COMPARATIVE STUDY OF RELIABILITY EVALUATION TECHNIQUES IN SHUFFLE EXCHANGE NETWORKS

Gaurav Khanna[1], Dr. Rajesh Mishra[2]

[1]M. Tech. Scholar (WCN), [2]Assistant Professor, School of ICT, Gautam Buddha University, Greater Noida, U.P (India)

ABSTRACT

Multistage Interconnection Networks (MINs) have been widely deployed in parallel computing for switching data between processing elements in fast and efficient way. Here it is important to analyze the reliability of these networks because failure of switching element or link may cause the failure in routing data from one stage to another, so to increase the fault tolerance of MINs various methods have been suggested as to increase the number of stages, increase the number of disjoint paths, increasing the size of switching element etc. In this paper we consider Shuffle Exchange Networks (SEN) which have been widely considered as practical interconnection systems and its variants with one extra stage (SEN+) and two extra stages (SEN+2) to compare its reliability obtained using various techniques. We also analyze their hardware cost and compare the three variants of SEN based on different features.

Keywords: Additional stages, Fault tolerance, Multistage Interconnection Network (MIN), Reliability, Reliability Block Diagram (RBD), Shuffle Exchange Network (SEN), Switching Element (SE)

I. INTRODUCTION

Early work on interconnection networks mainly evolved with the needs of the communications industry, particularly in the context of telephone switching to provide fast and efficient communication, but with the growth of the computer industry, applications for interconnection networks within parallel processing machines began to become apparent, as a result a large number of interconnection networks were proposed for connection between processors and memory modules [1]. Examples of the widely used MINs include: Shuffle Exchange Network (SEN) [2], [8] and [9] Gamma Network [4], Extra-Stage Gamma Network [5], Delta Network [6], Banyan Network [14] and Cyclic Gamma Interconnection Network (CGIN) [7] etc.

Due to the size of its switching elements (SEs) and uncomplicated configuration, SEN is one of the most commonly used MINs. In this paper we compare SEN and its variants with respect to reliability evaluation techniques, hardware cost and prime features.

The remainder of the paper is organized as follows: Section 2 discusses structure of SEN and its three variants, Section 3 presents comparison of terminal reliability for SEN, SEN+ and SEN+2 using analytical, RBD and multi-decomposition method, Section 4 presents hardware cost analysis, Section 5 presents a comparative analysis table based on various features, and Section 6 concludes this paper.

II. STRUCTURE OF SEN AND ITS THREE VARIANTS

SEN is a single-path MIN i.e. it has only one path between any pair of input and output nodes, This uses two operations, these can be defined using an m bit-wise address pattern of the inputs, $P_{m-1}P_{m-2} \ldots P_1P_0$, as follows:

$S (P_{m-1}P_{m-2} \ldots P_1P_0) = P_{m-2} \ldots P_1P_0\, P_{m-1}$

$E (P_{m-1}P_{m-2} \ldots P_1P_0) = P_{m-1}P_{m-2} \ldots P_1P_0'$

Here P_0' denotes complemented value. With shuffle (S) and exchange (E) operations, data is circulated from input to output until it reaches its destination [2]. SEN+ (SEN with one additional stage) is its double-path version, and SEN+2 (with two additional stages) is its quadruple-path version [8].

SEN uses switching elements with only two states: straight through or cross connection. The number of switches per stage, the number of links and the connection between stages are consistent [9]. An 8 x 8 SEN with three stages, 12 switches (SEs) and 32 links is shown in Fig. 1. An 8 x 8 SEN+ with 16 switches and 40 links is demonstrated by Fig. 2. The addition of an extra-stage to the SEN allows two paths for communication between each input and output node pair. While the paths in the first and the last stages of the SEN+ are not disjoint, the paths in the intermediate stages do disjoint links traverse.

An 8 x 8 SEN+2 with 20 switches and 48 links is shown Fig. 3. There are four terminal paths between any pair of input and output nodes.

