A Judgment Approach for Forward Link Load Based on Virtual Channels

Ning Wu, Fen Ge, and Shuai Ding

Abstract—**To solve the problems of congestion and packets transmission delay in Network on Chip (NoC), a judgment approach for forward link load is proposed based on the operation state of virtual channels in NoC routers. The approach can forecast the load of partially network through the operation state feedback of virtual channels in the adjacent routers, which used as the basis for adaptive routing calculation and packets transmission control, in order to reduce the transmission delay and avoid the delay for the sender waiting for acknowledgements. A new router structure for 2D-Mesh NoC architecture is developed to support this judgment approach. Based on the judgment approach, a partially adaptive XY routing algorithm which improves the deterministic XY routing algorithm is proposed, and a control circuit design without timer is also presented. Experiment results show that design using the judgment approach can reduce the average transmission delay of packets in NoC effectively.**

Index Terms—**Adaptive routing algorithm, forward link, transmission control, virtual channel.**

I. Introduction

Network on Chip (NoC) has been proposed for global communication in complex SoCs to meet the performance requirements. In NoCs, data communicate using packets, and the path of a packet traversing from the source to the destination is determined by the routers according to routing algorithms. Apparently, routing of packets is one of the most important challenges in NoC in order that network throughput and latency are highly dependent on the routers and routing algorithms.

Deterministic routing algorithm may use only the addresses of source and destination nodes to compute the determinate path. It used by many NoC designers benefits from its simplicity in router design. XY dimension-order routing algorithm is a commonly used deterministic routing algorithm, with the features of shortest path, deadlock-free, simple realization and applicable to Mesh topology. In [3]-[5], the routers designed based on 2D-Mesh topology all chose the deterministic XY dimension-order routing algorithm. However, deterministic routing algorithm is likely to suffer from throughput degradation when the packet injection rate increases.

When transmitting data between routers, Link Management Protocol is used to regulate the packets transmission in links. During the transmission of packets, as cache size and processing speed of receiver is limited, if the sender forwards data at a more rapid rate, the receiver could not receive the data, then lead to buffer overflow and data loss. There are two commonly ways used to solve this problem. One way is to add packet loss mechanism in the design of routers. When it is too late for receiver to accept, the packets would be discarded. After the option of discarding, the routers could give no treatment, or record the ID of the packet and apply for retransmission. However, packet loss will lead to incomplete data, and retransmission will increase delay. Another way is to take use of some flow control mechanism to get transmission rate between sender and receiver by consultation. In any case, in order to enable the cache of receiver not overflow, every time after the sender forwards a flit, it will stop to wait the confirmation of having received this flit from receiver [6]. Upon receipt of confirmation signals, the sender will transmit the next flit. As a result of not enough cache or some other reasons, the receiver can not receive flits when transmission, then the sender will waste a lot of time on waiting for the confirmation signals.

The difficulties above encountered on routing algorithm and transmission control, are due to that local router can not predict the status of other routers in the network. Therefore, forecasting the status of network and using a suitable adaptive routing algorithm is very necessary. To solve the above problems, we propose a judgment approach for forward link load based on the operation state of virtual channels in NoC routers. During the packets transmission, a router can get the status of neighbor routers according to the stress value of forward link, and then can predict the load of partially network. Based on the obtained status of partially network, we will have the flexibility to deal with the data routing and transmission control in order to reduce the data transmission delay and improve the network communication efficiency.

The paper is organized as follows: section II presents the proposed judgment approach for forward link load in detail; section III describes the adaptive routing algorithm and packet transmission control designed using the judgment approach; experimental results are discussed in section IV and finally we conclude the paper in section V.

