Temperature and Traffic Information Sharing Network in 3D NoC

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***Abstract*—Monitoring Network on Chip (NoC) status, such as the traffic and temperature distribution, plays a great role in improving the network performance. With the increase of the network scale, it is becoming more and more difficult to monitor the global network status in time. To avoid the status transmission introducing too much network load while keep the transmission cost limited, we construct a cost-effective auxiliary network based on 3D mesh NoC. The router microarchitecture and the packet structure have been modified to meet the requirement. Multicast communication based routing algorithm is proposed to improve the transmission efficiency. Experiments show that, in 9x9x4 3D NoC, under the uniform traffic distribution, our global status sharing scheme can reduce the 25% transmission latency compared to Global Congestion Awareness (GCA). And status information can be transmitted more frequently than GCA with less impact on the transmission of ordinary packets.**

***Index Terms*—Network on Chip, status monitor, global sharing scheme**

I. Introduction

With the increasing number of cores on a single chip, buses and point to point connections are unable to meet the requirements such as high performance, low latency and power efficiency. Networks on Chip (NoC) [1] has become a scalable and flexible interconnect solution for current multi-core architecture [2].

As technology evolves, 3D Integrated Circuits (ICs) are regarded as the promising technology to integrate more devices [3]. Therefore, 3D NoC systems are widely discussed recently. With the continuous decrease of system chip area and feature size and development of communication requirements, heat dissipation and congestion problems on chip become non-ignorable [4]. The temperature and traffic management mechanism is a key solution in improving the NOC performance, among which, the temperature and traffic monitoring mechanism is of great importance. However, with the scale increase of 3D NoC, it is very difficult to achieve real-time and effective monitoring of the network.

Recently, several distributed routing schemes that rely on regional or global congestion information were proposed [5-7]. Gratz introduces Regional Congestion Awareness (RCA), an approach that propagates congestion information across the network in a scalable manner, to improve the ability of adaptive routers to spread network load [7]. RCA does not require centralized tables, all-to-all communication, or in-band signaling that contributes to congestion. RCA can propagate the congestion information among the adjacent nodes along the opposite direction of propagation of normal Packet. Congestion information each node received is the sum of the congestion in the direction of congestion information transmission. However the node can't get global congestion information. Adaptive routing algorithm cannot evaluate the performance of all possible paths.

To expand the view of the network, Ramakrishna introduces Global Congestion Awareness (GCA) [8]. GCA is a globally-aware routing scheme for NoC that provides each router with a timely and complete view of the congestion status of the whole network. GCA creates a centralized table which reflects the whole network traffic distribution for each node and collects all the nodes congestion information by all-to-all communication. However, this information sharing scheme will increase the amount of data and the transmission delay of the network. Moreover, the transmission of the congestion information will occupy a lot of bandwidth and increase the congestion risk.

Chao and his teammates propose a mechanism to propagate the temperature information of the whole network [9]. They simplify temperature information into a trigger flag which is 0 or 1. When global sharing, the temperature information of the whole network can be propagated within four flits. This global sharing scheme greatly reduces the additional data in the network. However, temperature information is condensed. Every single value stored in the temperature map can only represent whether a route exceeds a temperature threshold and stops packet exchange. This scheme may not meet the accuracy requirements of adaptive routing algorithms for selecting the coldest path.

In this paper, we adopt the 3D-mesh topology as a prototype. To overcome the defect of the traditional globally-aware scheme, this paper proposes Temperature and Traffic Information Sharing Network (TTISN). Additionally, we propose Temperature and Traffic Information

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Transmission Routing Algorithm (TTITR) which is based on multicast communication to release analysis results in the TTISN.

The rest of this paper is organized as follows. Section II describes the architecture of the TTISN, the architecture of the router, the format of the status packets and the multicast supporting routing policy. In Section III，the simulation experiments and results of TTISN will be given. Section IV is the conclusion of this paper.

II. DESIGN OF THE SHARING POLICY

A. Architecture

For some large-scale 3D NoC with hundreds of cores, traditional globally-aware schemes can aggravate congestion. Because of the delivery of a lot of temperature or traffic information, Globally-aware schemes can cause great transmission delay.

