A Survey on Fault Tolerance Techniques Used in GIN

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ABSTRACT

An Interconnection network plays an important role in multiprocessor systems. It is always desirable to have multiple / redundant paths networks, to ensure high performance of these multiprocessor systems. A major class of multistage interconnection networks (MIN), called Gamma Interconnection Networks (GIN), is popular for its redundant paths connectivity between any source and destination pair. These redundant paths prove very useful, when a switch or link is faulty or busy. This paper discuss various techniques used to tolerate faults in GIN.

INTRODUCTION

The Gamma Network\(^1\) is an interconnection network connecting \(N = 2^n\) inputs to \(N\) outputs. It consists of \((\log_2 N) + 1\) stages with \(N\) switches per stage. These switches are connected with each other using 3 X 3 crossbar switch. The input stage uses 1 X 3 crossbar, output switch uses 3 X 1 crossbar and all the intermediate switches use 3 X 3 crossbar. A sample Gamma Network is shown in figure 1. The stages are linked together using “power of two” and identify connections such that redundant paths exist. The path between any source to destination is represented using any one of the redundant forms of the difference between source and destination. These redundant forms are generated using Redundant Number System.

The Gamma Network uses binary redundant form of difference between source and destination. This form is better known as tag or routing tag. A bit in routing tag can take three values : 1, 0 and -1. The routing tag \(T = (t_{n-1}, t_{n-2}, \ldots, t_0)\), where the first bit is MSB and the \(n^{th}\) bit is LSB. There are three possible interconnections possible at a stage \(i\). The data from switch \(j\) takes straight path to deliver data to switch \(j\)

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in stage $i+1$, take upward path to reach switch $(j - 2^i) \mod N$ and take downward path to reach switch $(j + 2^i) \mod N$.

The Gamma Network can realize perfect shuffle, cyclic shifts and permutive shifts. Researchers tried various ways to provide fault tolerance to GIN. This paper presents a survey of these techniques. The paper is organized as follows: Section II – discuss about faults, tolerance and need to tolerate faults, Section III – discuss various techniques used for fault tolerance in GIN. Section IV – is conclusions and findings, followed by the references.

**FAULTS AND TOLERANCE**

In order to provide reliable interconnection between each source and destination, one need to look into the availability of switching nodes and links. The Gamma network suffers through two serious problems – first, there is exactly one path when source $S =$ destination $D$ and second, the redundant paths available are not necessarily disjoint.

Generally, a node / switching element is said to be faulty if it is down due to non-functionality or busy with transfer of packets. There are two possible faults in the Gamma Network, either a SE i.e. switching element is faulty or a link connecting two nodes or SEs is faulty. When a SE is faulty, then either the Source or the SE at previous stage should take a decision about retransmission of message or rerouting the message through some intermediate SE. In case of a link failure, the node connected with it should be able to choose an alternate path to the destination. In following section we discuss various techniques used to tolerate these faults.

**FAULT TOLERANCE TECHNIQUES**

We try to focus the major attempts made to tolerate the faults and improve the performance as well as terminal reliability of the Gamma Network. The major work is done by providing additional hardware or altering the connection patterns. Whenever these changes are done new routing strategies get devised.
1. **Adding Extra Stage:** Adding extra stage to the Gamma Network, eliminates following two problems: first, the unique path between a source and destination when \( S = D \) and second, the number of paths for even tag value are less than the number of paths for odd tag values. To provide multiple paths for \( S = D \), an extra stage is added to the Gamma Network. The connection pattern for this extra stage can be any stage of gamma network. The routing tag is again made up of three possible values: 1, 0, -1. By using an additional bit for the extra stage one can generate the multiple paths from source to destination. The routing tags are generated in similar manner as that of the Gamma Network. The routing algorithm is a simple extension of routing in Gamma Network. The Extra Stage Gamma Network uses this concept to provide multiple paths, those could be followed to handle the faults. Figure 2 shows the extra stage gamma network.