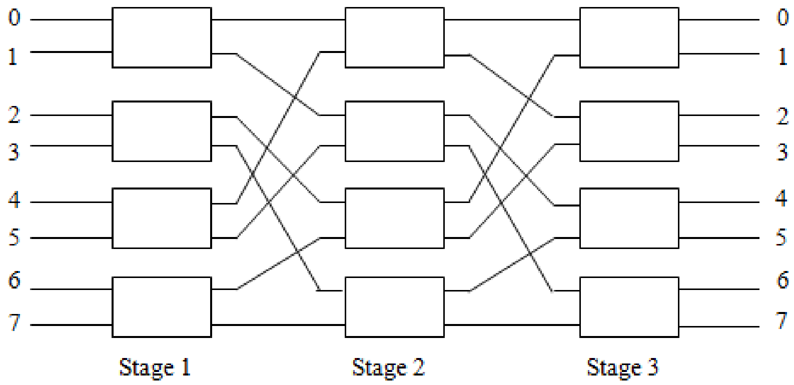

Fig. 1. A SEN of size 8 x 8

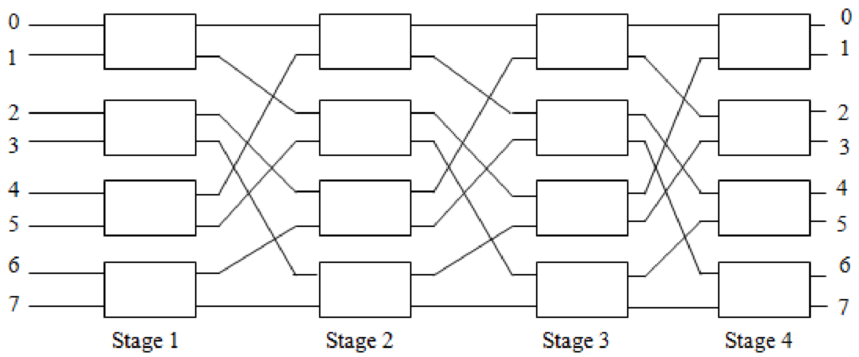

Fig. 2. A SEN+ of size 8 x 8

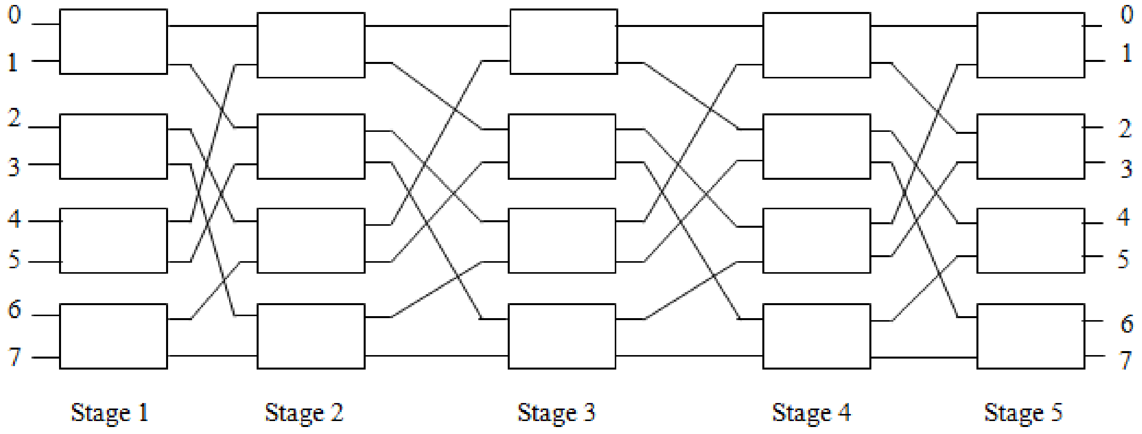

Fig. 3. A SEN+2 of size 8 x 8

III. COMPARISON OF TERMINAL RELIABILITY FOR SEN, SEN+ AND SEN+2 USING ANALYTICAL, RBD AND MULTI-DECOMPOSITION METHOD

Terminal reliability is defined as the probability of fault-free communication between any input and output node pair. In this section, terminal reliability of SEN, SEN+, and SEN+2 are compared. Most reliability modeling approaches in literature use either graph theoretic technique [10], [11], [15], [16] and [17] or state space method [3]. Accurate reliability computation of fault-tolerant networks of large size becomes unmanageable with existing tools. For example, using sum of disjoint products (SDP) techniques for a network of large size (higher than 32 x 32) the path enumeration and disjointing process takes large computer space and processing time [12]. In such a case, the main choice left is to strive for some straightforward and close estimation strategy like Reliability block diagram, simulation technique like Monte Carlo, Fuzzy Techniques etc. for computing the reliability of parallel computing systems.

