CHAPTER 2
Preliminaries and Background

The main task of interconnection network (IN) is to establish a fast and efficient communication among the processing nodes in a parallel computing system [1, 4, 5]. It can be classified in various categories based on the following strategies:

- Switching methodology
- Topology

According to the switching technique [3, 6, 15], it can be circuit switched network or packet switch network. In circuit switching, a physical path is established between a source and a destination. This technique is preferred for the messages of long size. The whole path is reserved for the message until it reaches at the given destination.

This is the major drawback of circuit switching technique [15]. In packet switching, the given message is divided into small packets for transmission from the sources to destinations through the network. In this technique, the path between the source and destination is not reserved for a single message and it is fully utilized by the data packets [6, 15].

Topology [1, 6, 15] is the pattern of the INs means it shows that how the switching elements (SEs) are connected to the other processing elements. Further, the connecting links in INs may be static or dynamic. In static, these links are fixed, e.g. ring, star, tree, mesh etc.

The static networks are also referred as the direct interconnection network since in this network each switch is directly connected to a processing element [15]. In dynamic, the links can be reconfigured e.g. bus, crossbar, mul-
ti-stage etc. The dynamic networks are also referred as the indirect interconnection network since some of the switches connected to the other switches [3, 4, 15].

2.1 Multi-stage Interconnection Networks

Multi-stage interconnection networks (MINs) are the most suitable network among all the previously proposed INs since it is dynamic, fault tolerant, cost effective and stellar in performance [1, 3, 5]. MINs come in the category of high speed networks. It has more than one stage and each stage consists of small interconnecting elements called the SEs.

Each stage in MIN connects with the previous and subsequent stage via the connecting links. At the one end it has the sources and at the other end it has the destinations. The sources and destinations are having connectivity via the given switching stages. Generally, the size of the SE is 2×2 in MINs. In figure 2.1, the author has shown the 8×8 omega network [16-19]. This network has 8 sources (S) and 8 destinations (D).

Figure 2.1. 8×8 Omega Network.
There are 3 stages in this network and each stage contains 4 SEs of size $2 \times 2$ for each one. In figure 2.1, the connectivity of all the given sources, stages, and destinations is shown. Further, MIN can be classified into the various categories based on the following parameters [1, 3, 15]:

- Number of paths
- Number of SEs
- Availability of paths

According to the number of paths [6, 15], MINs can be of single path nature or multipath nature. In single path, each source and destination are connected by a unique path in the network. This type of network cannot tolerate a single switch failure and therefore these are not used in the parallel communication system. The multipath networks provide more than one path between every pair of source and destination. High fault tolerability and good performance are the specialty of these types of networks.

According to SEs, MINs may be regular or irregular network [6, 15]. In regular MIN, the number of SEs are same in each stage whereas in irregular MIN, the number of SEs are not same.

Blocking and nonblocking [15] are two major categories of MINs which depends on the availability of paths. In blocking MINs, SE of some stage may gets multiple requests from the source or SE of the previous stage. In this case, the path will be blocked and data packets will not move towards the destination end e.g. omega network.

In nonblocking MINs, each source has multiple alternate paths in order to route the data packets towards the destination end. However, no two or more than two sources have the same destination e.g. clos network.
Further, the efficiency of MINs is the major concern of this thesis [1, 4-6]. A MIN can be made efficient when it does not have any fault or that can transmit the data in crucial faulty situations. Therefore, the author has provided five fault tolerant MINs and compared the proposed MIN with the existing MINs.

Although efficiency of a MIN depends on the various factors, but this thesis mainly emphasis on the switch fault problem and gave some contribution towards the crosstalk problem. Crosstalk [22-29] is also a critical problem in MINs. The data packets get distortion because of crosstalk and therefore performance of a MIN is degraded.

2.2 Faulty Switches in Multi-stage Interconnection Networks

Faults in MINs halt the data transmission process [30-35]. All the performance factors like throughput, processor utilization, and processing power are also affected because of faulty situations [21, 22].

In this thesis, faulty situations refer to the faulty switch problem. Sending data packets from a source to the given destinations through MIN in critical fault situations are only being possible when the network is highly fault tolerant [36-42].

Further, transmission of data packets from a source to a given destination through the MIN is possible in following situations.

- When the network is non-faulty.
- When the processing elements including switches are not busy.
- In case if the network has faulty switching elements, then it must have the sufficient number of alternate paths.
In figure 2.2, a simple 2-stage interconnection network has been shown [7].

![Diagram of 2-Stage Interconnection Network]

Figure 2.2. 2-Stage Interconnection Network.

