International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

EFFICIENT COMMUNICATION IN INTERCONNECTION NETWORKS: A RELIABILITY PERSPECTIVE

Mr. Rohini Prasad Prajapati
Research Scholar, Awadhesh Pratap Singh Vishwavidyalay, Rewa, M.P.

Dr. Prabhat Pandey
Research Supervisor, Awadhesh Pratap Singh Vishwavidyalay, Rewa, M.P.

Dr. Deepak Kumar Singraul
Guest Faculty, Govt College Amarpur, Dindori, M.P.

ABSTRACT

Interconnection networks are the backbone of contemporary computer systems, allowing processor parts, memory units, and peripherals to communicate and exchange data quickly and efficiently. High performance and scalability across a wide range of computer applications rely heavily on their design and optimization. The suggested approach's simulation results are checked against those of the standard method. Validation findings demonstrate a reasonable degree of disagreement when evaluating the network dependability of particular benchmark networks by utilizing a small subset of spanning trees rather than the whole set. Important types of interconnection networks such as the hypercube, crossing cube, folded hypercube, mesh, and torus are examined and their dependability is assessed. We analyze and assess the network resilience of fully linked networks ranging in size from 3 to 10.

Keywords: Interconnection, Communication, Minimal path, Reliability, Hypercube

I. INTRODUCTION

An interconnection network is a vital component in the realm of computer systems and high-performance computing, serving as the backbone for efficient communication and data exchange among various processing elements or nodes. Its significance cannot be overstated, as it directly influences the overall performance and scalability of computing systems, ranging from data centers and supercomputers to multiprocessor systems and even embedded devices. Interconnection networks are the intricate web of pathways that enable communication between processing elements, memory units, and various peripherals within a computer system. Whether it's the nodes in a cluster, the cores in a multi-core processor, or the compute elements in a supercomputer, these networks facilitate the exchange of data, instructions, and information that underpin computing tasks. The efficiency, scalability, and fault tolerance of these networks have a direct impact on the overall performance and reliability of the entire system.

As the complexity and demands of computing systems have continued to evolve, the design and analysis of interconnection networks have become increasingly challenging and critical.

They must accommodate a wide range of communication patterns, from simple point-to-point transfers to complex collective operations, and be scalable to handle the growing number of components in modern systems. Furthermore, they must provide low latency, high bandwidth, and robust fault tolerance, all while keeping power consumption in check.

In this regard, the evaluation and analysis of interconnection networks play a pivotal role in ensuring that these networks meet the required criteria. Researchers and engineers focus on understanding the strengths and weaknesses of different interconnection network topologies, routing algorithms, and flow control strategies. They aim to optimize these networks to achieve optimal performance while addressing the specific needs of the applications they serve.

The field of interconnection network analysis and evaluation is vast and multifaceted. Researchers employ a wide array of methodologies, simulations, and performance metrics to assess and compare the performance of different network designs. It is a multidisciplinary endeavor that draws from computer science, electrical engineering, and mathematics. The goal is to provide insights and guidelines that can inform the design decisions for interconnection networks, ensuring that they meet the performance and scalability requirements of contemporary computing systems.

Interconnection networks come in a variety of topologies, each with its own strengths and weaknesses. These topologies determine the physical layout and connectivity of the nodes or processing elements within the network. Common interconnection network topologies include mesh, torus, hypercube, fat-tree, and butterfly, among others. The choice of topology depends on the specific requirements of the computing system, such as the number of nodes, the expected communication patterns, fault tolerance needs, and available resources.

For example, a mesh or torus topology is well-suited for systems with a large number of nodes and regular communication patterns, as they provide a straightforward, structured layout. On the other hand, hypercube and fat-tree topologies offer scalability and fault tolerance for larger systems, albeit at the cost of increased complexity in routing and switch design. The choice of topology is a crucial decision in network design, and it often involves trade-offs between factors like performance, scalability, and cost.

Routing algorithms play a critical role in guiding data packets or messages through the network from source to destination. The efficiency of routing algorithms directly impacts factors like latency, throughput, and the network's ability to adapt to changing traffic patterns. Algorithms can be deterministic or adaptive, each with its own set of advantages and drawbacks. Deterministic routing, which follows a fixed path, is often simpler to implement but may result in congestion or suboptimal performance in certain situations. Adaptive routing, in contrast, dynamically selects the best path based on network conditions and can provide better performance but requires more complex control logic.

Performance metrics are essential for quantifying and comparing the performance of different interconnection networks. These metrics help researchers and engineers evaluate the effectiveness of a network design in meeting the requirements of specific applications. Common performance metrics include latency, throughput, bandwidth, and network saturation. Latency measures the time it takes for a message to traverse the network, throughput quantifies the amount of data that can be transmitted in a given time, bandwidth denotes the capacity of the network to carry data, and network saturation determines the point at which the network is operating at full capacity.

