Integrating Replicated Network in Reliability Shuffle Exchange Network System

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Abstract —Multistage Interconnection Network (MIN) offer an attractive way of implementing fast packet switches in communication networks. MINs are well known for its cost efficiency which enable economic solution in communication and interconnection. Important features in interconnection topologies are improvement towards performance and increment of reliability. With advancement in the multiprocessing field, an increasing focus need to be placed on multipath network. In this paper we proposed Replicated Shuffle Exchange Network topology to investigate the reliability performance and Mean Time to Failure. The results shows that the proposed provide highest reliability performance among all topological measured in this paper

Index Terms—Multistage interconnection network, shuffle exchange network, Benes, reliability performance, mean time to failure.

I. Introduction

Nowadays, interconnection networks are highly demanding in the switching process environment. MINs are known for its cost efficiency which enable economic solution in communication and interconnection [1]. MINs were operated by multiple stages with the input and output switches. MINs provide a unique path between every pair of source and destination. Therefore, the failure of a single switching element destroys several paths between the inputs and outputs [2]. The network topology is a key factor in determining a suitable architecture structure. A reliable interconnection network is a crucial factor to ensure overall system performance. The reliability performance is applied to measure the system ability to convert information from input to output. Reliability can be defined as the ability to ensure that a network works satisfactorily for a predefined time scale and environment [3]. For high reliability and performance, numerous methods have been recommended that offer fault tolerance to MINs [3]. Several of multipath MINs have been developed that offer alternate path in the network, however the challenge in accepting the new design to enhance of performance and reliability is become a crucial task [4]. Therefore, the major consideration when designing the network is keeping the complexity of the switch and links as low as possible [5]. Alternatively, the replicating approach has been applied to create multipath MINs [6]. This approach, offer the opportunity to decrease the number of stages in the network while maintaining the reliability performance [7]. Therefore, this paper will investigate the performance analysis of non-blocking MINs known as SEN and Benes network towards the terminal reliability performance. The topology measure in this paper consist of Shuffle Exchange Network (SEN), Shuffle Exchange Network with Additional Stage (SEN+), Replicated Shuffle Exchange Network (RSEN), Benes Network, Extra Stage Benes Network (EBN) and Replicated Benes Network (RBN).

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II. Background

When designing a communication network, reliability and Mean Time to Failure are important considerations, especially in the multistage interconnection network environment. With advancement in research field of multiprocessing, an increased focus needs to be placed on the reliability of multipath interconnection network [8]. Reliable operation in multistage interconnection networks depend on their topology, network configuration and number of stages in the system [9]. It is not possible to send all the source addresses at the same time to their corresponding destinations because it will create a major switch and link complete [10]. As the number of stage and system complexity increase the reliability performance becomes an important issues [11]. Mostly the basic network provide lower reliability performance as compared to modification networks. The previous researcher initiate the new approach by adding the stage replicating the network to increase the reliability performance [10], [12]. By adding the stage in the network, a fixed number of stages were added to the network to increase the reliability performance. The replicating approach has been applied to create multipath MINs [8]. The multipath MINs between each input and output in a network are provided by connecting the switching elements in the same stage. Replicating is a method to create the redundant path by replicate the network by L layer with the advantages of an auxiliary links [10]. The increasing number of layers in replicated

MINs can improve the reliability compared to basic and additional stage network.

A. Shuffle Exchange Network

Shuffle Exchange Network (SEN) consist of a unique path for each input and output pairs [11]. In this network, all SE are assumes as series connection. In this connection, the input for SE can be transmits either straight or cross connection. The connections between stages are shuffle exchange. SEN consist of *N* input and output switches with n stage where $n = \log_2 N$. SEN provide $(N/2)\log_2 N$ switching element in series [11]. Fig. 1 represents the topological view of SEN.