In first stage it has 2 SEs i.e. A and B. In the second stage it has SEs C and D. Both SEs of the first stage are connected with SE C and D of second stage. To send the data from source to destination, the network provides the following alternate paths:

Path1: Source-A-C-Destination  
Path2: Source-A-D-Destination  
Path3: Source-B-C-Destination  
Path4: Source-B-D-Destination

If the SE A is faulty then data packets can take any route via SE B. If both SEs of the first stage are faulty then data transmission will be stopped. In case, if required SE is busy then data packets have to wait for their chance. Therefore, it can be said that for excellent data transmission one has to design a MIN which has following qualities [43-49]:

- Provides excellent communication between source and destination  
- Offers good bandwidth  
- Posses high fault tolerability  
- Takes minimum hardware cost
Based on the fault tolerability [50-54], the author has considered two types of MINs i.e. single switch fault tolerant and double switch fault tolerant. In single switch fault tolerant MIN; the MIN can sustain a single faulty SE in each stage simultaneously and transmit the data packets from the given source to the given destination effectively [55-58].

Further, the MIN that can sustain two faulty SE in each stage simultaneously known as double switch fault tolerant network [7]. In literature, various fault tolerant MINs have been proposed. However, obtaining a highly fault tolerant MIN is a critical challenge. To increase the fault tolerability, many INs have been explained in the next section.

2.3 Earlier Proposed MINs

2.3.1 Irregular Augmented Shuffle Exchange Network

This network [20] has m stages, where m=log₂N/2 and N is the size of the network. In the first and last stage, it has an equal number of SEs i.e. 8 switches in the first stage of size 3×3 and 8 switches in the last stage of size 2×2. The middle stage has four SEs of size 3×3.

The source address, destination address, multiplexer, and demultiplexer are represented by S, D, Mux, and Demux respectively. This network forms a loop in the first stage and provides multiple paths to avoid a fault. In IASEN, two SEs of each group are connected with each source and destination address with the help of Mux and Demux respectively.

Figure 2.3 shows the structure of IASEN [20]. The IASEN is an irregular interconnection network with high cost and low accessibility. Routing of data packets in IASEN depends on condition of the network. If the network has faulty SEs then alternate path is used for data transmission. In each stage, the most suitable SE is selected for data transmission. The SE can be said suitable if it is free and non-faulty in order to receive a request.
2.3.2 Modified Alpha Network (MALN)

MALN [21] has $N$ sources and $N$ destinations with $n = \log_2 N$ stages. There are two subgroups in MALN. Each subgroup has $N/2$ sources and $N/2$ destinations. The network has connectivity with all the sources and destinations via multiplexers and demultiplexers. Connectivity of SEs through auxiliary links are exists in stage n-3, n-2, and n-1. In figure 2.4, the structure of MALN is shown. The source address, destination address, multiplexer, and demultiplexer are represented by S, D, Mux, and Demux respectively.

In MALN [21], routing of data packets is based on the binary values of source and destination addresses. MALN has two subnetworks i.e. $G_0$ and $G_1$ as shown in figure 2.4. Initially, the MSB of the destination address is checked in order to select a subnetwork. After selecting a subnetwork, data packets will be sent to the appropriate SE. Appropriate SE means it is free and non-faulty otherwise data packets are routed through auxiliary links to send them on another appropriate SE.
If the required SE cannot receive the data packets due to fault or any other problem, then the request will be dropped. In the next step, the same process is repeated for further data transmission. Data packets always send to non-faulty SE. If all the required SEs are faulty and then the request will be dropped otherwise send towards the given destination.

2.3.3 Irregular Modified Augmented Baseline Network

IMABN[22] stands for irregular modified augmented baseline network.
A 16×16 IMABN [22] is shown in figure 2.5. The source address, destination address, multiplexer, and demultiplexer are represented by S, D, Mux, and Demux respectively. The given sources and destinations are further divided into two subgroups i.e. G₀ and G₁. Every source is connected to both groups via multiplexers e.g. SE A, B, C, and D exist in stage 1 and comes in subgroup G₀. These SEs make a conjugate subset. SE A and B make a conjugate pair, and SE A and C makes a conjugate pair.

Similarly, SE of subgroup G₁ has the conjugate pairs. In IMABN the size of each Mux and Demux are 4×1 and 1×4 respectively. The size of each SE in the first stage, second stage, and third stage is 3×3, 5×5, and 2×2 respectively. SEs of middle stage also have the auxiliary links. IMABN is based on the irregular topology. IMABN is a dynamic interconnection network and has more alternate path than the MABN [22].
2.3.4 Irregular Modified Augmented Baseline Network-2

Irregular modified augmented baseline network-2 (IMABN-2) is a five stage interconnection network [58].

