Analysis on Local Congestion of Network-on-Chip

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Abstract—**In Network-on-Chip (NoC), adaptive routing provides packets multi paths to reach their destinations. Thus, packets can escape the hot-spot nodes. However, as our study indicates that adaptive routing cannot distribute traffic evenly in the network as expected. A local region will be injected more packets than others, which makes congestion takes place in that local region. Local congestion has significant impact on network performance. In this paper, we carry out a detail studying on local congestion in NoC.**

Keywords-local congestion; Network-on-Chip; routing algorithm;

I. INTRODUCTION

As integration technology advances, more and more processing cores are integrated in a single chip [1]. The communication efficiency among these cores along with other factors decides the system performance. As a substitute of bus-based communication architecture, NoC is proposed to be the new interconnect mechanism [2, 3].

Topology, routing, arbitration, switching, and flow control are among the critical factors in determining NoC performance. The routing algorithm, defining which path (in deterministic routing), or paths (in adaptive routing) are allowed for every packet, is classified into deterministic routing and adaptive routing. Using an ideal routing algorithm the traffic will be evenly distributed in the network, eliminating congestion.

Unfortunately, we found that traffic is never evenly distributed in the network after detailed studying on the state-of-the-art routing algorithms, i.e. the Odd-Even (OE) routing [4], the APSRA routing [5], the RABC routing [6] and turn model [7]. Some local regions will be loaded more seriously than others. Congestion firstly takes place in those regions as more and more packets are injected into network.

Local congestion has great impact on network performance. Firstly, some communication pairs locate in the congested local region, that is, the source nodes and destination nodes are all in that region. After the local region is congested, the packet latencies for those communication pairs increase drastically. Secondly, some communication pairs have paths passing through the congested local region. Their packets arriving at that region have to also wait in line, increasing the packet latency.

In addition to account for packet latency increasing, local congestion can be used to explain why there is changing in network throughput. As observed in numerous papers, network throughput will drop after reaching the peak as more packets are injected into the network. It is related with local congestion. When network throughput reaches the maximum, congestion begins to occur in the network. However, at first, only the most loaded region is congested, not the entire network. Consequently, there are still nodes which are not congested. As more packets are injected into the network, those uncongested nodes before begin to be congested gradually. That is why network throughput drops continuously.

The rest of this paper is organized as follows: The local congestion of some routing algorithms is analyzed in Section 2. The application of local congestion is presented in Section 3. Finally, we conclude our paper in the last Section.

II. ROUTING ALGORITHM CONGESTS LOCALLY

In this paper, we study routing algorithms through detail simulations, the configurations are shown in Table 1. We use the *Noxim* [8] simulator which is an open source simulator and based on SystemC. The network payload traffic is regulated by packet injection rate (referred to as PIR).

TABLE I. SIMULATION CONFIGURATIONS

Simulator	*Noxim*
Topology	Mesh-based
Network size	7×7
Port buffer	Four flits
Switch technique	Wormhole switching
Arbitration	Round-Robin
Selection strategy	Random
Traffic scenario	Uniform, Transpose1, Transpose2
Packet size	Eight flits
Traffic distribution	Poisson
Routing algorithm	turn model, OE, APSRA, RABC

In uniform traffic, packets generated at a node are sent to other nodes with the same possibility. For a symmetrical network of size N, packets generated at node (i, j) are all sent to node (N-1-j, N-1-i) in transpose1 traffic scenario. In transpose2 traffic, node (i, j) only sends packets to node (j, i).

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We start from a fully adaptive routing. Glass and Ni propose the turn model [8] for adaptive routing. Three routings can be generated from turn model, west-first, north-last, and negative-first, where negative-first (NF) is fully adaptive for transpose2 traffic.

In the first simulation for NF routing and transpose2 traffic, we record the buffer utilization for every switch. The results are depicted in Figure 1.

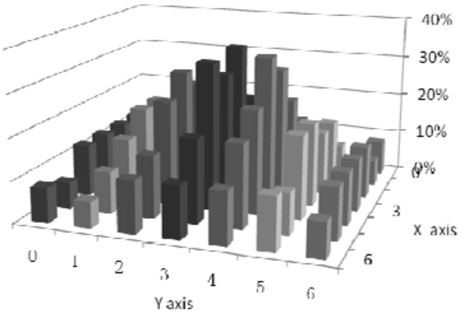


Figure 1. Buffer utilization of NF under transpose2.

