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A fair arbitration for Network-on-Chip routing with odd-even turn model

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ABSTRACT

With the increasing of Network-on-Chip size, deterministic routing algorithms suffer from a poor performance under heavy traffic. Therefore, routing schemes with varied candidate paths and fair selection strategy are required to relieve congestion. We propose an alterable priority arbitration for the fair granting of packet transmission from all possible directions permitted by the odd-even turn model. To achieve fairness, the proposed arbitration strategy alters the priority orders based on an optimized pointer, its granting decisions are made according to fixed mechanism under varied priority orders. Under a cycle-accurate simulator based on System C, the proposed alterable priority arbiter is verified to achieve better fairness than the RR arbiter. Simulation results show that the average packet latency of the odd-even turn model is reduced by 26.46%, and the saturation throughput is improved by 29.79% with the introduction of proposed arbitration scheme. Furthermore, the proposed arbiter achieves ignorable increasing of the hardware implementation overhead.

1. Introduction

With the rapid development of Integrated Circuits technology, highly scalable Network-on-Chip (NoC) has replaced conventional bus connection as an effective solution to communication issues on highly integrated chips [1,2]. Routing algorithm influences the performance of NoC significantly, which determines the paths of packets transferred in the network [3,4]. For classic deterministic XY routing [5], the routing path is determined by given source-destination pair [6,7]. As a minimal routing, XY routing provides the feature of deadlock-freedom. However, deterministic routings result in disability to avoid congested regions under heavy traffic, which impacts the transmitting of packets. To improve the network performance, routing algorithms with varied candidate paths are required [8].

The adaptiveness degree of a routing algorithm is defined as the number of possible shortest paths for packets to traverse from the source to the destination [9]. Routing algorithms with higher adaptiveness degree provide more candidate paths for transferred packets. Furthermore, by employing proper path selection strategy, effective routing scheme with better traffic distribution can be achieved to relieve congestion [10]. Since conventional adaptive routing algorithms are prone to deadlock [11,12], Virtual Channels(VCs) are introduced for deadlock-free adaptive routings [13]. Nevertheless, the applied VCs would involve extra hardware overhead and complex control logic on routers. As a sort of partial adaptive routing, turn models prohibit the minimal number of turns based on analyzing possible turns and loops for packet traversal, in this case, turn models achieve both adaptiveness and deadlock-freedom without introducing VCs [14]. Turn models such as west-first(WF), north-last(NL) and negative-first(NF) prohibit certain turns for global routing, which are vulnerable to highly unevenness of adaptiveness degree and traffic distribution [15]. For odd-even(OE) turn model [16], turns are restricted according to the parity of the node's column, instead of prohibiting certain turns globally. As a result, OE turn model solves the problem of unevenness. In addition, OE turn model is proved to achieve more candidate paths for routing selection than other turn models do [17].

As the odd columns and even columns appear alternatively in the network, conventional OE turn model is limited to a relatively determined routing path [16]. To improve the number of candidate paths, proper selection strategy among all possible paths is recommended, instead of determining the transmission merely according to column's parity. In this paper, arbitration scheme is employed as the selection strategy, the packet's traversing is determined by the granting result for all turns permitted by OE turn model.

Fairness is one of the most important evaluations for the performance of an arbiter [18]. As arbitration determines the packet transmission on every router, to balance the network load, each possible adjacent router should be granted as next hop to receive packet with equal probability [19,20]. The Round Robin(RR) arbiter [21] is a conventional arbitration that can grant requests under different priorities fairly, while its fairness is limited by the pointer scheme. In this paper, to improve the fairness of path selection, an arbitration that alters priority orders according to an optimized pointer is proposed.

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The remainder of this paper is organized as follows. The related works are reviewed in Section 2. The mechanism of the proposed alterable priority arbiter is introduced in Section 3. The realization of routing applying the proposed arbitration as path selection strategy is described in Section 4. Simulation results are presented in Section 5. The conclusions of this paper are drawn in Section 6.

2. Related works

In recent research works, the arbitration is employed as a solution to address ports contention [22,23], widely applied in crossbar or VC allocators to deal with several input ports contending for the same output port or VC. Arbitration for ports contention helps allocating network resources, as a result, waiting times on packets are reduced. Nevertheless, for the scenario that more than one output directions are permitted, no selection mechanism among them is introduced. The novelty of this paper is to apply arbitration as a selection for candidate directions. To determine the path among all permitted directions, fairness is required to balance the loads across the network [24,25].

Most of the existing fair arbiters are designed based on the RR arbiter [21], which is known for granting all requests under different priorities fairly. To realize fair granting, the RR arbiter rotates the priority order, which provides requests under lower priorities with higher probabilities than fixed granting. Most of the existing arbiters focus on the improvements in the performance of RR arbiter, in [26] requests are grouped for RR arbitration, while in [27], the statuses of ports are considered as factors of granting based on RR arbiter. Improvements in RR arbiter lead to better performance metrics of NoC, while the granting results failed to show fairness enhancement. For arbitration applied as path selection, to meet the demand of network load balance, the goal of this paper is to optimize the arbitration for better fairness.