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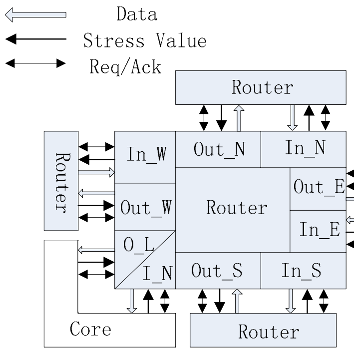

Fig. 1. Router Architecture based on 2D-Mesh topology

II. The Judgment Approach for Forward Link Load

In this paper, we select 4 × 4 2D-Mesh as the network topology. The architecture of router in 2D-Mesh based NoC is shown in Fig. 1.

A router contains a total of five ports, and communicates with five other units including its four neighbor routers and the core unit. Every port contains the input and output modules, and can send or receive packets.

As the performance of input link is directly determined by the receiving rate of input module, we assume that the condition of input module represents the stress value of link. Input modules (In_E, In_S, In_W, In_N, In_L) receive packets and send the stress value of link to the previous router. Output modules (Out_E, Out_S, Out_W, Out_N, Out_L) send packets and receive the stress value of the link from the forward router. Without packets backdating, every input module of a router may receive packets from four input modules of the previous router.

The technology of virtual channel is used in the design of router. It divides a physical channel into multiple virtual channels. When one virtual channel is blocked, packets can still continue to transfer via the other virtual channels. The virtual channel used can prevent the deadlock caused by congestion of network, reduce the transmission delay and improve the network throughput. Therefore, for the router with virtual channels, the forward link load between routers can be judged based on the operation state of virtual channels.

Logically, the capability of each virtual channel is 1/N of the physical channel, in which N means the number of virtual channels the physical channel divided. The packets transmission in router with virtual channels is shown in Fig.2.

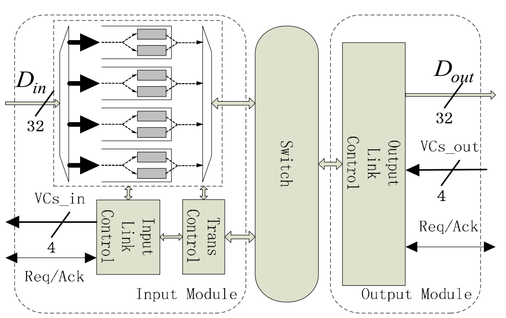

Fig. 2. The packets transmission in router

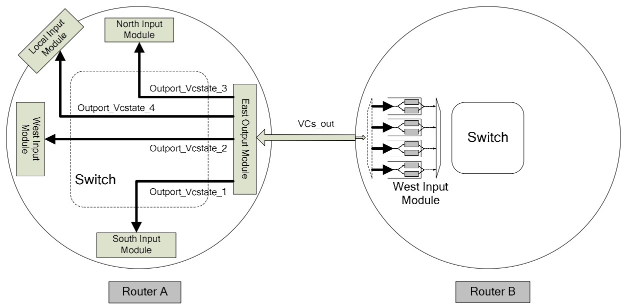

Fig. 3. Feedback of virtual channels' condition

The router, supporting store-and-forward packets, consists of input modules, switch and output modules, in which the virtual channels are set in the input modules. Input module is composed of input link control, transmission control, as well as four virtual channels, in which each virtual channel contains buffer for two flits.

The distribution mechanism of virtual channels is static, that is, the four virtual channel of an input module is fixed to the four input modules of the previous router, to provide packets *Din* forwarding services from the corresponding direction.

Input link control completes the packet reception, at the same time records the operation state of virtual channels, and then sends the state to the previous router through feedback signal *VCs_in*. The signal *VCs_in* is 4bit, and each bit represents whether the corresponding virtual channel is transmitting packets.

Transmission control is the sender of the packet forwarding process, which controls the sending of packets in virtual channels. According to *VCs_out* signal from the next router, output module informs the four input modules in the current router with the state of output link. The feedback process is shown in Fig. 3.

Router B sends *VCs_out* which represents the condition of virtual channels in its west input module to the east output module of Router A. After receiving the signal *VCs_out*, the east output module pre-handles it and generates four-way signal *Outport_Vcstate*, and then transmits them to the four input modules in Router A.