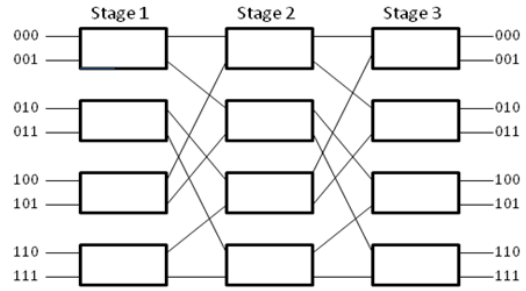

Fig. 1. Shuffle exchange network [11]

B. Benes Network

Benes topology is built through an extension of inverse Baseline. The first stage and the last stage of the inverse Baseline are merged. This lead to $2n-1$ stages for Benes networks. When switching is performed in the network, the Benes networks can be classified as non-blocking MINs [7]. Compared to others non-blocking MINs, Benes has the smallest complexity packet switched in the network. Fig. 2 shows the topology for Benes network.

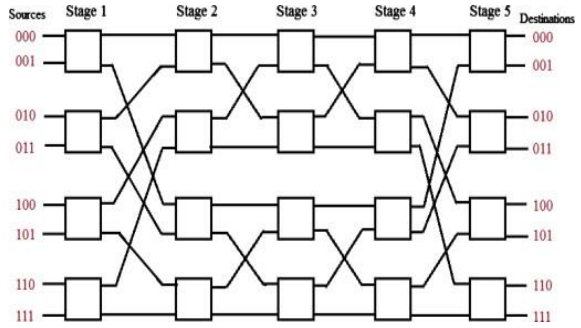

Fig. 2. Benes network [7]

C. Shuffle Exchange Network with Additional Stage

Shuffle Exchange Network with Additional Stage (SEN+) implementing by adding one extra stage to the network. SEN+ has four stages and *N* inputs outputs pairs. Referring to SEN+ topology the increment of stages lead to the increment of the number of switch and links. It consist of $n = \log_2 N + 1$ stages with *N/2* switching element for each stage. The additional stage of SEN+ has enabled extra path connection to provide double paths for communication process for each source and destination pairs [8]. SEN+ topology are illustrated in Fig. 3.

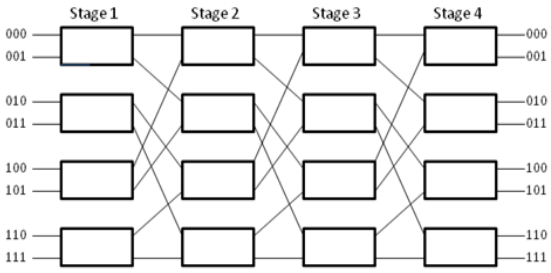

Fig. 3. Shuffle exchange network with additional stage [8]

D. Extra Stage Benes Network

Extra-stage Benes Network (EBN) was design to construct redundancy the number of paths between each source and destination pairs as shown in Fig. 4. This network improve the path length for each source and destination. However, the additional stage method is not efficient to be used in Benes network because this approach decreases the reliability in this network [6].

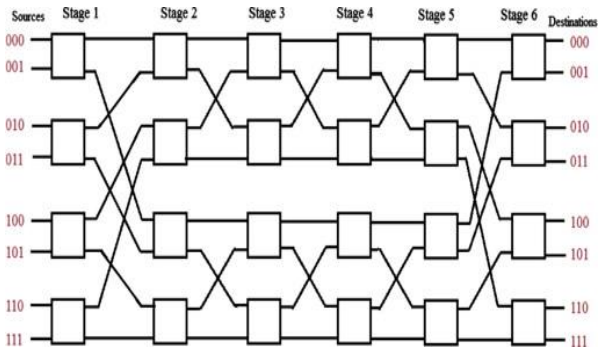

Fig. 4. Extra stage Benes network [6]

E. Replicated Benes Network

The design pattern of the Replicated Benes Network (RBN) is a modification from Benes network by replicating the network to create the redundant path [6]. The Replicated Benes are arrange in *L* layer. Normally, for RBN topology all switching elements are size 2×2. It has $[2(\log_2 N) - 1]$ number of stages. Replicated Benes Network is shown in Fig. 5.

