UNIVERSITI PUTRA MALAYSIA

INTEGRATING REPLICATED NETWORK WITH LOOPING METHOD FOR MULTISTAGE INTERCONNECTION NETWORK RELIABILITY

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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February 2022

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Faculty : Computer Science and Information Technology

Multistage Interconnection Network provides communication in parallel and high-performance computer systems related to memory modules, processors, and other devices. These networks are considered to offer a reasonable cost of implementation with efficient and fast communication. The interconnection topology, number of stages, and network configuration differentiate the reliability of each network. Reliability measurement for each network depends on the system performance component's reliability to deliver the information from source to destination pairs.

This thesis analyses the reliability performance in the shuffle exchange network environment. Shuffle Exchange Network and Augmented Shuffle Exchange Network are the types of MIN. In this network, the main problem arises when the switching element fails to route in the stages. Therefore, there is a concern to provide fault tolerance network to create a redundant path with an additional link between the source and destination communication. Enhanced Augmented Shuffle Exchange Network implementing the final looping method at the last stage to helps enhance the fault tolerance in the network, leading to higher reliability performance up to 16.65% and 1.11% as compared to SEN and ASEN. The final looping and double looping features help to minimize the failure at any links by providing an additional auxiliary link. Then, the alternate paths can be utilized in case of a fault in a path.

Due to link and switch failure, all the data from the source are not possible to be sent to the same destination simultaneously by using a single path network. Therefore it is essential to design a network that provides multipath data transmission. In this thesis we proposed, the integration of replicated network to Shuffle Exchange Network, Augmented Shuffle Exchange Network, and Enhanced Augmented Shuffle Exchange Network topology. We replicate the network into two layers for each network. The increasing number of layers will improve the reliability performance result within the

network up to 13.65% and 1.62% as compared to SEN and ASEN. The replicated network features provide more availability of redundant paths in the network.

A common problem in network design is creating a reliable and cost-effective network. Network topologies can connect links to different nodes, communicating with each other to transfer data. In addition, this thesis also integrates the hybrid network combination of Shuffle Exchange Network with Additional Stages and Benes network known as Shuffle Exchange Benes Interconnection Network. The implementation of Benes topologies in Shuffle Exchange Network makes a resultant topology that has advantages of Benes topology instead of having only Shuffle Exchange Network topology. This hybrid network consists of fewer switching since we reduce one stage from the Benes topology and combine with the Shuffle Exchange Network with Additional Stages to reduce the 20% of hardware cost.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENYEPADUAN RANGKAIAN REPLIKASI DENGAN KAEDAH GEGELUNG UNTUK KEBOLEHPERCAYAAN RANGKAIAN SAMBUNGAN BERBILANG PERINGKAT

Oleh

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Rangkaian Sambungan Berbilang Peringkat menyediakan komunikasi dalam sistem komputer selari dan berprestasi tinggi yang berkaitan dengan modul memori, pemproses dan peranti lain. Rangkaian ini dianggap menawarkan kos pelaksanaan yang berpatutan dengan komunikasi yang cekap dan pantas. Topologi rangkaian sambungan, bilangan peringkat, dan konfigurasi rangkaian membezakan kebolehpercayaan setiap rangkaian. Pengukuran kebolehpercayaan untuk setiap rangkaian bergantung pada kebolehpercayaan komponen prestasi sistem untuk menyampaikan maklumat dari sumber ke destinasi tujuan.

Tesis ini menganalisis prestasi kebolehpercayaan dalam persekitaran Rangkaian Pertukaran Rombakan. Rangkaian Pertukaran Rombakan dan Rangkaian Pertukaran Rombakan Ditambah mempunyai konfigurasi yang tidak rumit di dalam MIN. Dalam rangkaian ini, masalah utama timbul apabila elemen pensuisan gagal dihalakan secara berperingkat. Oleh itu, terdapat kebimbangan untuk menyediakan rangkaian toleransi kesalahan untuk mencipta laluan berlebihan dengan pautan tambahan antara komunikasi sumber dan destinasi. Rangkaian Pertukaran Rombakan Dipertingkatkan yang melaksanakan kaedah gegelung terakhir pada peringkat terakhir membantu meningkatkan toleransi kesalahan dalam rangkaian, yang membawa kepada prestasi kebolehpercayaan yang lebih tinggi sebanyak 16.65% dan 1.11% dibandingkan dengan SEN dan ASEN . Ciri-ciri gegelung terakhir dan gegelung berganda membantu meminimumkan kegagalan pada mana-mana pautan dengan menyediakan pautan tambahan. Kemudian, laluan alternatif boleh digunakan sekiranya berlaku kerosakan pada laluan.