II. REVIEW OF LITERATURE

Dash, Ranjan (2019) In order to determine the dependability of MINs, a novel graph-theoretic approach is proposed in this research. With the described procedure, MIN may be transformed into a reliability logic graph (RLG). A novel approach is provided to discover all the smallest cut-sets of the RLG and then utilizes inclusion-exclusion principle to assess the network dependability of the MIN. As an illustrative example of the suggested technique, we will use the Extra stage shuffle exchange network (ESEN). The values of network dependability estimated using the suggested technique and certain current analytical methodologies are compared and contrasted. This comparison assures the offered algorithms to be highly competent in predicting the dependability values of MINs. We have investigated the network dependability of nine distinct MIN types operating in the same functional context under varying situations (time dependent and time independent).

Gupta, S. & Pahuja, Gobind (2018) Redundant Multistage Interconnection Network (MIN) describes the Gamma Interconnection Network (GIN), which is being investigated for use in broadband communications. Terminal Reliability (TR), Broadcast Reliability (BR), and Network Reliability (NR) are only some of the Reliability indices that have been enhanced by recent developments. Despite these advances, there are still questions that have not been fully investigated, such as the complexity, cost, and number of alternative pathways assuming source and destination are fault-free. Fewer efforts have been put into analyzing BR and NR, but more have been put into analyzing TR. Despite the importance of network dependability for parallel processing systems, only networks of 8 by 8 nodes have been investigated in the literature. This study analyzes the current class of Gamma Networks in depth, and makes suggestions for improving the design in order to address and maybe eliminate the aforementioned drawbacks. When compared to existing networks, the proposed Gamma-Minus Network features more redundant routes. Proposed Network has been compared with other newly announced members of this class. The findings demonstrate that the newly suggested Gamma-Minus Network offers a disjoint minimal-path set for network sizes ranging from 8×8 to 1024×1024. This is achieved with higher reliability at lower cost and shorter route lengths. This study employs a routing technique that avoids backtracking overhead, hence reducing the time it takes for data to be sent.

Goyal, Neeraj & Rajkumar, S. (2017) Parallel and distributed systems often employ multistage interconnection networks (MINs) as switching fabrics to provide fast and efficient communication between high-capacity processors. Assessing MIN dependability is crucial to meeting network performance targets. Reliability research on MIN has looked at the standard features (two/broadcast/all terminal reliability). The demand for accurate evaluation of multi-cast nodes in a supercomputer setting rises in tandem with the number of input and output nodes. If you want to trace the sets of minimal pathways linking any MINs and judge the reliability (or lack thereof) of the connected expressions, try using the proposed Path Tracing Algorithm. The technique was tested by tracing the minimal route sets of various networks and evaluating the dependability of multi-source, multi-terminal nodes in networks with several levels of interconnection, proving its simplicity and robustness. The method also determines the total number of redundant and broken connections between any two points in the network. We evaluate, analyze, and contrast the reliability of various MINs.

Yunus, Nur et al., (2016) In parallel computing systems, interconnection networks provide communication between various components, including processors, memory modules, and other devices. Different interconnection networks may be distinguished from one another by to the number of stages, interconnection architecture, and kinds of SE utilized in the network construction. To give you an example, the process of developing interconnection networks involves a multitude of facets, each of which is very vital. It is possible that reliability is a significant component to consider while attempting assessing the performance of the network. The dependability of an interconnection network is directly proportional to the dependability of the network's individual components. In this article, we take a look at the many different topologies of interconnection, analyze the various communication protocols, and evaluate the dependability challenges that are associated with interconnection networks.

Bistouni, Fathollah & Jahanshahi, Mohsen (2016) The performance of parallel computers and multiprocessor systems is significantly impacted by the presence of multistage interconnection networks, abbreviated as MINs. The delivery of multicast traffic is a requirement that cannot be ignored for today's advanced computer systems. As a result, it is essential to develop effective MINs that are compliant with the routing requirement. Utilizing duplicated MINs is one of the primary concepts that have been proposed as a solution to this issue. However, one of the primary issues that arise with these networks is the problem of superfluous layer replication in the early stages. As a solution to this issue, a novel concept known as multilayer MINs has been recently proposed. Previous research has shown that this novel concept has the potential to result in topologies that are both cost-effective and have a performance that is quite similar to that of replicated MINs in terms of throughput. Additionally, the results of these analyses suggest that the delay performance of these networks is superior to that of replicated MINs. However, another essential criterion that must be satisfied to demonstrate a system's performance is its reliability. Therefore, in this paper, we will concentrate on the two essential parameters of cost and reliability in order to accomplish both goals; first, evaluating the performance of multilayer MINs in terms of reliability, and second, to find the best topology among the multilayer MINs introduced in previous works in terms of cost-effectiveness (mean time to failure/cost ratio). Both of these tasks are necessary in order to accomplish both goals.