As per our knowledge, in literature SEN's terminal reliability has been evaluated by using a simple analytical method proposed by Gunawan [9], Reliability Block Diagram (RBD) [8] and multi-decomposition method [13], we use the reliability obtained using the three techniques and compare them in Table 1- Fig. 4, Table 2- Fig. 5 and Table 3- Fig. 6, to find the best technique for terminal reliability evaluation to be used in evaluation of other complex MINs.

TABLE 1: Comparison of the values of Terminal Reliability of SEN computed by - Analytical Method, RBD Method and Multi-decomposition Method

Terminal Reliability	Switch Reliability	using Analytical Method	using RBD Method	using Multi-decomposition Method
0.0	0.90	0.7290	0.7290	0.7502
0.2	0.92	0.7786	0.7786	0.8056
0.4	0.94	0.8305	0.8305	0.8507
0.6	0.95	0.8573	0.8573	0.8679
0.8	0.96	0.8847	0.8847	0.9025
1.0	0.98	0.9411	0.9411	0.9605
1.2	0.99	0.9702	0.9702	0.9865

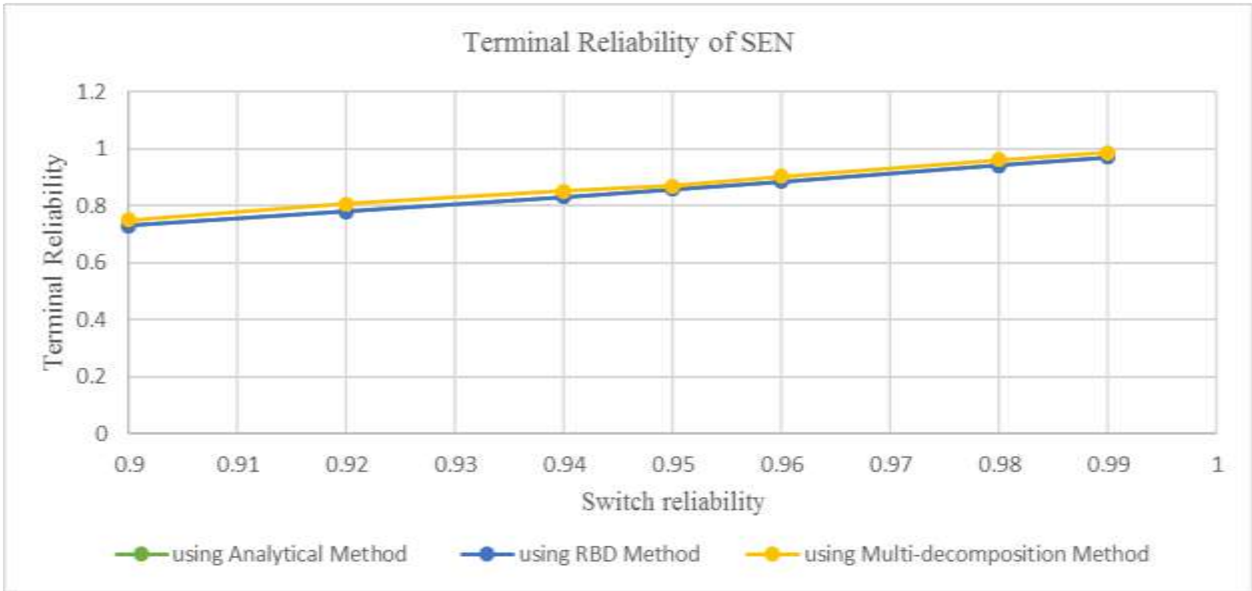

Fig.4. Graph of Terminal Reliability of SEN computed by - Analytical Method, RBD Method and Multi-decomposition Method