The RR arbiter employs the previous granting result as a pointer to vary the priority order, under the rotation based on pointer scheme, the previously-granted request is located at the end of the updated priority order queue, while the request lying behind it is provided with the highest priority [21]. According to the pointer scheme, the priority queue is rotated dynamically, which improves the opportunities for requests with lower priorities to be granted significantly. On the contrary, the Fixed Priority (FP) arbiter [28] assigns the priority order in a fixed pattern, the requests are granted under a fixed mechanism as well. The FP arbiter suffers from unfair granting, which leads to starvation of lower priority. In comparison, the RR arbiter grants all requests fairly, nevertheless, its pointer is determined by the previous granting, which prevents the priority rotation from reaching higher equality, the fairness of RR arbiter is limited.

To propose an arbitration mechanism with better fairness, the key solution is to design an optimized pointer scheme. We propose an alterable priority arbiter that adjusts the priority order under a varied pointer value, instead of priority rotation. Since the FP arbiter possesses the advantages of simple logic structure and low area overhead, the proposed arbitration applies the granting mechanism of FP arbiter, while its originally fixed priority order is altered based on the optimized pointer.

3. Proposed fair arbitration

3.1. Background

The restriction of OE turn model is based on the position that locates the packet, which prohibits ES and EN turns on even columns and prohibits NW and SW turns on odd columns. As discussed in [16], more candidate routing paths are provided than prohibiting certain turns for global network routing. According to the limitation for directions determined by both the column's parity and the coordinates between the source-destination pair, the network is divided into the nodes that permit merely one direction for packet to traverse and more than one directions.

Nevertheless, as the odd columns and even columns appear alternatively, with the lack of selection strategy, the routing algorithm of conventional OE turn model is limited to a relatively determined routing level. Take eastbound routing for instance, EN or ES turns on even columns can be avoided by accomplishing the turns and the transmission in direction N or S when encountering first odd column. This scheme is accepted by the conventional OE turn model, which limits the number of candidate routing paths. Limited candidate paths impact the opportunities for packets to void congestion regions, therefore, to improve the number of candidate paths, selection scheme for all permitted turns is required. In this paper, arbitration is applied as the selection strategy. To ensure the load balancing performance of NoC, fair granting is required. In this paper, we propose the alterable priority arbitration to improve the fairness of RR arbiter, by applying the mechanism of FP arbiter and an optimized pointer scheme.

The mechanism of FP arbitration can be described in Eq. (1) [28]. Requests are numbered from i to 0 with the priority order from the highest to the lowest. According to Eq. (1), requests with higher priority would be granted in precedence when contentions occur.

$$\begin{cases} g_i = r_i \\ g_{i-1} = \bar{r}_i r_{i-1} \\ \cdots\cdots \\ g_k = \bar{r}_i \bar{r}_{i-1} \ldots\ldots r_k \quad k \in [0,\, i-1] \end{cases} \tag{1}$$

FP arbiter provides advantages of simple logic structure and low hardware overhead, while its fixed granting scheme leads to starvation of requests under lower priority. RR arbiter is known for its fairness by introducing the pointer scheme for priority rotation [21], which employs the previously granted request as a pointer. The pointer scheme of RR arbitration improves the chances for lower priority requests to be granted significantly, which compensates the unfairness of FP arbiter. However, the fairness of the rotation is limited by the previously granting result. In this case, the key to improve fairness is to optimize the pointer scheme of RR arbitration. In this paper, we propose an alterable priority arbiter that applies the granting mechanism of FP arbiter under varied priorities instead of fixed order, while the pointer to adjust the priority order is optimized for alterable priority arbitration.

3.2. The proposed alterable priority arbitration

According to the priority allocation principle of FP arbiter, the alterable priority arbiter numbers the requests initially from the highest to the lowest. Take 4 contending requests for instance, they are numbered from 3 to 0 based on the priority order. To improve the fairness of granting, the alterable priority arbitration varies the priority order under an optimized pointer scheme, instead of the scheme with priority order unchanged [28] or rotating the priority order based on previous granting result [21]. In demand of fair arbitration, fairness is required in the varying of priority order, it is indicated that the times for every request to appear on every priority should remain the same. In this paper, the priority order combinations are set to 3210, 2301, 1032 and 0123, furthermore, the 4 states should appear in the ratio of 1:1:1:1 to provide each request with an equal opportunity to appear on every position of priority. The key to realize the equality is to determine an optimized pointer inspired by the priority rotation of RR arbiter. The alterable priority arbitration renews the priority order with the pointer value increased by 1, while the remainder of the pointer divided by 4 is applied as the index to select the corresponding priority order state. Table 1 shows the relationship between the pointer value and the corresponding state of priority order. In addition, the granting mechanisms under different priority states are listed. It can be observed that the alterable priority arbitration employs the granting mechanism of FP arbiter, while it is applied to deal with varied priority order based on