Rajkumar, S. & Goyal, Neeraj (2015) In closely connected large-scale multiprocessor systems, multistage interconnection networks, or MINs, are frequently utilized for the purpose of achieving reliable data transfer. Because of their enormous complexity, the evaluation of the reliability of interconnection networks is still a difficult task. Because these metrics deliver results that are tailored to the needs of the user, there is an undeniable requirement for MINs to undergo reliability testing. Terminal pair reliability, often known as TPR, is the reliability performance metric of MINs that is used the most frequently. The purpose of this work is to offer a comprehensive overview of various dependability metrics as well as ways for evaluating these measures. In light of the comprehensive literature evaluation, gaps in the research are singled out and examined. After that, the multi-variable inversion procedure is utilized to assess the dependability of one of the most widespread MINs, specifically the Omega network, in a condensed format. The Omega, Omega with an extra stage (Omega+), and Omega with two additional stages (Omega+2) systems had their terminal, broadcast, and network dependability studied and compared. After that, we broaden the scope of our study by tracing the minimal path sets of a variety of MINs, and we assess and compare the terminal pair reliabilities.

Jena, Sudarson et al., (2012) As systems have gotten more complicated, the repercussions of their dependable behavior have been more severe in terms of cost, life, size, and so on. As a result, there is a growing interest in accessing system dependability and a growing need to improve the reliability of systems. Within the scope of this research, an analytical model for the reliability assessment of multipath multistage interconnection networks (MINs) is presented. The behavior of a variety of multipath MIN networks has been described in order to establish the fault tolerance. A comparison and analysis of the results will follow.

III. RESEARCH METHODOLOGY

The steps followed in the proposed method are as follows:

1. First, it creates all minimum pathways between any two nodes in the network that don't share an edge.
2. Second, if doing so does not create a cycle, the edge-disjoint minimum pathways from each source node to the remaining nodes are merged.
3. Step 2 is analogous to generating spanning trees in that it guarantees that all nodes in the interconnection network are connected without a cycle.
4. It is possible to build several spanning trees, one rooted at each source node, by repeating steps 1-3.

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

5. Next, we use sum of disjoint product approaches to these spanning trees to determine the network's dependability.

IV. DATA ANALYSIS AND INTERPRETATION

Comparison and Validation of the Proposed Method

The suggested method's accuracy is checked by comparing the computed network reliability to the conventional method's reliability computations for the same set of benchmark networks. Table 1 displays the verified outcomes and the total number of spanning trees employed. This table clearly demonstrates that the suggested technique uses a significantly smaller subset of spanning trees compared to the whole set of spanning trees when evaluating the dependability of the aforementioned network.

Table 1: Comparison and Validation of the Proposed Method against standard Method

Sl. No	Network	Network reliability Computed by standard method	Network reliability Computed by Proposed method	Number of spanning trees		% of error
				Used by Proposed method	Maximum Possible no.	
1	6N9L	0.9929	0.9752	18	81	1.79
2	7N10L	0.9717	0.9272	14	96	4.52
3.	8N11L	0.9701	0.9363	16	168	3.40
4.	8N12L	0.9715	0.9415	18	247	3.02
5.	8N13L	0.9923	0.9739	20	576	1.81
6.	9N14L	0.9705	0.9290	18	647	4.08

Network Reliability Evaluation of Regular Interconnection Network

The suggested approach is utilized on several types of interconnection network viz. Regular network, Irregular network, communication network etc. In this scenario, the hypercube (HC) and its variants (such as the twisted hypercube (THC), crossed cube (CC), varietal hypercube (VHC), fault tolerant hypercube (FTHC), folded hypercube (FHC), and three-dimensional torus and mesh) are of particular relevance as interconnection networks. Table 2 displays the results of this evaluation over a range of input link dependability values, from 0.1 to 0.9, along with the corresponding path set for this sort of interconnection network.