TABLE 2: Comparison of the values of Terminal Reliability of SEN+ computed by - Analytical Method, RBD Method and Multi-decomposition Method

Terminal Reliability	Switch Reliability	using Analytical Method	using RBD Method	using Multi-decomposition Method
0.0	0.90	0.7807	0.7807	0.8129
0.2	0.92	0.8264	0.8264	0.8420
0.4	0.94	0.8716	0.8716	0.8890
0.6	0.95	0.8939	0.8939	0.9109
0.8	0.96	0.9159	0.9159	0.9320
1.0	0.98	0.9588	0.9588	0.9667
1.2	0.99	0.9797	0.9797	0.9801

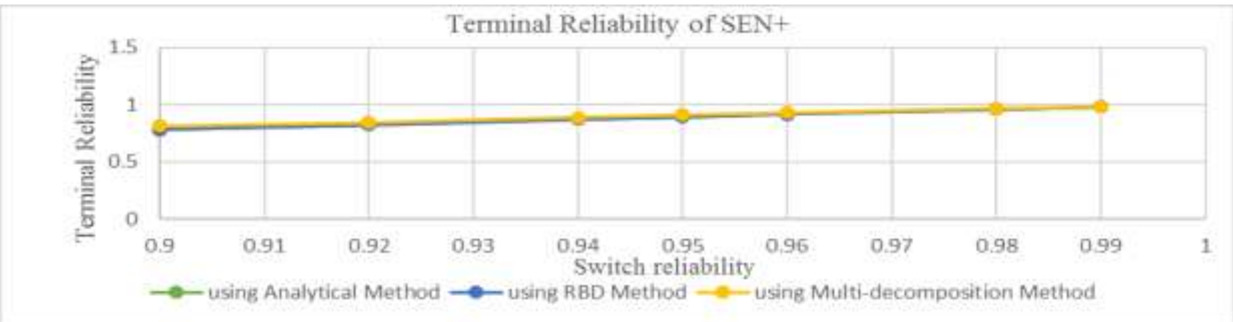

Fig.5. Graph of Terminal Reliability of SEN+ computed by - Analytical Method, RBD Method and Multi-decomposition Method

TABLE 3: Comparison of the values of Terminal Reliability of SEN +2 computed by - Analytical Method, RBD Method and Multi-decomposition Method

Terminal Reliability	Switch Reliability	using Analytical Method	using RBD Method	using Multi-decomposition Method
0.0	0.90	0.5209	0.7782	0.5409
0.2	0.92	0.5792	0.8249	0.6098
0.4	0.94	0.6518	0.8709	0.6930
0.6	0.95	0.6946	0.8935	0.7630
0.8	0.96	0.7426	0.9157	0.8165
1.0	0.98	0.8567	0.9588	0.9067
1.2	0.99	0.9234	0.9797	0.9508

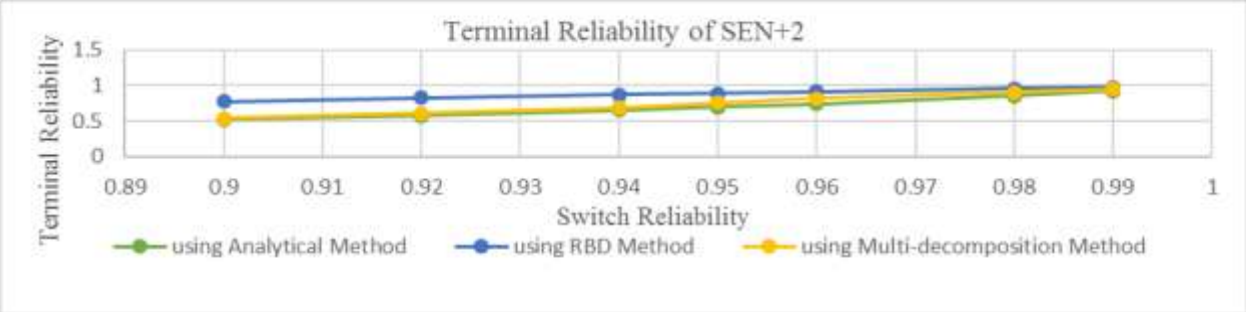

Fig.6. Graph of Terminal Reliability of SEN+2 computed by - Analytical Method, RBD Method and Multi-decomposition Method