Disebabkan kegagalan pautan dan suis, semua data daripada sumber tidak mungkin dihantar ke destinasi yang sama secara serentak dengan menggunakan rangkaian laluan tunggal. Oleh itu adalah penting untuk merekabentuk rangkaian yang menyediakan penghantaran data berbilang laluan. Dalam tesis ini kami mencadangkan, penyepaduan rangkaian yang direplikasi kepada Rangkaian Pertukaran Rombakan, Rangkaian Pertukaran Rombakan Ditambah dan topologi Rangkaian Pertukaran Rombakan Dipertingkatkan. Kami mereplikasi rangkaian menjadi dua lapisan untuk setiap rangkaian. Peningkatan bilangan lapisan akan meningkatkan hasil prestasi kebolehpercayaan dalam rangkaian sehingga 13.65% and 1.62% dibandingkan dengan SEN dan ASEN. Ciri-ciri rangkaian yang direplikasi memberikan lebih banyak ketersediaan laluan berlebihan dalam rangkaian.

Masalah biasa dalam merekabentuk rangkaian adalah untuk mencipta rangkaian yang boleh dipercayai dan kos efektif. Topologi rangkaian boleh menyambungkan pautan kepada nod yang berbeza-beza, berkomunikasi antara satu sama lain untuk memindahkan data. Selain itu, tesis ini juga mengintegrasikan gabungan rangkaian hibrid Rangkaian Pertukaran Rombakan Satu Peringkat Tambahan dan rangkaian Benes yang dikenali sebagai Rangkain Pertukaran Sambungan. Pelaksanaan topologi Benes dalam Rangkaian Pertukaran Rombakan menjadikan topologi terhasil yang mempunyai kelebihan topologi Benes dan bukannya hanya mempunyai topologi Rangkaian Pertukaran Rombakan. Rangkaian hibrid ini terdiri daripada pensuisan yang lebih sedikit kerana kami mengurangkan satu peringkat daripada topologi Benes dan bergabung dengan Rangkaian Pertukaran Rombakan Satu Peringkat Tambahan untuk mengurangkan 20% kos perkakasan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ABN	Augmented Baseline Network
ASEN	Augmented Shuffle Exchange Network
DEMUX	De-multiplexer
DL	Double Looping
E-ASEN	Enhanced Augmented Shuffle Exchange Network
E-ASEN DL	Enhanced Augmented Shuffle Exchange Network with Double Looping
EGN	Extra Group Network
GIN	Gamma Interconnection Network
IIASN	Improved Irregular Augmented Shuffle Exchange Network
IMABN	Irregular Modified Augmented Baseline Network
MA	Multiple Acceptance
MIN	Multistage Interconnection Network
MLMIN	Multi Layer Multistage Interconnection Network
MTTF	Mean Time To Failure
MUX	Multiplexer
PBN	Parallel Benes Network
R_ASEN	Replicated Augmented Shuffle Exchange Network
RBD	Reliability Block Diagram
R_EASEN	Replicated Enhanced Augmented Shuffle Exchange Network
ReNo	Reducing Node
RIN	Reliable Interconnection Network
R_SEN	Replicated Shuffle Exchange Network

RUFT	Reduced Unidirectional Fat Tree
SA	Single Acceptance
SCN	Scalable Crossbar Network
SEN	Shuffle Exchange Network
SEN+	Shuffle Exchange Network with Additional Stage
SEN+2	Shuffle Exchange Network with Two Additional Stage
TDMA	Time Division Multiple Access

CHAPTER 1

INTRODUCTION

1.1 Background

Advances in parallel and high performance computing field have placed the Multistage Interconnection Networks (MINs) as a potential choice of network system to fulfill the increasing demands in interconnection networks. MINs itself contains of multiple stages with switching element. MINs are categorized into two categories namely single path and multipath. Shuffle Exchange Network (SEN) extensively used and studied as preferred topologies by several researchers. Shuffle exchange network is associated with multiple stages of switches (Bistouni& Jahanshahi, 2014a).Shuffle-exchange networks are widely considered as practical interconnection systems due to its simple configuration and their size of switching element. From the previous work evaluation, it is shown that SEN has been able to offers a reliable interconnection network for input and output communication (Shilpa Gupta & Pahuja, 2019). The reliable operation of MINs is crucial to maintain the system performance. In order to increase the reliability performance within the network, numerous techniques have been applied to increased fault tolerance in MINs by modifying the network such as adding, reducing, augmenting, replicating and layering the network. The vast advancement in hybrid technology in the last few years offers excellent flexibility in usage. The general configurations and modifications can be planned and designed according to the users' requirements and the organizations that optimize their available resources. It proves to be more flexible, reliable, effective, and scalable than other networking topologies but at the same time challenging to manage and costly also.