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

Table 2: Network Reliability Evaluation of Regular Interconnection Network

Sl. No.	p	HC	VH	CC	THC	FTH	FH	Mesh	Torus
1	0.1	0.0189	0.0281	0.0279	0.0279	0.1244	0.1244	0.0000	0.1017
2	0.2	0.0742	0.1029	0.1032	0.1032	0.2781	0.2781	0.0003	0.2120
3	0.3	0.1579	0.2137	0.2136	0.2136	0.4380	0.4380	0.0024	0.3343
4	0.4	0.2683	0.3471	0.3467	0.3467	0.5882	0.5882	0.0102	0.4667
5	0.5	0.3971	0.4909	0.4907	0.4907	0.7188	0.7188	0.0313	0.6033
6	0.6	0.5382	0.6343	0.6341	0.6341	0.8246	0.8246	0.0778	0.7344
7	0.7	0.6840	0.7658	0.7656	0.7656	0.9043	0.9043	0.1681	0.8480
8	0.8	0.8259	0.8752	0.8750	0.8750	0.9587	0.9587	0.3277	0.9320
9	0.9	0.9480	0.9539	0.9537	0.9537	0.9899	0.9899	0.5905	0.9780

Network Reliability Evaluation of Fully Connected Network

Table 3 displays the results of a calculation into the network dependability of a fully linked network with nodes ranging from 3 to 10. In the third and seventh columns of this table, we see the maximum number of spanning trees that can be formed and the time needed to generate them, respectively. In Column 4, we can see the total number of produced edge disjoint pathways connecting each node to all the others. It is clear from the table that the suggested technique uses a far less number of spanning trees than is strictly necessary, which results in significant savings in terms of CPU time.

Table 3: Network Reliability Evaluation of Fully Connected Network

S. No.	G(N,L)	No. of spanning trees		Total no. of edge Disjoint Paths generated from each node to the rest of nodes	Network reliability	CPU time to generate all possible spanning trees	CPU time required by proposed method
		maximum possible	used by proposed method				

1	G(3,3)	3	3	12	0.99	0.0109	0.012
2	G(4,6)	16	12	36	0.99	0.1147	0.022
3	G(5,10)	125	20	80	0.99	0.7489	0.0495
4	G(6,15)	1296	30	150	0.99	56.5741	0.0895
5	G(7, 21)	16807	42	252	0.99	121.6098	0.1580
6	G(8, 28)	262144	56	392	0.99	364.1097	0.1872
7	G(9, 36)	4782969	72	576	0.99	710.8720	0.2458
8	G(10, 45)	100000000	90	810	0.99	10761.9651	0.3408

V. CONCLUSION

The evaluation and analysis of interconnection networks utilizing the Edge-disjoint Minimal Path Method represent a vital and sophisticated approach to network design and optimization. This method's focus on ensuring robust, low-latency communication through the creation of redundant paths offers significant advantages in terms of fault tolerance and overall network performance. As we've explored the various components and considerations in this approach, including network topologies, routing algorithms, and performance metrics, it becomes evident that the Edge-disjoint Minimal Path Method holds promise for addressing the growing demands of modern computing systems. With the ever-evolving landscape of technology and the need for reliable and efficient communication in data centers, supercomputers, and emerging technologies, this methodology provides a valuable tool for engineers and researchers to enhance the performance and reliability of interconnection networks. Its continued development and implementation will play a pivotal role in shaping the future of high-performance computing and its diverse range of applications.

REFERENCES: -

1. Dash, Ranjan. (2019). Network Reliability Evaluation and Analysis of Multistage Interconnection Networks.
2. Gupta, S. & Pahuja, Gobind. (2018). Design and Reliability Evaluation of Gamma-Minus Interconnection Network. International Journal of Reliability, Quality and Safety Engineering. 26. 10.1142/S0218539319500037.

3. Goyal, Neeraj & Rajkumar, S.. (2017). Multi-source multi-terminal reliability evaluation of interconnection networks. Microsystem Technologies. 23. 10.1007/s00542-015-2743-9.

4. Panda, Deepak & Dash, Ranjan. (2017). Reliability Evaluation and Analysis of Mobile Ad Hoc Networks. International Journal of Electrical and Computer Engineering. 7. 479-485. 10.11591/ijece.v7i1.pp479-485.

5. Yunus, Nur & Othman, Mohamed & Zurina, Mohd Hanapi & Lun, Kweh. (2016). Reliability Review of Interconnection Networks. IETE Technical Review. 33. 1-11. 10.1080/02564602.2015.1130595.

6. Bistouni, Fathollah & Jahanshahi, Mohsen. (2016). Reliability analysis of multilayer multistage interconnection networks. Telecommunication Systems. 10.1007/s11235-015-0093-7.

7. Rajkumar, S. & Goyal, Neeraj. (2015). Reliability Analysis of Multistage Interconnection Networks. Quality and Reliability Engineering International. 32. n/a-n/a. 10.1002/qre.1941.

8. Yunus, Nur & Othman, Mohamed. (2015). Reliability Evaluation for Shuffle Exchange Interconnection Network. Procedia Computer Science. 59. 162-170. 10.1016/j.procs.2015.07.533.

9. Jena, Sudarson & Sowmya, G Sri & Radhika, Pulicherla & Reddy, Venkat. (2012). Reliability Analysis of Multi Path Multistage Interconnection Networks. International Journal of Computer Science & Information Technology. 4.