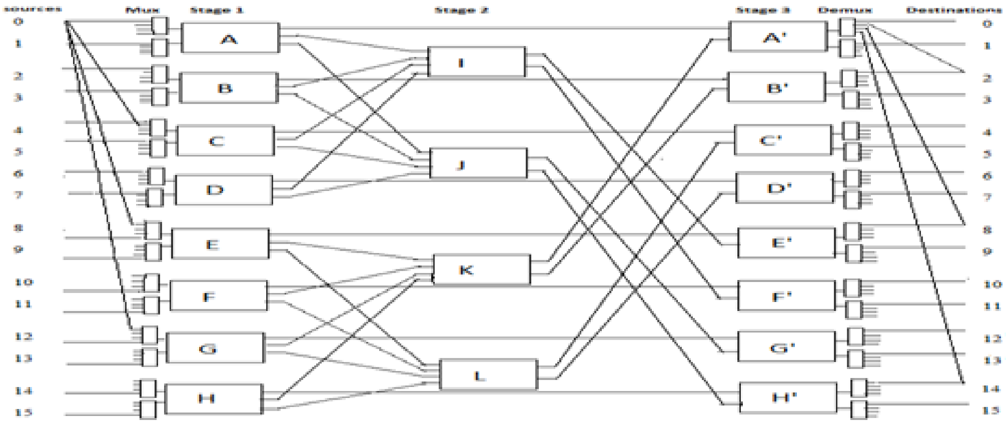

Figure 1: IASEN-4 of size 16x16

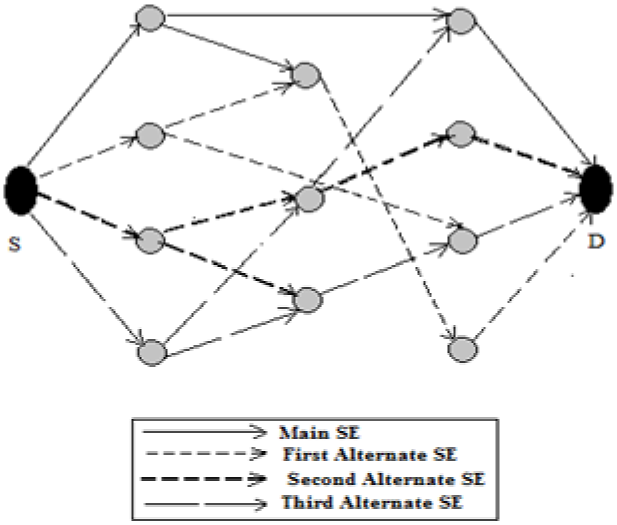

Figure 2: Redundancy graph of IASEN-4

3. ROUTING ALGORITHM OF IASEN-4:

In the routing algorithm of IASEN-4, initially data packets arrive on the main SE of first stage (MSE_1). If it is faulty then data packets will be received by the first alternate SE of first stage (FAS_1), If it is also faulty or busy then data packet will be collected by second alternate SE of first

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stage (SAS_1). If it is also busy or faulty then data packets will be collected by third alternate SE (TAS_1). If all the required SEs are faulty or busy then request will drop otherwise anyone of the SE i.e. MSE_1, FAS_1, SAS_1 and TAS_1 will collect the data packets.

Further, data packets will be sent to PSE_2. If it is faulty or busy then data packets will be sent to SSE_2. If it is also faulty or busy then communication is not possible and network will fail otherwise data packets will be sent to appropriate SE of third stage. In third stage, data packets will be collected by non- faulty SE. If all the required SE are faulty then network will fail otherwise data packet will be transmitted to given destination through de-multiplexer.

```
BEGIN
FIRST STAGE (Source)
    If $MSE_1$ == FBY
    $FAS_1$
    else SECOND STAGE
    If $FAS_1$ == FBY
    $SAS_1$
    else SECOND STAGE
    If $SAS_1$ == FBY
    $TAS_1$
    else SECOND STAGE
    If $TAS_1$ == FBY
    Drop the data packet
    else SECOND STAGE
SECOND STAGE (Source)
    If $PSE_2$ == FBY
    $SSE_2$
    else THIRD STAGE
    If $SSE_2$ == FBY
    Drop the data packet
    else THIRD STAGE
THIRD STAGE (Source)
    If $MSE_3$ == FBY
    $FAS_3$
    else send data packet to given D
    If $FAS_3$ == FBY
    $SAS_3$
    else send data packet to given D
    If $SAS_3$ == FBY
    $TAS_3$
    else send data packet to given D
    If $TAS_3$ == FBY
    Drop the data packet
    Else send data packets to given D
END
```