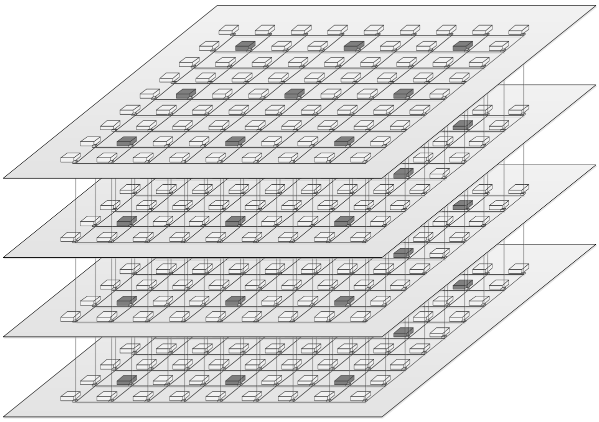

Fig. 1. Distribution of aggregation nodes in NoC

A typical architecture of 3D-Mesh NoC is shown in Figure 1. The size of the NOC is up to 9*9*4, which means traditional globally-aware schemes have to gather the temperature or traffic information of 324 nodes and release all the information to each node. This will increase the traffic load in the network and increase network latency. When the load of network is great, the information will be greatly delayed. This would reduce the temperature or traffic balancing ability of adaptive routing policy based on the information. Therefore, it is necessary to propose a transfer strategy which takes up lower network bandwidth and makes lower delay in the transmission of the network status information.

Future many-core architectures with hundreds of cores can be managed more efficiently in a decentralized way [10]. In this work, we divide the NOC into regions. All the status information will be collected locally and exchanged among regions. We propose a special network called TTISN which is used to transmit the network status information. This network is an auxiliary network built on the basis of the NOC. As shown in Figure 2, every layer in the three-dimensional NOC is divided into regions. In every region we choose one node to collect status data from all the nodes of the region. Then all the chosen nodes are linked to each other to form a new network. In this auxiliary network, the temperature or traffic information is transmitted on a Hamilton path. By constructing the auxiliary network, the maximum hops and traffic load can be reduced.

For most of adaptive temperature or traffic balanced routing algorithms, average layer temperature or average layer traffic is the only information affecting the vertical routing. Thus, for a global sharing mechanism, it just needs to transmit the average status information of different layers. When the status information is gathered, the last aggregation nodes will get the average temperature or average traffic of a layer. Then the packets containing the average values are exchanged vertically by using the original network.

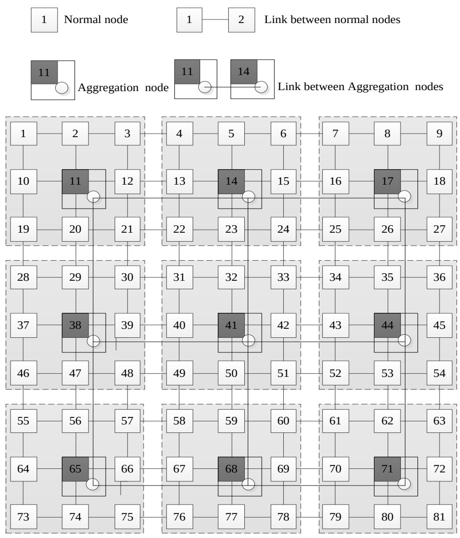

Fig. 2. Top view of TTISN

In order to build an auxiliary network for status information propagation, specialized router architecture is required for the aggregation nodes. All the status information within the sub net are transmitted to the aggregation node and then packed into a status packet. Therefore, the aggregation router requires a status message buffer and a status information packer. Additionally, aggregation node router has a special architecture of Routing Control Logic2 for routing in auxiliary network. The router architecture is shown in Figure 3.

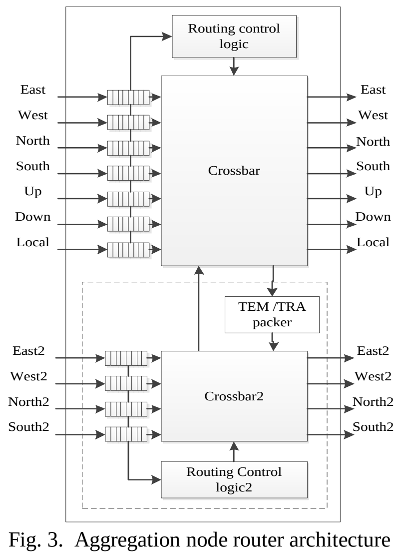

Fig. 3. Aggregation node router architecture

B. Packet Structure

There are five kinds of data packets, which are ordinary data packet, temperature information upload packet,

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temperature information download packet, traffic information upload packet and traffic information download packet. Temperature information upload packet is used to upload the temperature information of each node to the aggregation node. Temperature information download packet is downloaded by each node to refresh the whole network temperature map. The traffic information packets are similar to the temperature information packets and have two types.