1.2 Problem Statements

This thesis emphasizes the gaps as described below. Providing a reliable interconnection network is essential to increase the network performance target. Reliability performance hardware cost measurement is an essential consideration when developing a communication network, particularly in an interconnection network environment. The three main problems that motivate this research are as follows:

1. Multistage Interconnection Network was designed to offer effective communication within the switching network environment (Rajkumar & Goyal, 2016b) (Bistouni & Jahanshahi, 2014b). The main idea for fault tolerance is to create a redundant path with an additional link between the source and destination communication. The implementation of the early looping method has been used in ASEN to create an additional auxiliary links. In ASEN, the main problem arises when the switching element fails to route in the last stage of the network due to the unavailability of the final looping method. The unavailability of the final looping method will lead to decreasing in reliability performance (Bistouni & Jahanshahi, 2014b).

2. All the source addresses is not possible to be sent to the same destination at the same time by using a single path network since it will creating link and switch failure (Indra Gunawan & Fard, 2012). SEN is known as a single path network. These networks provide lower reliability performance than multipath networks. The limited number of paths within SEN results in the network being easy to fail for data transmission. The data transmission in SEN needs to employ the multipath network since it will provide an alternate path whenever the first path has any failure during the data transmission. Therefore, the implementation of multipath SEN is crucial to increase the reliability performance of data transmission (Jahanshahi & Bistouni, 2015).

3. Hardware cost implementation is an important measurement when designing the network. Many methods have been implemented to develop a reliable network by creating a multipath network in SEN, such as adding, layering, and replicating the stages within the network. However, those methods increase the reliability performance within SEN by creating the multipath network and, at the same time, will increase the hardware cost implementation. Those methods will increase the number of switches within the network to provide the multipath network. The increasing number of switching used in SEN will increase the hardware cost implementation within the network (Khanna et al., 2017).

1.3 Research Objectives

The main objective of this research to propose a reliable Enhanced Augmented Shuffle Exchange Network with looping method by implementing the topology in replicated network to improve the reliability performance. And also to implement hybrid network in shuffle exchange network to reduce the hardware cost. In order to accomplish the goals, the detailed objectives are defined as the following:

1. To propose an enhancement of shuffle exchange network topology by implementing the final looping and double looping method in Enhanced Augmented Shuffle Exchange Network and Enhanced Augmented Shuffle Exchange Network Double Looping to increase the reliability performance in multistage interconnection network.

2. To propose two layers replicated network in Shuffle Exchange Network, Augmented Shuffle Exchange Network and Enhanced Augmented Shuffle Exchange Network topologies to increase the reliability performance by creating multipath network in shuffle exchange network environment.

3. To integrate the hybrid network between Shuffle Exchange Network with Additional Stages topology and Benes network to reduce the hardware cost in hybrid shuffle exchange network.

1.4 Research Scope

In this research, the Shuffle Exchange Network topology was investigated, which has different connection patterns. Besides, this thesis also focuses on the integration of looping method, replicated network, and even hybrid network Figure 1.1 describes the flow of the thesis scope:

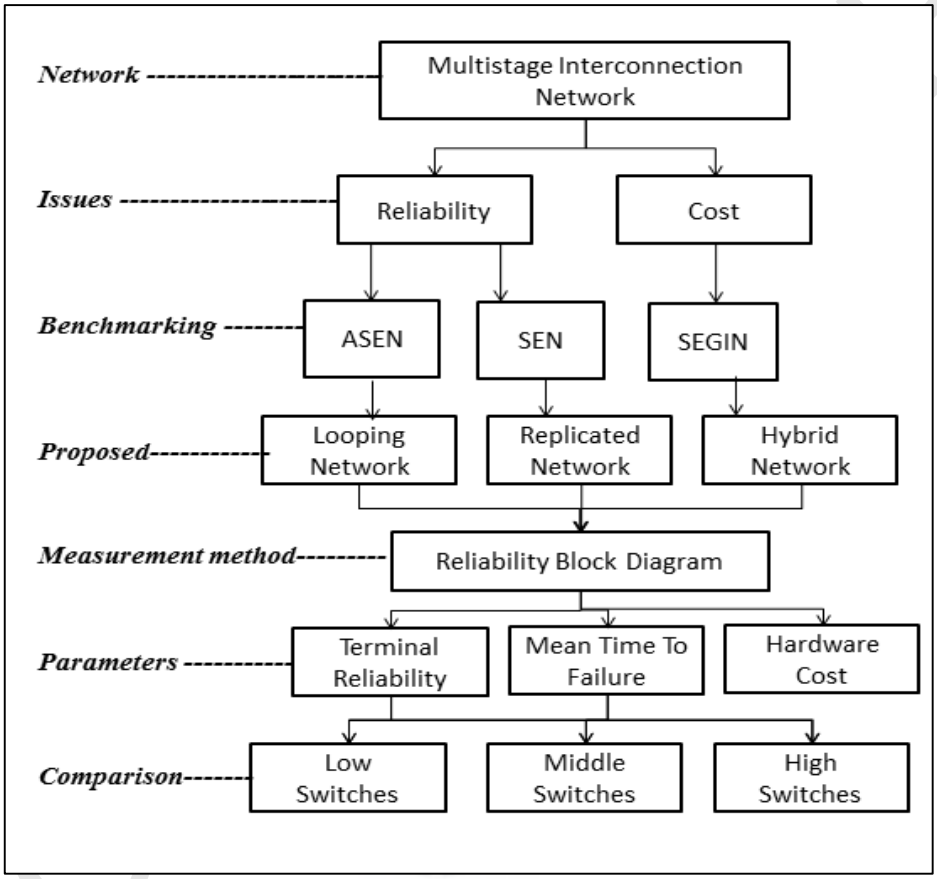

Figure 1.1 : Research Scope

1.5 Research Contributions

The main contribution of this thesis can be summarized from the results obtained from the studies as follows:

1. The implementation of final looping in proposed Enhanced Augmented Shuffle Exchange Network improved the results for the reliability measured in the reliability performance approximately 16.65% and 1.07% for SEN and ASEN

topology respectively. While the implementation of double looping in Enhanced Augmented Shuffle Exchange Network Double Looping increase the reliability performance approximately 16.70% and 1.11% for SEN and ASEN respectively.

2. For overall performance the integrating of looping network and replicated network in Replicated Enhanced Augmented Shuffle Exchange Network improved the results for the reliability measured in the reliability performance approximately 17.35%, 1.67%, 3.25% and 0.05% for SEN, ASEN, Replicated SEN and Replicated ASEN respectively. However, the implementation of two layer in replicated network also double the hardware cost for network implementation.
3. The hybrid Shuffle Exchange Gamma Networks improved the reliability measured in the reliability performance by approximately 7.41%, 7.41%, 0.8%, 7.5%, and 1.15% for SEBIN, SEN, SEN+, Gamma, and Benes network respectively. In contrast, for hardware cost comparison, SEBIN provides 20% lower hardware cost implementation than SEBIN.

1.6 Thesis Organization

This thesis is illustrated in seven chapters that provide an efficient background of information related to the shuffle exchange network in MINs. It also described the problem statement, including a list of objectives and contributions of this research. The remaining chapters are structured as the following:

Chapter 2 discusses the literature review overview, which covers the interconnection networks and reviews of the shuffle exchange network category and reliability measurement in networks. Also, present the related works towards the looping method and replicated network.

Chapter 3 explains the suggested methods of constructing the proposed approaches for message routing in MINs. A detailed description of shuffle exchange networks with different connection patterns in this research is explained here. Besides, this chapter also describes the performance evaluation used for data analysis in this research.

Chapter 4 explores the design and evaluation of shuffle exchange networks with a looping method called Enhanced Augmented Shuffle Exchange Network. It presents terminal reliability, mean time to failure, and hardware cost comparison in the network.

Chapter 5 describes replicated method in a shuffle exchange connection pattern called Replicated SEN, Replicated ASEN, and Replicated E-ASEN. The experimental results and the comparative analysis for reliability performance and hardware cost are shown in this chapter.

Chapter 6 presents a hybrid network in Shuffle Exchange Network with Additional Stages and Benes network called Shuffle Exchange Benes Interconnection Network. The reliability analysis and hardware cost comparison is investigated in this chapter. The conclusion and future works are concluded in Chapter 7.

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