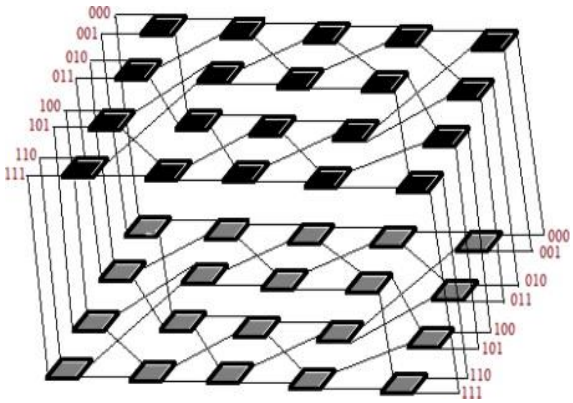

Fig. 5. Replicated Benes network [6]

III. Proposed Topology

In this section, we proposed a new topology named the Replicated Shuffle Exchange Network by replicating

the network on SENs topology. Different to the MINs, the replicated MINs lead to the out of order packet sequence due to the availability of multipath for each source and destination pair.

A. Replicated Shuffle Exchange Network Description

Replicated SEN enlarges regular SEN by replicate the network equal to L times. The corresponding input and output were synchronously connected. Packets received by the inputs of the network and distributed throughout the layers. Each series system is comprise $\log_2 N$ of SE. The rationale to sending packets belongs to the same source is to avoid packet order destruction. For the reliability purposes the increment of the number of layer will lead to a reliability improvement in the network. In a view of terminal reliability the system can be said as a parallel system, where the system consists of two series systems in parallel.

B. Replicated Shuffle Exchange Network Topology

Topology called the Replicated Shuffle Exchange Network was proposed. Replicated SEN adopted the SEN topology to create the multipath MINs, however there is some modification, the applied replicating method by replicate the network into $L = 2$ layer to create the redundant path and increase the reliability performance. Fig. 6 show the three dimensional view of the Replicated SEN with two layers of replication.

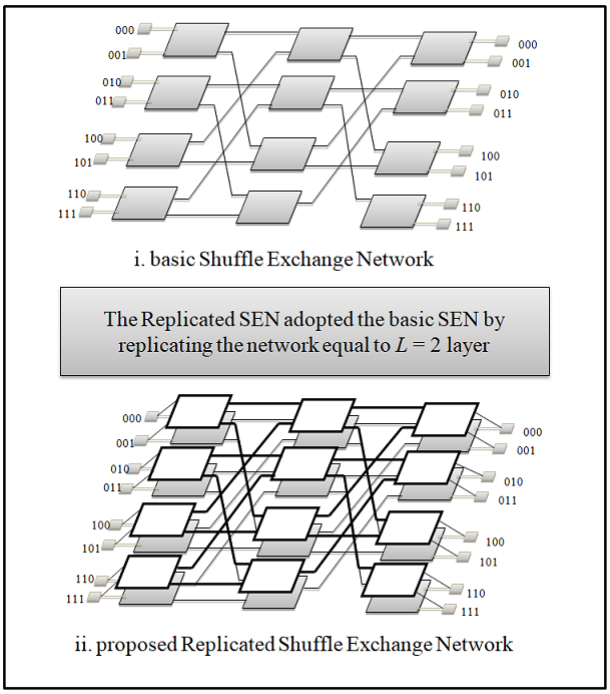

Fig. 6. Replicated shuffle exchange network

IV. Reliability Measurement

Interconnection network topologies provide the ability to improved performance and the reliability in the network. The reliability of an interconnection network is defined as measurement method to identify the capability of a system to converts information from the input to the output [13].The choice of interconnection network is dependent on a number of factors, such as the topology, routing algorithm, and communication properties of the network [14]. Reliability block diagram are applied to determine the overall system reliability even for large scale and complex system. Most researchers believe that the RBD method is one of the essential steps for system reliability analysis since the reliability analysis for RBD requires details calculation [3]. Therefore, this method can provide accurate information about reliability of the networks compared with others method. Terminal reliability can be describes for the possibility of existing of at least one fault free path connecting a selected of inputs and outputs pairs [9]. The basic switching element for time dependent reliability can be referred as r equal to (0.90-0.99). SEN consist of N input/output switches and $n = \log_2 N$ stage, where each stage has $N/2$ switching elements as shown in Fig. 7. The variable r can be defined as the possibility of a switch being operational. The terminal reliability for SEN topology are derived as follows:

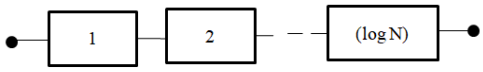

Fig. 7. Shuffle exchange network

$$SEN = r^{\log_2 N} \tag{1}$$

According to reliability block diagram of Benes topology as shown in Fig. 8, the terminal reliability for 8×8 can be calculated by following equation :

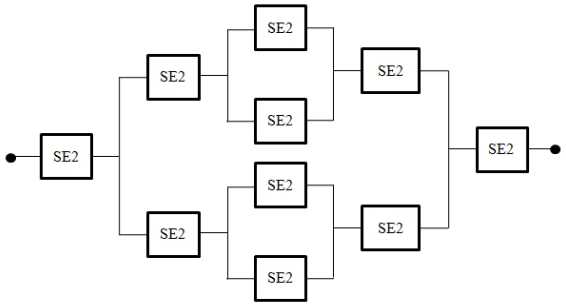

Fig. 8. Benes network

$$Benes = r^2[1-(1-(r^2(1-(1-r)^2)))^2] \tag{2}$$

SEN+ has two paths MIN. It consists of $\log_2 N + 1$ stages, providing two paths for communication process for each source and destination pairs as shown Fig. 9. The terminal reliability for SEN+ with $N \times N$ size are derived as follows:

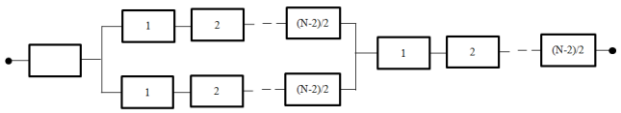

Fig. 9. Shuffle exchange network with additional stage

$$SEN+ = r^2[1-(1-r^{(\log_2 N)-1})^2] \tag{3}$$

Similar to Benes network, for EBN the terminal reliability for this topology can be formulated based on

the Fig. 10. Therefore we have the following equation to calculate the terminal reliability for EBN:

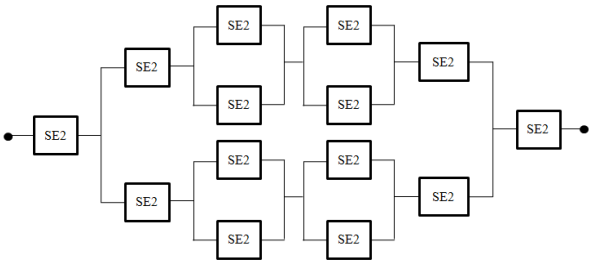

Fig. 10. Extra Benes network

$$Extra\ \ Benes\ Net. = r^2[1-(1-\ (r^2(1-(1-r)^2)^2))^2]\ (4)$$

The time dependent reliability of the basic switching element can be defined by r. By replicating the SEN topology it will improve the reliability performance as shown in Fig. 11. Therefore, the terminal reliability for Replicated SEN are derived as follows:

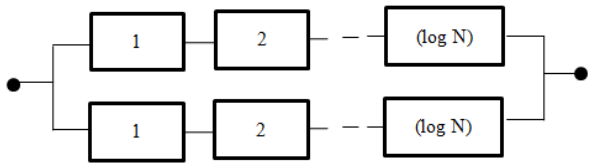

Fig. 11. Replicated shuffle exchange network

$$R.\ SEN = 1-(1-(r^{\log_2 N}))^2 \quad (5)$$

Furthermore, the replicated Benes arranged $L=2$ layer as shown in Fig. 12. Therefore the terminal reliability for 8×8 Replicated Benes can be calculated as follows:

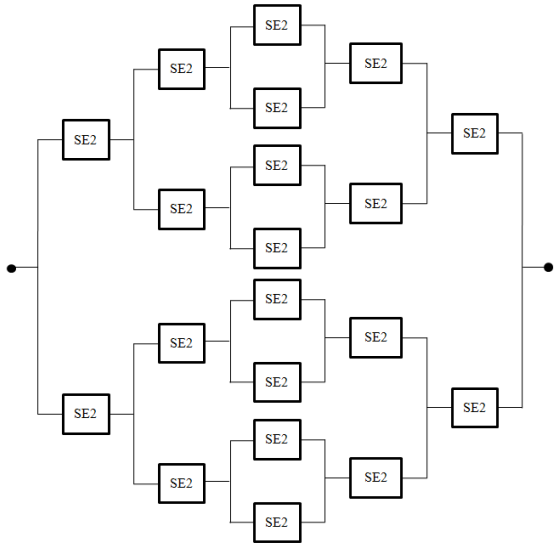

Fig. 12. Replicated Benes network

$$R.Benes = 1-(1-(r^2[1-(1-(r^2(1-(1-r)^2)))^2]))^2 (6)$$

V. Result and Discussion

This paper focus on the reliability measurement known as terminal reliability for the SEN and Benes network topologies including the SEN, SEN+, Replicated SEN, Benes, Extra Stage Benes and Replicated Benes. Fig. 13 shows for the basic network the results indicates that Benes network provide the highest reliability, since it provide more redundant path as compared to SEN topologies. For SEN+ and Extra Stage Benes network provide an equal reliability performance as shown in Fig. 14. In contrast with SEN, the Benes network reliability does not essentially affect by adding the extra stage in the network. Additional of extra stage in Benes network provide more complexity due to its configuration and redundant paths availability. For replicated topology, the results indicate terminal reliability for Replicated Benes is superior compared to Replicated SEN as shown in Fig. 15. The advantages of redundant paths in the Replicated Benes enhance the reliability in the network.