![Figure 2.6. 16×16 IMABN-2.](image)

A 16×16 IMABN-2 is shown in figure 2.6. The source address, destination address, multiplexer, and demultiplexer are represented by S, D, Mux, and Demux respectively. In IMABN-2 the size of each Mux and Demux are 2×1 and 1×2 respectively. The size of each SE in first, second, third, fourth, and the fifth stage is 2×3, 8×3, 3×3, 2×8, and 3×2 respectively. It follows irregular network topology.

In the routing process [58], if a request arrives on a SE, then it forwards it towards the given destination side. If the SE is faulty then request arrives on the non-faulty SE. There are always two possibilities, both the required SE is available and fault free otherwise it is not available for data transmission or faulty. In the first case, data packets move to the given SE to get its given destination otherwise the request will be dropped.
2.3.5 Advance Omega Network

It is a blocking MIN [16]. The size of each SE in AON is 4×4.

![Figure 2.7. 16×16 AON.](image)

Figure 2.7. 16×16 AON.

It is the advance version of the omega interconnection network. A 2-stage interconnection network is shown in figure 2.7. In this figure, the source and destination are represented by S and D respectively. This network [16] is more fault tolerant than the omega network. There are 16 sources 16 destinations in figure 2.7. Designation tag routing is followed by AON in its routing methodology.

2.4 Crosstalk in Multi-stage Interconnection Networks

Crosstalk is the challenging problem in MINs [27, 28, 42]. The signal to noise ratio is affected because of crosstalk. It also limited the size of a network and therefore, MIN gets deprivation in terms of efficiency. It can be defined as:
“Crosstalk occurs when two signal channels interact with each other. In cross talk, a small fraction of the input signal power may be detected at another output, although the main signal is injected at the right output. For this reason, the input signal will be distorted at the output due to the loss and crosstalk introduced on the path [23].”

![Crosstalk diagram](image)

*Figure 2.8. Crosstalk in an electro optic SE.*

Crosstalk is shown in figure 2.8 [29]. To overcome the crosstalk problem, many approaches have been proposed in literature which is explained in the next section.

### 2.5 Methods to Reduce the Crosstalk in MINs

Basically, there are two approaches which are used to reduce the crosstalk in MINs i.e. space domain approach and time domain approach. These approaches are explained in the next subsections.

#### 2.5.1 Space Domain Approach

In space domain approach (SDA), a duplicate copy of a MIN is combined with the original MIN to minimize the crosstalk problem [29, 42].
This method requires more than the double network hardware to obtain the crosstalk free routes. Further, extra SEs and links are used in SDA. Therefore, it can be said that the space domain is an expensive and time consuming approach. The legal passes [23] are shown in figure 2.9.

2.5.2 Time Domain Approach

The time domain approach (TDA) reduces the crosstalk problem by allowing only one source and its corresponding destination address to be active at a time within a SE in the network [28,42]. Crosstalk is treated as a conflict in TDA. This approach makes its important because of various reasons like most of the multiprocessor system use electronic processor and optical MINs.

Therefore, there is a big mismatch between the processing speeds of the network carrying optical signals [23-29]. In TDA, permutation and semi-permutation is applied to the message groups so that each group is routed in a different time slot. A combination matrix is obtained by combining the given source and destination address.

Further, message partitioning is performed based on the combination matrix. The all activity is performed so that a particular set of messages should get their given destinations in the first pass in crosstalk free environment. The other messages are passed in next passes. There are various methods for message partitioning e.g. window method [23-27], improved window method [23-29], heuristic routing algorithms [23-29]. Message separation in window method is based on the bit pattern. If the bit patterns of two or more messages are same then they will be routed in the different passes.
This method also generates a combination matrix. This matrix has a window size $M-1$, here $M=\log_2 N$ and $N$ is the size of network. In window method, the first and last columns of combination matrix are always avoided and calculations are performed on the rest of the columns. Improved window method always avoids the first window and does the calculations on rest of the windows. This method takes less time as compared to window method. In heuristic routing approach, messages can be scheduled in four ways which are as follows:

- Schedule the messages in their increasing order.
- Schedule the messages in their increasing order.
- Schedule the messages in their lowest degree of conflict.
- Schedule the messages in their highest degree of conflict.

2.6 Conclusion

In this way, the author has explained the faulty switch problem and crosstalk problem. Both these problem creates a negative impact on the efficiency of MINs. Further, he has also given a brief description of earlier proposed methods regarding both problems. The author presents solutions against faulty switch problem in chapter 3 and 4. In chapter 5, he has given solutions against the crosstalk problem. He has mainly focused on increasing efficiency of MINs and therefore, he has proposed solutions in chapters 3, 4, and 5 towards these problems.