Microprocessors and Microsystems 38 (2014) 991–999

Contents lists available at ScienceDirect

Microprocessors and Microsystems

journal homepage: www.elsevier.com/locate/micpro

A low overhead, fault tolerant and congestion aware routing algorithm for 3D mesh-based Network-on-Chips

Hoda Naghibi Jouybari *, Karim Mohammadi

College of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Article history:
Available online 5 October 2014

Keywords:
Three dimensional Network-on-Chip
System-on-Chip
Fault tolerant routing
Adaptive routing
Congestion

ABSTRACT

Nowadays, three dimensional Network-On-Chips (NOCs) have emerged as most efficient and scalable communication structures for complex and high performance System-on-Chips (SOCs). These structures are so susceptible to manufacturing and runtime faults. Thus fault tolerant routing is essential to increase reliability and performance of NOC-based SOCs. In this paper, we propose FT-DyXYZ, an adaptive fault tolerant routing to tolerate permanent faulty links in 3D mesh based NOCs that uses proximity congestion information to balance traffic. Our routing achieves fault tolerance without using routing tables, redundancy or global information of paths and faults. To evaluate performance of our routing, we compared it with fault tolerant planar-adaptive routing in terms of average packet latency, throughput and reliability. Simulation results demonstrate significant improvement of saturation injection rate, average throughput and reliability of our routing under synthetic traffic patterns.

1. Introduction

Recently, three dimensional integrated circuits (3D ICs) using stacking of multiple active layers connected with vertical Through-Silicon-Vias (TSVs) have been proposed to address some challenges of 2D ICs. This technology provides short interconnects, performance improvement, power consumption reduction and ability to integrate different types of dies that are stacked on top of each other (such as logic, memory, digital, analog or RF) [1,2].

Network-on-Chips (NOCs), as scalable and efficient communication structures for complex SOCs [3,4], together with short interconnects in 3D ICs have led to appearance of 3D NOCs for future complex and high performance SOCs.

On the other hand, by scaling trends and novel 3D technology in integrated circuits, some new mechanisms of defects will be occurred such as manufacturing defects, misalignments of TSVs and random open defects that may lead to system failures [5].

Thus utilizing some methods which introduce fault tolerance is essential for system reliability requirements. In NOC-based SOCs, fault tolerant routings are promising solution to increase reliability of communications between devices on the chip against faults that occur in manufacturing phase or system runtime.

In this paper, we propose an adaptive routing algorithm for 3D mesh based NOCs that can tolerate permanent faulty links and uses congestion information to balance network load. Our proposed routing has low overhead because of no need to any routing table, global information of faults and paths and redundancy of packets.

The rest of paper is organized as follows. In Section 2 related works on 3D NOC routing are reviewed. In Section 3, our proposed routing algorithm is described in details. Simulation results are presented and analyzed in Section 4 and finally Section 5 offers conclusion and future works.

2. Related works

Prior works presented so many fault tolerant routing algorithms for 2D NOCs [6–13]. But a few works have been proposed to tolerate faulty links in 3D NOCs. In this section we review some fault tolerant routings that have been designed for 3D NOCs.

In [14], Rusu et al. presented a reconfigurable inter-layer routing mechanism for partially vertical connected 3D NOC with heterogeneous topology of 2D layers. This method uses two virtual networks for deadlock avoidance.

Akbari et al. proposed AFRA [15], a simple and low overhead routing that can tolerate just vertical faulty links. This scheme relies on ZXY and XZXY routings in absence and presence of faulty links respectively. AFRA needs some global fault information, so some overhead is added to routers to store this information to route packets on fault free XZXY path.

* Corresponding author. Tel.: +98 9111292810.
E-mail addresses: hoda.naghibi@gmail.com (H. Naghibi Jouybari), mohammadi@iust.ac.ir (K. Mohammadi).

http://dx.doi.org/10.1016/j.micpro.2014.09.005
0141-9331/

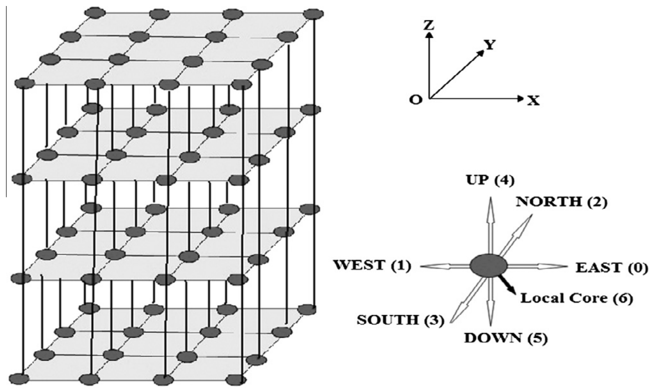

Fig. 1. A 3D mesh network with six directions.