It is well known that under fully adaptive routing, traffic in the network tends to congregate in the middle of the network. As observed from Figure 1, the buffer utilizations of the central switches are higher than others. Those switches have to process more packets than other switches around them. Consequently, congestion will firstly take place in that local region.

We then run the simulation 200 times. In each simulation, we record the communication pair which transmitted the largest latency packet. After the simulations, the recorded number for each communication pair is summed. The results are shown in Figure 2.

As observed from Figure 2, each communication pair which transmitted the largest latency packet has paths passing through the central region of the network. If a packet is forwarded to the busy region then its latency will be large.

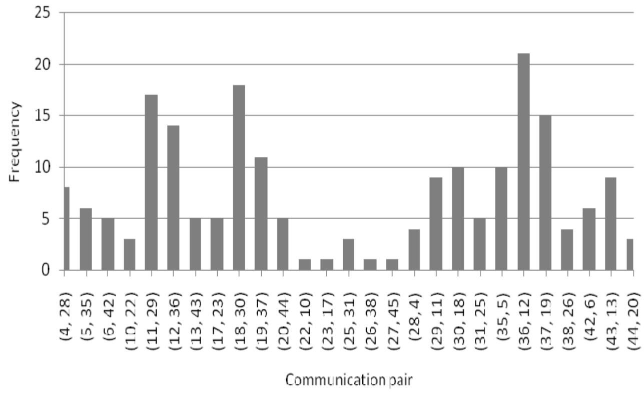
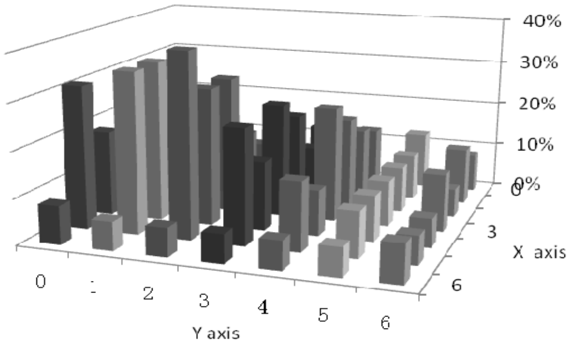
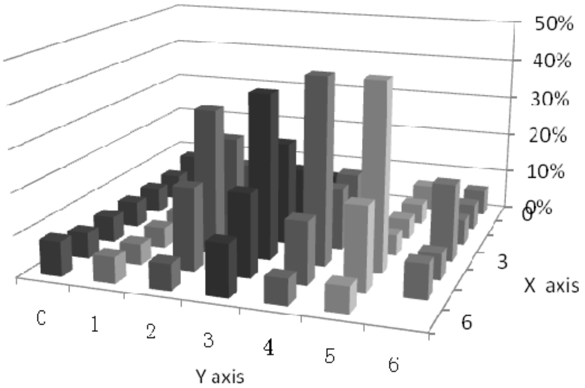


Figure 2. The communication pairs which have the largest latency packet.

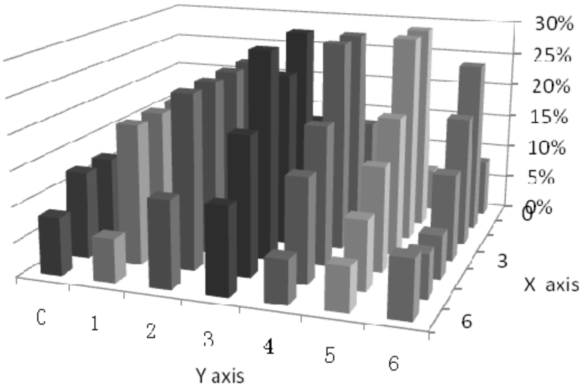
tive rou (c) depict the buffer utilizations for the three routing algorithms respectively, under transpose1 traffic.



(a) OE routing



(b) APSRA routing



(c) RABC routing

Figure 3 Buffer utilizations of OE, APSRA and RABC routings under transpose1 traffic.