![Extra Stage Gamma Network](image)

**Fig. 2: The Extra Stage Gamma Network**

2. **Providing Back Links:** In any multiprocessor system, the memory requests from processing elements are generated randomly, hence the path or memory conflicts are inevitable. By increasing switch sizes the path conflicts may be reduced, but memory conflicts still are unavoidable. Providing extra buffer space will certainly reduce the memory conflicts, but the implementations become very costly. Therefore, some networks use Backward Links to provide multiple paths, to cater with path / memory conflicts. The B-network is the network using this particular fault tolerant technique. Figure 3 shows the B-network. In this type of technique, the requests blocked due to path / memory conflict, are simply send back one stage and from there a new path is selected for the packet. In this approach, the packet may follow any number of back links, and then may get
forwarded to destination. Following are certain features observed with back links – 1) The backward links act as implicit buffers, 2) The backward links at very last stage can handle the memory contention, which can not be done by crossbars.

![Fig. 3: The B-Network with Backward Links Shown with Dashed Lines](image)

3. **Providing the Extra Link:** Some network architectures use an additional link that may connect to some additional SE in next stage. The Balanced Gamma Network uses this approach. In Balanced Gamma Network\(^5\), X 4 SEs are used at intermediate switches, and 1 X 4 and 4 X 1 SEs are used at input and output stages respectively. Figure 4 shows a Balanced GIN.

![Fig. 4: The Balanced Gamma Network](image)
It uses the distance tag routing. These networks are 1-fault tolerant. Two more modified GINs, namely, PCGIN⁶ and FCGIN⁶, make use of additional links at 0th stage. In PCGIN, all the nodes are connected to each other, forming a chain from 0 to N. It uses 2 X 4 crossbar at input, 3 X 3 at intermediate stages, 3 X 2 at n-1 stage and 2 X 1 at output switch. Using this layout it ensures at least 2 disjoint paths between any source to destination pair. It uses backtracking to tolerate faults. On the other side, FCGIN, uses a fully chained approach at each stage to avoid backtracking. Due to chaining at every stage, it provides distributed control and dynamic rerouting, hence a better fault tolerance is provided. Figure 5 shows PCGIN and Figure 6 shows FCGIN.
4. Changing the Interconnection Patterns: GIN uses $\pm 2^i$ interconnection pattern to connect various SEs at different stages. It provides multiple paths for many source to destination pairs. But for certain Source and Destination it provides unique paths, which prove risky if a node fails. Then for certain pairs the communication becomes impossible. One can provide multiple disjoint paths for all source to destination pairs by altering the interconnections between any stage $i$ and $i+1$. The Reliable Gamma Network (RGIN)\textsuperscript{7}, uses the altered interconnection patterns to provide multiple paths and disjoint paths. Figure 7 shows the RGIN.

![Figure 7: Reliable GIN](image)

Another network, called Monogamma Network\textsuperscript{8} also uses the altered interconnections to provide multiple paths between any source to destination pair, but they are not disjoint in nature. Figure 8 shows the Monogamma Network with same connection pattern used between stage 1 and 2.

![Figure 8: A Monogamma Network](image)
Another approach to provide multiple disjoint paths between any pair of source, destination – a cyclic interconnection was introduced. The approach was known as Cyclic Gamma Interconnection Network (CGIN)\(^8\). Here any interconnection pattern between any two stages can be repeated to provide multiple disjoint paths without increasing the hardware cost. As it uses, the repetition of connection pattern the pin count reduces. Figure 9 shows a CGIN.

![Fig. 9: Cyclic GIN Repeating Connection Pattern between Stage 0 -1 at Stage 3 - 4](image)

Another approach, Balance modified GIN\(^9\), reverses the connection patterns for upper links as compared with GIN, while keeping the connection patterns intact for lower and straight links. This approach balances the distances between any communicating pair. Figure 10 shows balanced modified GIN.

![Fig. 10: Balanced Modified GIN](image)
5. *By combining the switching elements*: 3DGIN\textsuperscript{10} is a network which combines the switches to provide 3 disjoint paths. Here, the switches at initial stage are combined together, the crossbars are 2 X 4. The intermediate stages use 2 X 3 and 3 X 3 crossbars, while the last stage uses 3 X 1 crossbar. It ensures without one lookahead, less hardware cost, 3 disjoint paths and two faults tolerance. Figure 11 shows a 3DGIN.

![Figure 11. 3DGIN](image)

**Findings**

The faults are inevitable in interconnection networks. While requesting the packets from memory elements, PEs always encounter faulty / busy links or nodes. The paper tried to summaries the techniques used to tolerate faults, by providing disjoint paths, multiple paths.

**REFERENCES**

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