The signal *Outport_Vcstate* is composed by 3bit ($b_2b_1b_0$). The highest bit b_2 indicates that whether the forward router do have virtual channels to receive packets from the input module. The two lower bits b_1b_0 show that the other three virtual channels' condition, that is the utilization rate of physical channel.

For an input module, there will be four *Outport_Vcstate* signals from four output modules, which indicate the stress values of four possible forward directions. The stress values represent the congestion condition of current communication network, and according to it we will have the flexibility to deal with the data routing for next forward direction.

III. The Router Design based on the Judgment Approach

In contrast with the deterministic routing algorithm, adaptive routing determines routing paths based on the congestion conditions in the network. The adaptiveness reduces the chance for packets to enter hot-spots or faulty components, and hence reduces the blocking probability of packets. However, the realization of adaptive algorithm is difficult due to the superiority. The work in [7], [8] proposed dynamic XY routing via improving deterministic XY dimension-order routing, which could provide adaptive routing based on condition of the FIFO used or congestion conditions in the network, and achieved the purpose of balancing network load and reducing the average transmission delay. In this paper, we design the router according to the proposed judgment approach. The design ideas include two aspects.

Firstly, during the routing calculation, routers can carry out adaptive routing algorithm based on partially network status got from the stress values of forward links. Secondly, during the process of packets transmission management, the router is able to predict whether the forward router could receive packets according to the stress value, thereby the time that the sender waiting for confirmation will be saved.

(1) Adaptive XY Routing Algorithm

The regular two-dimensional grid topology can be decomposed into two orthogonal dimensions, and the distance between the current and destination node can be got by calculating the offset in each dimension. With deterministic XY routing, a packet first traverses along the x dimension and then along the y dimension.

In this paper, the proposed partially adaptive algorithm is the improvement of deterministic XY routing. The main idea of the algorithm is that packets need to calculate routing when go through each router using adaptive routing. The module for adaptive routing is shown in Fig. 4.

The routing calculation function gets the X and Y dimensional shift direction by calculating in accordance with the addresses of local (*Local_ID*) and destination (*Dest_ID*) node. Then, the direction which is low in stress value will be chosen by the Direction Choose module. The detailed routing algorithm can be summarized as follows.

① Get the destination ID (*Dest_ID*) of the sending packets.

② Compare *Local_ID* and *Dest_ID*, then get the offset in the direction of X (*X_dir*) and Y (*Y_dir*) dimension.

③ Compare the stress value of the two directions according to *Outport_Vcstate*.

④ Choose the direction in which the stress value is lower, and then send it to input module through *Dir*.

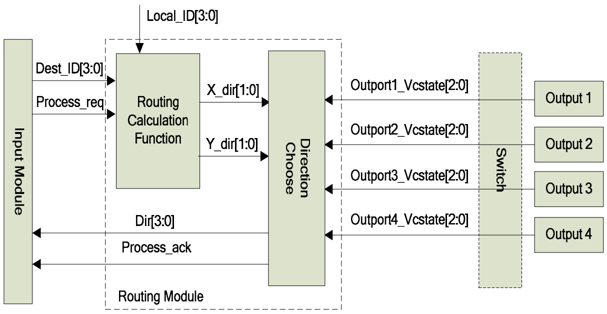

Fig. 4. The module for adaptive routing

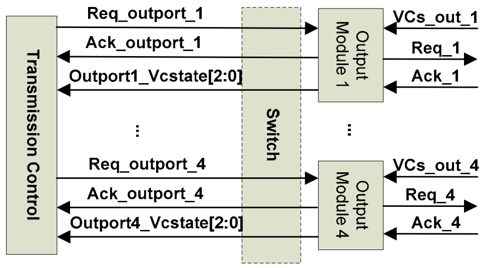

Fig. 5. Packet transmission based on the forward link load

At this time, packets can finally reach the destination node through the Y dimension even if there is jam in the link of X dimension. The increase of overall latency caused by the high load of partially network can be avoided due to the dynamic choice of direction. Compared to the deterministic routing algorithm, the overhead of implementing the proposed adaptive routing algorithm added by Direction Choose module is very low.