As can be observed from Figure 3, under each routing, there is a local region which buffer utilization is higher than that of other switches.

Higher buffer utilization of a switch stands for that switch is very busy. Packets forwarded to it have to wait longer time. Figure4 – Figure 6 shows communication pairs which have the largest packet latency for OE, APSRA and RABC respectively.

The first three pairs which most frequently have the largest delay packets are (10, 26), (3, 27) and (5, 13) for OE routing, Figure 4.

All the paths for the three pairs are contained in the local congested region. It is not strange that their packets have long time to reach destinations.

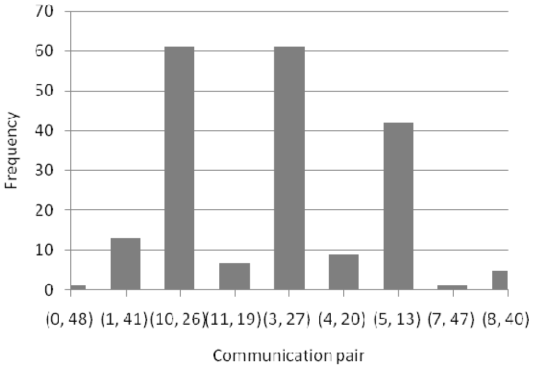


Figure 4. The communication pairs which have the largest latency packet for OE. routing.

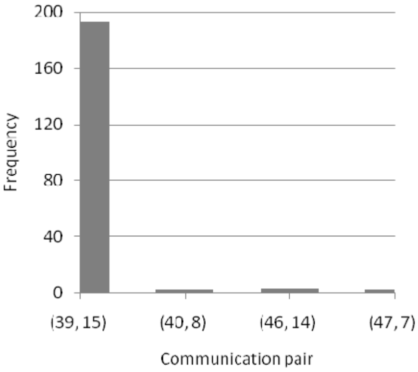


Figure 5. The communication pairs which have the largest latency packet for APSRA. routing.

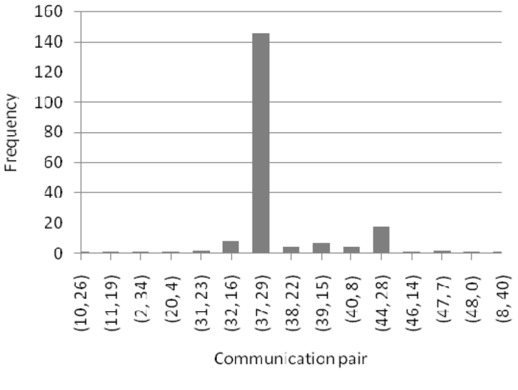


Figure 6. The communication pairs which have the largest latency packet for RABC. routing.

As observed from Figure 5, the pair of (39, 15) has the largest latency packet in nearly all the simulations. Its paths also pass through the most loaded region as shown in Figure 3 (b).

Figure 6 shows that the pair of (37, 29) transmits the largest latency packet in most of the simulations. Its frequency is lower than (39, 15) in Figure 5. Packets generated at node 37 have to be forwarded by some heavily loaded nodes to reach destination, which is coherent with Figure 3 (c).

III. LOCAL CONGESTION DECREASES NOC PERFORMANCE

Local congestion may significantly degrade NoC performance. For OE routing, NoC performance is decreased 13.5% by the three pairs (10, 26), (3, 27) and (5, 13), in terms of average packet latency. For APSRA routing, NoC performance is decreased 26.4% by pair (39, 15) in terms of average packet latency. For RABC routing, NoC performance is decreased 5.1% by pairs (37, 29) and (44, 28), in terms of average packet latency.

Local congestion has most impact on NoC performance under APSRA routing and least impact under RABC routing.

IV. LOCAL CONGESTION ACCOUNTS FOR THROUGHPUT DECREASING

As observed by a number of researchers, the throughput of a network will decrease after reach the maximum [4, 5, 6].

An example of OE routing is shown in Figure 7. The peak throughput is achieved when PIR equals 0.016. After that, the throughput decreases continuously.