Results show that Multi-decomposition method provides very accurate reliability values for SEN and SEN with one extra stage (SEN+). However, strangely for SEN+2, RBD produces much better results in comparison of multi-decomposition method.

IV. HARDWARE COST ANALYSIS

The crossbar switch sizes and the number of crossbar switches of various SEN architectures in each stage, for N = 8, are provided in Table 4. The cost of a network is calculated using design details as number of components like switches and links used in the network and number of connection points [6]. For a switch, its hardware cost is proportional to the number of cross points (total switch crossing points), i.e. number of gate counts used within the switch. Total cost of switches is calculated for SEN and its variants as product of number of input pins (I), output pins (O) and switches (S). The cost thus calculated is provided in last row of Table 4. A sample cost calculation is shown below for SEN:

Total number of 2 × 2 switching elements = 12 giving cost = $I \times O \times S = 2 \times 2 \times 12 = 48$.

Total cost of SEN for N = 8 is 48 units.

Table 4, reveals that the SEN+2 has highest cost and SEN has lowest cost, while SEN+ has cost intermediate to the cost of SEN and SEN+2.

TABLE 4: Size of Crossbar Switches and cost of SEN and its variants for N=8.

Stage No.	Crossbar switches [Input pins (I) x Output pins (O) x Switches (S)]		
	SEN	**SEN+**	**SEN+2**
1	2 x 2 x (4) = 16	2 x 2 x (4) =16	2 x 2 x (4) =16
2	2 x 2 x (4) = 16	2 x 2 x (4) =16	2 x 2 x (4) =16
3	2 x 2 x (4) = 16	2 x 2 x (4) =16	2 x 2 x (4) =16
4	--	2 x 2 x (4) =16	2 x 2 x (4) =16
5	--	--	2 x 2 x (4) =16
Cost = ∑ (I x O x S)	**48 units**	**64 units**	**80 units**

V. COMPARATIVE ANALYSIS BASED ON VARIOUS FEATURES

Table 5 shows the comparative analysis of the reviewed networks. For the comparison we have used features like Cost, Fault-tolerance, Switching elements, Links, Alternative paths, Stages, Reliability and Network complexity. This comparison may be easily extended with some other features and can be used to decide about the impact produced by increasing the number of stages or links or some other parameter on the cost and complexity.

TABLE 5: Comparative analysis of the reviewed networks

S. No.	Features	SEN (8 x 8)	SEN+ (8 x 8)	SEN+2 (8 x 8)
1.	Cost	48 units	64 units	80 units
2.	Fault-Tolerance	No	Yes	Yes
3.	Switching Elements	12	16	20
4.	Links	32	40	48
5.	Alternative Paths	No	Yes	Yes
6.	Stages	3	4	5
7.	Reliability	Lowest	Highest	Moderate
8.	Network complexity	$(N/2)*(\log_2 N) = 12$	$(N/2)*((\log_2 N)+1) = 16$	$(N/2)*((\log_2 N)+2) = 20$

VI. CONCLUSION

In this paper, we review three reliability evaluation techniques used in Shuffle Exchange Networks and its variants with extra stages. We infer that multi-decomposition technique is best of the three and can be used in other type of complex MINs in future. We also calculated the hardware cost of the three MINs namely SEN, SEN+, SEN+2 to reveal that SEN has the lowest cost out of the three and furthermore, we provide a comparative table that maps the various features to SEN, SEN+ and SEN+2. Through this our aim is to throw more light on Shuffle Exchange Networks.

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