(2) Packet Transmission Control

When forwarding packets, if the status of next router is unknown, with the stop and wait protocol, the sender will be always in waiting state if receiver can not process the transmission request of packet. The usual solution is to add a timer in sender. Then, if the sender does not capture feedback in a certain period of time, we assume the request is failed, so the sender will get itself out from waiting state.

If the sender can get the status of forward link, then it does not need to design the special timer. At this time, the sender may not request transmission if the next router is too busy to receive in order to avoid the waiting delay. The packet transmission based on the load of forward link is shown in Fig. 5.

In the process of packet transmission, the transmission control is the initiator of sending, and the next router is receiver, in which the output module is used as a transceiver interface. The output module transmits the request and acknowledgement signals. Before sending the request signal, the transmission control will judge whether the next router can process the current request according to the highest bit b_2 of *Outport_Vcstate*. Only when *Outport_Vcstate* signal indicates that the receiver is ready to receive, the sender will transmit packets. At this point, as the status of receiver has been known, the delay caused by waiting acknowledgement signal will not appear.

IV. Experimental Results

To evaluate the performance of the judgment approach, we developed a RTL-level router model using Verilog-HDL in Synopsys EDA platform, and then built a 4×4 2D-Mesh based NoC architecture.

The first experiment is conducted to verify packet transmission control designed with the judgment approach. We have found that the router would not request transmission if the next router is too busy to receive. Therefore, the approach can achieve the purpose of avoiding the waiting delay.

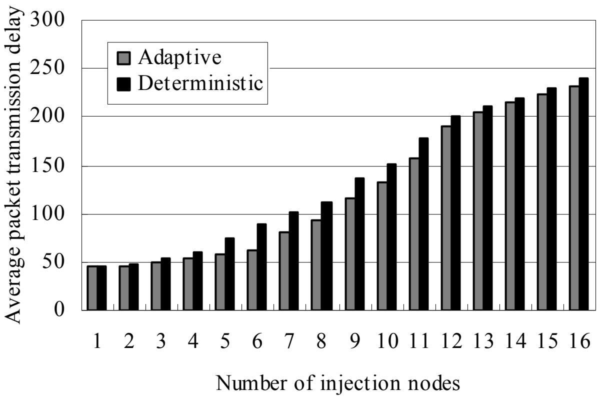

Fig. 6. Average packet transmission delay in 4×4 NoC

The second experiment is conducted to verify the proposed adaptive routing. This experiment changed the number of injection nodes from one to sixteen. The injecting packets have 10 flits (one head flit and nine data flits), and the destinations of which are randomly chosen. The results with running 20,000 clock cycles are shown in Fig. 6. It can be observed that the adaptive routing achieves the best performance in average transmission delay in both cases compared to the deterministic XY routing algorithm. Especially, significant performance improvements can be achieved by using the proposed adaptive routing algorithm under the middle network load (the number of injection nodes from five to nine).

V. Conclusions

To avoid the network congestion in NoC and reduce the packets transmission delay, this paper have designed the NoC router using virtual channels, and proposed a judgment approach for forward link load based on the operation state of virtual channels in routers. The approach can forecast the load of partially network through the operation state feedback of virtual channels in the adjacent routers, which used as the basis for adaptive routing calculation and packets transmission control. Based on the judgment approach, the paper presents an adaptive XY routing algorithm which improves the deterministic XY routing algorithm and can select packets forwarding direction dynamically, and a packets transmission control design without timer which can avoid the delay for the sender waiting for acknowledgements. 4×4 2D-Mesh NoC architecture design with the judgment approach was developed for both adaptive XY routing and deterministic XY routing to evaluate their performance. The experiment results show that the proposed adaptive routing can achieve better performance than the deterministic XY routing in average packets transmission delay, and significant performance improvements can be achieved under the middle network load.

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