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A new approach to improve reliability of the multistage interconnection networks ☆

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ABSTRACT

Because of their cost-effectiveness, multistage interconnection networks are widely used in parallel multiprocessor systems to make a connection among the processors and memory modules. One of the most important requirements for these communication systems is reliability. Adding a number of stages to these networks is one of the main approaches to promote this issue. Despite its modest cost and ease of implementation, this approach improves the reliability only to a small extent, which is not desirable, especially for large-scale systems. In this paper, we propose a new approach to improve reliability of the networks, called reducing nodes. Extensive reliability analyses from two major perspectives, terminal and broadcast, demonstrate that this idea can achieve a tremendous advantage over the aforementioned approach.

1. Introduction

An interconnection network consists of switches and links that connects N input channels to M output channels that can be used for internal connections among processors, memory modules and I/O devices. The role of interconnection networks is to transfer data among computer components in general, and memory and processors in particular. This is important for all parallel computers, whether they are on a single processor chip (a chip multiprocessor or multi-core) or built from multiple processor chips connected to each other forming a large-scale parallel computer. Therefore, design of an efficient interconnection network is a challenging issue for construction of efficient multiprocessor systems [1].

These networks can be divided into two main categories: *static* and *dynamic*. Static networks are composed of point-to-point connections which do not change during the execution of a program. The examples of this type of networks are linear array, ring, tree, star, fat tree, mesh, tours, systolic arrays, and hypercube. Dynamic networks are implemented using switched channels, which can be switched on to match the communication demands of the program. Dynamic networks include bus, crossbar, and multistage interconnection networks (MINs), which are often used in the multiprocessor systems [2]. Shared bus networks have lower cost but also lower performance because the network suffers from a performance bottleneck due to bus connections. On the other hand, the crossbar networks are the most efficient but the most expensive. MINs provide a compromise between the above networks because they provide efficient performance using a reasonable number of switches [2,3]. Therefore, MINs are often used in the context of SIMD (single-instruction multiple-data) and MIMD

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(multiple-instruction multiple-data) parallel machines and also are increasingly adopted for implementing the switching fabric of high-capacity communication processors, including ATM switches, gigabit Ethernet switches, and terabit routers [4]. For instance, MINs are frequently used to connect the nodes of IBMSP [5] and CARY X-MP series [6].

MINs can be categorized in two main classes: *single-path MINs* (*non-fault-tolerant MINs*) and *Multiple-path MINs* (*fault-tolerant MINs*). Typically, single-path MINs are built from switching elements of size 2×2 and the number of stages in an $N \times N$ single-path MIN is equal to ($\log_2 N$) and there are ($N/2$) switching elements in each stage. The network complexity is defined as the total number of switching elements of size 2×2. Therefore, the network complexity of single-path MINs is equal to ($(N/2) \times \log_2 N$) that is a reasonable complexity compared to the complexity (N^2) of the crossbar. However, a major problem in this kind of MINs is that there is only one path between each source-destination pair. Therefore, if one of the switching elements in the path fails, then the network will be down [7]. As a result, one of the main requirements in these networks is to improve the capability of fault-tolerant and reliability [7–12].

Fault-tolerance is the network ability to operate even in the presence of faults, albeit at a degraded performance. One of the main ideas to improve the fault-tolerance and reliability of the networks is to provide multiple paths between each source-destination pair can be used in case of faults. The multiple-path MINs are usually derived from the single-path MINs. In these networks, the main approach to provide multiple paths between each source-destination pair is to create redundancy in the network components such as switching elements and links.

A common method to improve the reliability of MINs is to increase the number of switching stages [3,9–11]. This approach can be used to provide multiple paths between each source-destination pair by adding the number of stages. One of the main reasons for the popularity of this method is its relatively low cost property. Because it increases the network complexity as merely one switching stage, therefore, this method is considered as a low-cost approach. Several researchers have proven that adding one switching stages to MINs can improve the reliability [3,8,11,13,14] that makes it attractive. However, there is a fundamental problem with this approach; it has been proven that adding more than one stage to network is not efficient in terms of reliability [8,14]. The main reason for this is the increased rate of network complexity resulting in reduction of reliability [8,14]. As a result, a high reliability cannot be brought into the network by using this method. In other words, the method of adding a number of switching stages to the network will increase the reliability to a small extent. However, we need a higher level of reliability in these networks, especially for large-scale systems with thousands of processors. Therefore, although this is a relatively low cost, but it cannot be an ideal solution for the problem of MINs reliability.

Given the above discussions, our motivation in this paper is to present a new approach providing a higher level of reliability in comparison with the adding a number of stages method. It should be noted that the proposed approach is entirely a new idea that was not presented in the previous works. The approach is based on reducing the number of input and output nodes providing multiple paths between each source-destination pair.

In order to prove the efficiency of the proposed method, like [3,8,11,14], firstly, we consider a common MIN, called shuffle–exchange network (SEN) to implement our approach on network and then we will compare our proposed approach with the previous one (I.e., adding a number of stages) in terms of reliability. Also, in order to prove the superiority of the proposed method in comparison with other modern methods, we will investigate its efficiency in contrast to recent ideas in the field of high-performance MINs namely multilayer MINs and replicated MIN [1,10,15].

The rest of the paper is organized as follows: A helpful background will be discussed in Section 2. The proposed approach, reducing nodes, will be presented in Section 3. In Section 4, network reliability is comprehensively analyzed. Finally, Section 5 concludes the paper.

2. Background

2.1. Motivation

The main approach for improving the fault-tolerance of MINs is creating redundant paths between each source-destination pair. Increasing the number of stages is one of the major ideas for creating redundancy in MINs paths [9–11,14]. Therefore, the question that arises here is what the impacts of increasing the number of stages on reliability are? Previous analyzes have shown that one extra stage have positive impact on the reliability of MINs [2,3,11,14]. However, another argument here is how the additional stage will affect the network reliability. To answer these questions, the reliability of three MINs SEN, SEN+ (SEN with one extra stage), and SEN+2 (SEN with two extra stages) have recently been analyzed [8,14]. In these studies, it is proved that adding more than one switching stage to MINs is not efficient in terms of reliability. The main reason for this is increased network complexity due to adding more than one stage. Therefore, in [8], it was concluded that adding the number of switching stages can lead to more reliability in MINs. But this improvement is limited and may not be responsive to large-scale systems. Therefore, we need to look for more advanced solutions for improving reliability and fault-tolerance of MINs.

According to the above discussions, the motivation here is to present a new approach with higher efficiency in terms of reliability important factors of MINs namely terminal reliability and broadcast reliability in contrast to the approach of adding a number of stages. The proposed method in this paper is based on reducing the number of input and output nodes providing multiple paths between each source-destination pair. For this, the approach is called as reducing nodes which will be explained in details in Section 3. The conducted analyses demonstrate that the proposed method can be achieved the aforementioned major requirements. Clearly, in this paper, our main focus is basically on the method of increasing the