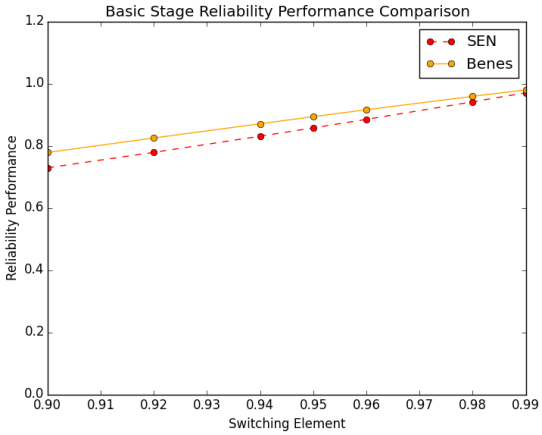

Fig. 13. Basic network reliability comparison

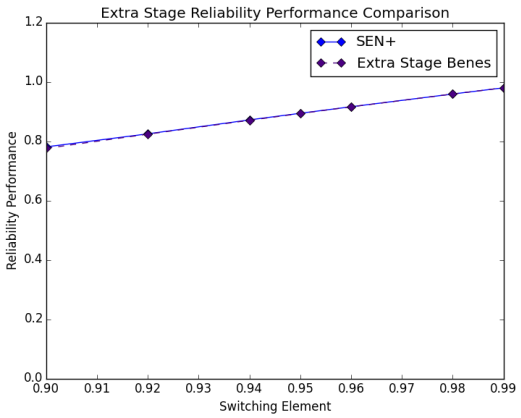

Fig. 14. Additional stage network reliability comparison

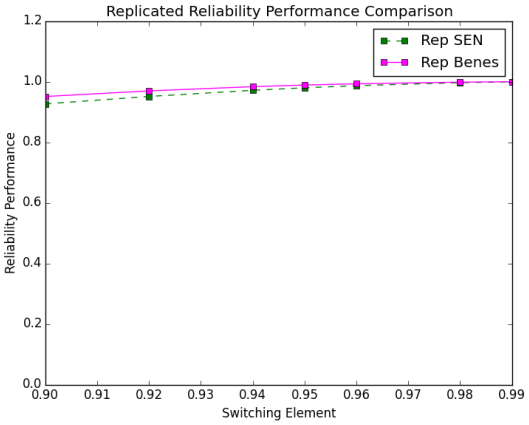

Fig. 15. Replicated network reliability comparison

In general, when the size of the network increase it will increase the failure rate in the network. However, it is shown in Fig. 16 - 18 the replicated network provide less failure rate as compared to single path network. It can be conclude that for each sizes comparison the Replicated SEN and Replicated Benes has a lowest failure rate as compared to other networks. Despite the equal failure rate in the network the replicated network for both network lead to highest reliability performance for SEN and Benes topology. The advantages of an auxiliary link and redundant path providing from the replicated network help to decrease the failure rate in the network.

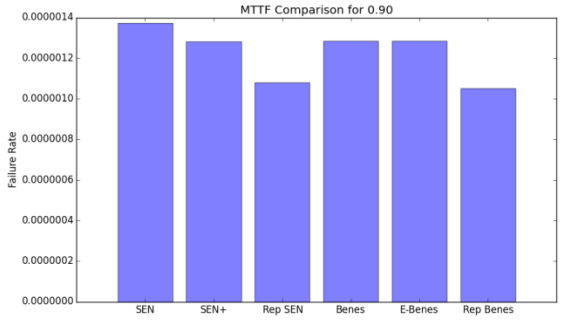

Fig. 16. MTTF comparison for r=0.90

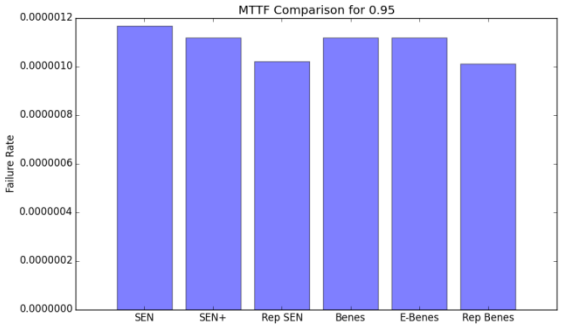

Fig. 17. MTTF comparison for r=0.95

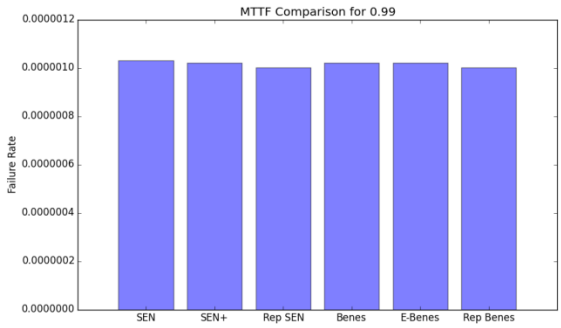

Fig. 18. MTTF comparison for r=0.99

VI. Conclusion

The network topology, the number of stage and the types of network configuration are difference for each interconnection network. The existed of additional paths in interconnection network resulting to the increment of reliability performance. The SEN topology itself has lower reliability performance due to the disadvantages of lesser stage and lesser path to route the message in the network compared to Benes topology. However, for overall performance the replicated network provides a higher reliability for SEN and Benes topology. The additional stage for both network enhance the reliability performance to small extent. It can be summarize that the replicated network provide the availability of more redundant path that can lead the network with highest reliability performance. An additional, the result shown that the replicating method achieve significant fault tolerance as compared to other network. The MTTF analysis showed that the replicated network perform in general more reliable compared to others network. The failure rate of replicated network is the lowest as compared other networks in general.

Acknowledgment

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