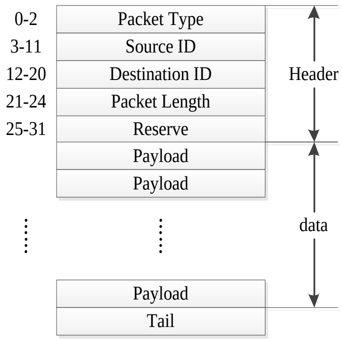

Fig. 4. Packet structure

Packet structure is shown in Figure 4. In order to be able to distinguish between different data packets, the bits 0-2 in head flit are used to indicate the data packet type. 100 is for the temperature information upload packet. 101 is for the temperature information download packet. 110 is for traffic information upload packet. 111 is for traffic information download packet. The rest of the values indicate that the packet is the ordinary data packet. There are 324 nodes in the network. We have to use 9 bits to represent the node ID. The 3-11 bits indicate the source node ID. The 12-20 bits are the destination node ID. The packet length information is saved in 21-24 bits. The last 6 bits are reserved and these bits are 0 in general.

When temperature or traffic upload packets are transmitted in the auxiliary network, the temperature information of the sub network is added to the end of the upload packets. Eventually a complete network status information packet is formed when the upload packet reaches the last aggregation node. When a network status information packet is formed, the last bit of the Packet Type is set to 1 to form the download packet. The download packet must include the status information of the whole network, so that the packet can update temperature or traffic information table of every node in the network.

C. Routing Algorithm

Due to the different functions and different transmission directions of the data packets, we have to design a routing algorithm suitable for various data packets delivery.

The transmission of the network status information packet is divided into two stages, which are the data upload phase and the data download phase. The process of uploading or downloading data can be divided into the transmission process in subnet and the transmission process in the auxiliary network. In the upload phase, the network status information packet is sent to the aggregation node by using the XY routing algorithm. After receiving the status information of the nodes in the subnet, the aggregation node saves the information to a data set. When the status information is transmitted to the auxiliary network, the router uses the Hamilton routing