4. COST-EFFECTIVENESS ANALYSIS:

To estimate the cost of a network it has been assumed that the cost of a switch is proportional to the number of cross points within a switch. For example a 4x4 switch has 16 units of hardware cost whereas a 4x2 switch has 8 units of hardware cost. For the multiplexers and de-multiplexers, we roughly assume that each of mx1 multiplexer or 1xm de-multiplexers has m units of cost. The cost of IASEN-4 is evaluated as:

- Total no. of 2x3 switches = 8
- Total no. of 4x2 switches = 4
- Total no. of 2x2 switches = 8
- Total no of 4x1 multiplexer = 16
- Total no. of 1x4 de-multiplexer = 16
- Hence cost of the network is = 240

Table 1: Comparison of cost- effectiveness of IASEN-4, IASEN-3, IAON and IASEN-2

NETWORK	COST(in units)
IASEN-4	240
IASEN-3	288
IAON	278
IASEN-2	268

5. PERMUTATION PASSABLE ANALYSIS:

Permutation passable determines the data routing capability in the presence and absence of faults. A one to one correspondence between source to destination is called permutation. One of the major aspects of permutation is that it varies with path length [9].

To find out this parameter for a network, it is assumed that source and destination is represented by:

S_i (where i = 0, 1, …..N-1)

D_i (where i = 0, 1, ….N-1)

Permutation can be evaluated in two ways:

Identity Permutation

A one to one correspondence between same source and destination number is called Identity Permutation.

$S_i = D_i$

Where i = 0, 1, …..N-1

For e.g. connectivity between source to destination for identity is represented by:

S_0 - D_0, S_1 – D_1, ------------------- S_{15} – D_{15}

Incremental Permutation

In this each source is connected to destination in a circular chain.

For e.g.: A connectivity between source to destination for

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incremental is represented by:

$S_0 – D_3$, $S_1 – D_4$, $S_2 – D_5$, ----------$S_{15} – D_2$

There are two cases to find out the permutations

1. If fault is present in a single switch (Non-Critical Case)
2. If fault present in a loop (Critical Case)(If it is exists)

Table 2, Table 3, Table 4 and Table 5 shows Incremental (S_0 – D_3, $S_1 – D_4$, ----------$S_{15} – D_2$) permutation of IASEN-4, IASEN-3[12], IAON[8] and IASEN-2[11] and proves IASEN-4 has better permutation passable.

Table 2: Incremental permutation of IASEN-4

Faults	Total Path Length	Total No. of Passes	Avg. Path Length	Percentage Passable
Without	40	16	2.5	100
Mux	38	15	2.53	93.75
SE0 at S1	35	14	2.5	87.5
SE0 at S2	34	14	2.42	87.5
SE0 at S3	35	14	2.5	87.5
Demux	37	15	2.46	93.75

Table 3: Incremental permutation of IASEN-3

Faults	Total Path Length	Total No. of Passes	Avg. Path Length	Percentage Passable
Without	40	16	2.5	100
Mux	37	15	2.46	93.75
SE0 at S1	35	14	2.5	87.5
SE0 at S2	28	12	2.33	75
SE0 at S3	35	14	2.5	87.5
Demux	38	15	2.53	93.75

Table 4: Incremental permutation of IAON

Faults	Total Path Length	Total No. of Passes	Avg. Path Length	Percentage Passable
Without	44	16	2.75	100
Mux	41	15	2.73	93.75
SE0 at S1	33	12	2.75	75
SE0 at S2 A	32	12	2.66	75
SE0 at S2 B	20	8	2.5	50
SE0 at S3	33	12	2.75	75
Demux	41	15	2.73	93.75

Table 5: Incremental Permutation of IASEN-2

Faults	Total Path Length	Total No. of Passes	Avg. Path Length	Percentage Passable
Without	16	4	4	25
Mux	16	4	4	25
SE0 at S1	16	4	4	25
SE0 at S2 A	8	2	4	12.5
SE0 at S2 B	0	0	0	0
SE0 at S3 A	8	2	4	12.5
SE0 at S3 B	0	0	0	0
SE0 at S4	16	4	4	25
Demux	16	4	4	25

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6. ONCLUSION:

Faults are not a new issue in MINs. However, developing a MIN with high performance and great fault tolerability is an important factor in recent networks [8]. An irregular class of Fault Tolerant Multistage Interconnection Network called Irregular Augmented Shuffle Exchange Network-4 has been proposed and analyzed. It has been observed from table 1 that proposed network (IASEN-4) has lesser cost in comparison to existing fault tolerant networks. It has been also observed from the analysis of permutation passable that IASEN-4 is better than existing IASEN-3[12], IAON[8] and IASEN-2[11].

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