In [16], a well-known fault tolerant routing named planar-adaptive, for 3D mesh and torus networks was proposed by Chien et al. This method makes use of adaptation in 2D planes and uses three virtual channels (VC) to avoid deadlock. In this scheme, convex faulty regions should be built to tolerate faults and route packets around these regions, so some healthy components of network will be disabled to build these convex regions.

Pasricha and Zou in [17], extended 2D turn models to define two 3D turn models to route packets without deadlock situations and provided fault tolerance by packet redundancy in high fault rates. In this scheme, one copy of original packet is generated in the source node and the algorithm sends each of them based on one 3D turn model through one VC, so two VCs are required in this routing scheme.

In [18] an adaptive routing was proposed by Nordbotten, et al. that achieves fault tolerance using intermediate nodes and routing tables are required to determine intermediate nodes.

Routing schemes that have been proposed until now, usually have high overhead of routing tables, data redundancy, global route or fault information to tolerate faulty links. These overheads increase area and power consumption that is not suitable for on-chip networks. Besides, to support runtime faults, global fault or route information needs to be updated frequently and this takes some cycles during which network may be unstable. Also some proposed routings need to build convex or rectangular faulty regions that lead to disabling some healthy components of network.

We propose a low overhead routing algorithm for 3D mesh NOC. Our method uses adaptive routing based on congestion parameter to route packets over less congested and fault free minimal path and if all of minimal paths are affected by faulty links, randomly chosen intermediate nodes are used to route packets.

3. Fault tolerant routing algorithm

In this section we describe our proposed routing algorithm, FT-DyXYZ (Fault Tolerant Dynamic XYZ), that is designed to tolerate design time and runtime permanent faults on 3D NOC vertical and horizontal links.

3.1. Preliminaries

The topology that is considered in our routing is 3D mesh. As is shown in Fig. 1 every node has six neighbors in the directions of east, west, north, south, up and down. The corresponding output ports for these six directions are respectively 0, 1, 2, 3, 4, 5 and 6 for the local core. Every node in the network is defined by its coordinates in 3 dimension of X, Y and Z as (node_X, node_Y, node_Z).

Each two neighbor nodes are connected through a bidirectional link. The fault model that is employed in our routing is based on the assumption that when a permanent fault occurs in one direction of a bidirectional link, that unidirectional link is considered as completely broken and other direction will work correctly.

We assume that every node is aware about its own faulty links and there is no need to any information about faulty links in the rest of network for each node.

3.2. DyXYZ routing

Dynamic routing method (DyXY) that was proposed by Li et al. [19] uses congestion information in proximity of each router to present a dynamic and congestion aware routing in 2D meshes. We use this method in our routing to distribute the load over the network for 3D mesh-based NOCs. So extended version of DyXY routing (DyXYZ) is used in our method to choose less congested path between minimal paths that a packet can move toward destination. DyXYZ routing algorithm is shown in Fig. 2.

```
  // destination node: dest: (dest_X, dest_Y, dest_Z)
  // current node: cur: (cur_X, cur_Y, cur_Z)
  // output set is an array that stores all preferred output ports based on minimal routing.

if  (dest = cur)
        Deliver the packet to the local core and exit;
else {
      if  (dest_Z > cur_Z)
              Add UP to output set;
      else if  (dest_Z < cur_Z)
              Add DOWN to output set;
      if  (dest_Y > cur_Y)
              Add NORTH to output set;
      else if (dest_Y < cur_Y)
              Add SOUTH to output set;
      if (dest_X > cur_X)
              Add EAST to output set;
      else if (dest_X < cur_X)
              Add WEST to output set;
      }
if (number of outputset = 1)
      Out_port = outputset[0];
else if (number of outputset > 1)
      Out_port = direction that has less congestion parameter.
```

Fig. 2. DyXYZ routing algorithm.