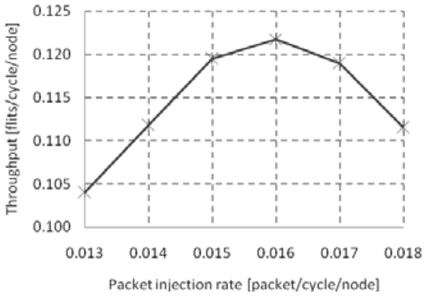


Figure 7. Throughput variation of OE routing under uniform traffic.

Figure 8 depicts the varying of the buffer utilization as PIR increases from 0.015 to 0.017. The increment of buffer utilization is not uniform in the network. On the contrary, it spreads one by one local region. After a threshold, the throughput reaches the peak, and then drops.

When PIR is 0.015, buffer utilizations of nodes in the most seriously congested region reach 40%, as shown in Figure 8 (a). These nodes are firstly congested. Buffer utilizations for the remain nodes are below 40%.

As PIR increases to 0.016, buffer utilizations of more nodes reach 40%. However, the buffer untilizations for the firstly congested nodes are beyound 50%, Figure 8 (b). At this time, network throughput reaches the peak.

As PIR continuously increases to 0.017, buffer utilizations for nearly all the nodes are larger than 40%. In this case, buffer utilizations for the most congested nodes are beyond 70%. Network throughput begins to drop.

This example shows that congestion takes place in the network one by one local region. When congestion status of a certain local region reach a threshold, network gets its maximum throughput. After that, more local regions become congested, network throughput drops.

V. CONCLUSION

Usually, when network begins to be congested, it is not congested uniformly. A certain local region will be firstly and seriously congested. It has huge impact on network performance. Therefore, local congestion should be addressed when desgining routing algorithm.

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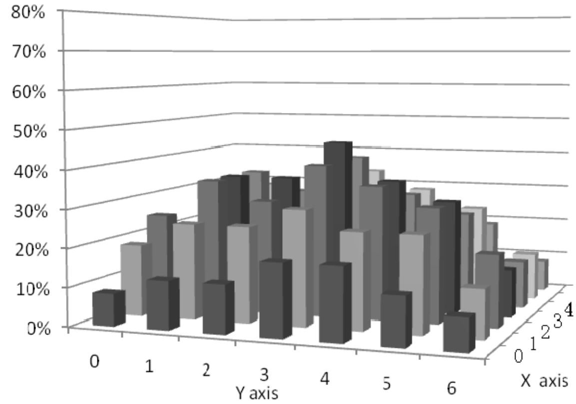
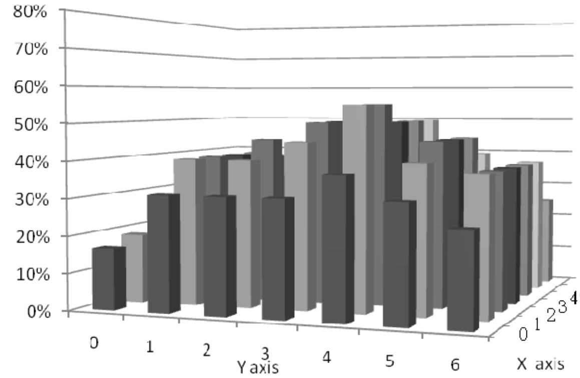
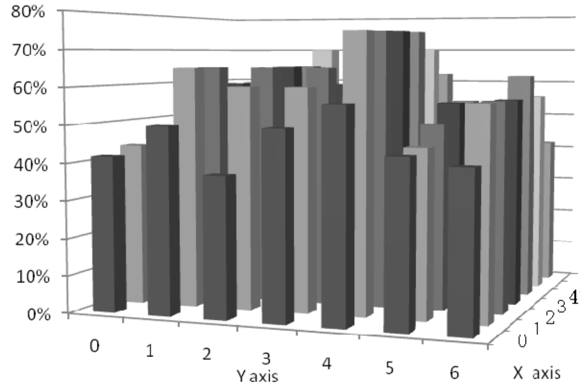


(a) PIR=0.015



(b) PIR=0.016



(c) PIR=0.017

Figure 8. Buffer utilizations of OE routing under uniform traffic for three PIRs.

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