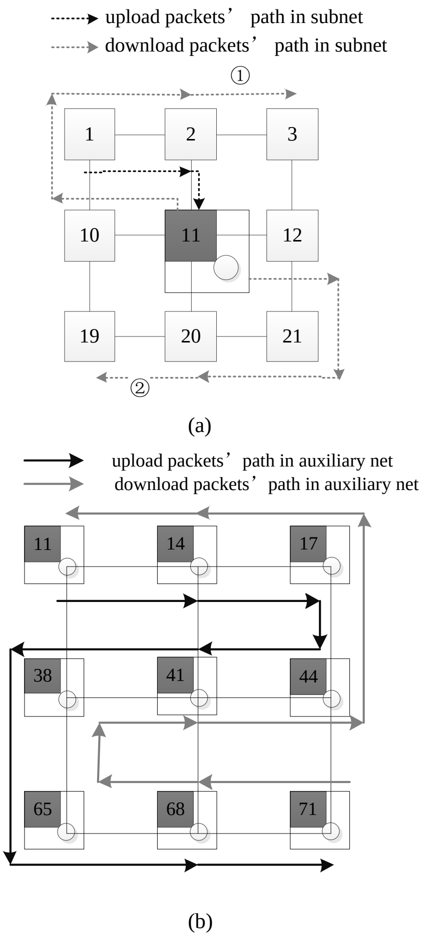

Fig. 5. Routing path in a layer

Pseudo code of thermal and traffic information transmission routing algorithm

```
input:  CurrentNode (Xc,Yc,Zc)
        Aggregation Node(Xg,Yg,Zg)
        DestinationNode (Xd,Yd,Zd)
        CurrentNodeType CT
        PacketType PT
output: Next Node
if PT is upload packet then
    if CT is aggregation node then
        if this aggregation node is not the last one then
            add the local subnet status information to packet and transmit
            the new packet to next aggregation node
        else
            construct the download packet
        end if
    else
        transmit the packet to the aggregation node along the XY path
    end if
else if PT is download packet then
    if CT is aggregation node then
        if this aggregation node is not the first one then
            copy the packet to local subnet and then transmit to the previous
            aggregation node
        else
            copy the packet to local subnet
        end if
    else
        transmit the packet to the normal node along the Hamilton path
    end if
else
    transmit the packet by using normal routing algorithm
end if
end
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Fig. 6. Pseudo code of routing algorithm

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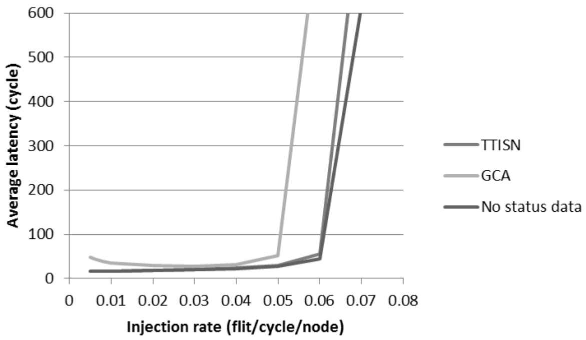

Fig. 7. Load latency at different injection rate

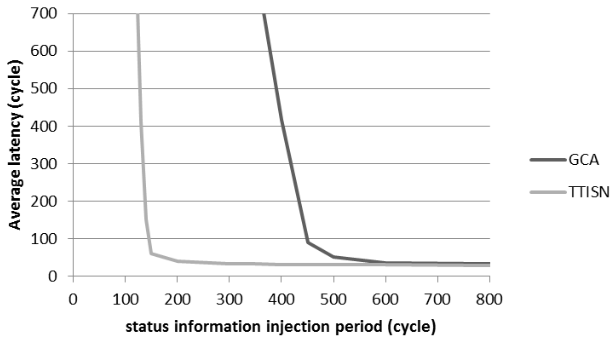

Fig. 8. Load latency at different status information injection period

algorithm to select the path and the status information of local subnet is added to the upload packet. Eventually, all the status information is gathered and saved to the temperature or traffic information download packet.

In the download process, the status information packets are transmitted in multicast mode. When transmitted in the auxiliary network, the state information packets are copied and sent to the next aggregation node. The copies of the packets are transmitted to each node in the subnet and the status tables are updated.

The routing path for the status information in a layer is shown in Figure 5. Figure 5(a) shows the routing path in the subnet and Figure 5(b) shows the routing path in the auxiliary network. The routing algorithm applied to transmit temperature and traffic information is shown in Figure 6.

The definitions of parameters are as follows, the coordinate of current node (Xc,Yc,Zc), the coordinate of destination node (Xd,Yd,Zd), the coordinate of aggregation node (Xg,Yg,Zg), the type of current node CT, and the received packet type PT.

III. Experiments and results

In this chapter, we will evaluate the performance of TTISN. Performance evaluation experiments are implemented on the basis of the Noxim platform. It is necessary to modify the structure of the NOC and design the structure of the router. We build a 3D mesh NOC with the size of 9x9x4 on the basis of Noxim and build the auxiliary in the network. The simulation experiments are to investigate the role of TTISN in reducing the traffic for status information transmission. In this experiment, Noxim simulation configuration parameters configuration are shown in TABLE I.

TABLE I
NOXIM SIMULATION CONFIGURATION

Characteristic	Configuration
Topology	3D mesh
Size	9*9*4
Switching mechanism	Wormhole
Routing algorithm	XYZ
Traffic workload	Uniform
Virtual channel	2
Buffer depth	32
Packet length	3~24
Data Width	32
Simulation period	100,000

In the first experiment, the performance of two kinds of status information transmission strategy on the network under different information injection rate is reflected. In the experiment, the injection period of temperature and traffic information is 500 cycles and the length of the ordinary data packet is 3~8. By changing the injection rate, the average latency of different transmission strategies under different injection rate is obtained. As shown in Figure 7, temperature and traffic information transmitted in TTISN only increases about 5% transmission delay. Compared to GCA, TTISN reduces the network delay of about 25%.

The second experiment is to investigate the influence of the status information injection period on the network transmission. Figure 8 shows the impact of the status information input period on the network information transmission when the injection rate is 0.05. When network status information transmission is not transmitted frequently, it has little impact on the ordinary information transmission. However the performance difference between GCA and TTISN is obvious when the state information is transmitted more frequently. While the injection period of the status information reaches 450 cycles, the average latency increases rapidly. The Network delay of TTISN is stable between 35 and 60 while the status information injection period is bigger than 200 cycles.

IV. Conclusion

In this paper, we modify the architecture of 3D NoC to construct the global sharing network of temperature or traffic information. Based on the modified network, we implement a global sharing routing algorithm based on multicast mechanism. Experiment results show that in the 9x9x4 3D NoC, under the uniform traffic distribution, our global sharing scheme can reduce the 25% transmission latency compared to GCA and can transmit the status information more frequently than GCA with less impact on the transmission of ordinary packets.

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