Performance Analysis of Arbitration Scheduling Algorithm Based on RR Optimization for Network-on-chips

Ruofei Ma, Liyong Bao*, Hongwei Ding and Zheng Guan

School of Information, Yunnan University, Kunming, China

*Corresponding author email: bly.yx@163.com

Abstract. The RR arbitration algorithm commonly used in the current Network-on-chips cannot meet the requirements for low power consumption and rapid response under high load conditions, with the continuous development of microelectronics technology. In order to solve this problem, based on the idea of non-competitive transmission and parallel optimization, this paper improves on the RR algorithm to obtain a MAC layer arbitration scheduling algorithm suitable for the Network-on-chips. By optimizing the service and query transfer process in parallel, the algorithm reduces the queue length of information grouping in the system and shortens the query period of the system. The algorithm model is established by using Markov process and probability generating function, mathematically analyze the first-order characteristics of the system, and obtain an accurate solution. The simulation model of the algorithm is established based on the simulation platform to verify the accuracy of the precise solution. After optimization, the system's average queue length and average cycler have been greatly improved.

Keywords: Network-on-chips; Arbitration scheduling algorithm; Parallel optimization.

1. Introduction

Network-on-chips (NoC) is a widely used on-chip communication subsystem, which can provide higher bandwidth and lower latency than bus-based communication[1]. With the rapid development of integrated circuit manufacturing technology, the number of cores of the Network-on-chips has evolved from multi-core to many-core, and its structure has evolved from two-dimensional to three-dimensional. The emergence of the Network-on-chips has opened up a new field of chip technology research and has become a new driving force for the development of chip technology and a new direction for future development.

The topology of the Network-on-chips can be divided into direct interconnection structure and indirect interconnection structure. Common topological structures are Mesh, Ring, Torus[2], SPIN[3], BFTh[4] and Star[5]. Compared with other topologies, the Mesh topology has the characteristics of simple topology, strong scalability, and convenient routing and arbitration algorithm design. It has become a more common topology in the Network-on-chips. Figure 1 shows a microstructure of communication node.

![Figure 1. Microstructure of communication node.](image-url)
Both the Network-on-chips and the computer network face the same problem. Because since a large number of concurrent requests may simultaneously send information in the shared medium, it will bring more conflicts to the competition of using the shared medium. Based on the simple and efficient requirements of NoC, the arbiter uses RR (Round Robin), TDMA, fixed priority, Lottery and other algorithms to arbitrate and schedule the transmission data requests sent from each direction. In the current stage of the Network-on-chips design, most of them use the RR\cite{6} polling arbitration algorithm with good fairness. However, with the continuous emergence of new scenarios and new applications, higher requirements are put forward on the on-chip network. The traditional RR polling scheduling method can no longer meet the requirements of low power consumption and rapid response under high load conditions.

At present, the research to improve the efficiency of polling services is mainly divided into two directions, One is to obtain the reservation and queue status in advance during the polling process to reduce the number of queues that the server queries\cite{7}, the second is to improve the overall efficiency of the system by optimizing the query service process in parallel\cite{8}. Based on the idea of conflict-free transmission and parallel optimization, this paper improves on the RR algorithm to obtain a MAC layer arbitration scheduling algorithm suitable for the Network-on-chips. This algorithm optimizes the two processes of service and query transfer in the traditional RR scheduling algorithm in parallel. After optimization, the system's average queue length and average query cycle have been greatly improved, and at the same time, the system's energy consumption is reduced and the system's response speed is accelerated. The mathematical tools such as Markov process and multi-dimensional probability generating function are used to construct the mathematical model of the system, and the probability generating function of the system state variables is derived. The first order of the system is mathematically analyzed and accurately solved. The simulation model of the algorithm is established based on the simulation platform to verify the accuracy of the precise solution.

2. System Modeling of the Arbitration Algorithm

2.1. Queue Model Establishment

According to the analysis of the Network-on-chips topology, the communication node can be abstracted into a polling service system. The shared medium is a service resource that is contended, and data requests for concurrent access to various ports compete for resources, which will cause queuing, waiting or delay for service resource requests. Based on the parallel optimized RR scheduling algorithm, a queuing system composed of an arbiter and five access queues is established. The scheduling algorithm model is shown in Figure 2:

![Figure 2. Scheduling algorithm model.](image)

2.2. Establishment of System Mathematical Model

Assuming that the system is working in discrete time, the site buffer capacity is large enough and no information loss will occur. It is set that the probability generating function \( A_i(z_i) \) of the arrival process of the number of information grouping entering the ith queue satisfies the independent Poisson distribution, the mean value is \( \lambda_i = A_i'(1) \), and the variance is \( \sigma_i^2 = A_i''(1) + \lambda_i - \lambda_i^2 \). After the arbiter finishes serving one queue, it passes through a transfer process and starts the service transfer.
process for the next queue, the mean and variance are respectively: \( \gamma = R'(1) \), \( \sigma_{\gamma}^2 = R''(1) + \gamma - \gamma^2 \), and its probability generating function is \( R(z) \). The mean and variance of the service process of the queue are respectively: \( \beta_1 = B'_1(1) \), \( \sigma_{\beta_1}^2 = B''_1(1) + \beta_1 - \beta_1^2 \), and its probability generating function is \( B_1(z_1) \). The three processes of arrival, service and transfer are independent of each other and obey the same probability distribution.

The arbiter polls the pointer to point to the ith queue at time \( t_n \) and serves it in a Gated service mode, at this time, the information grouping waiting for service in the ith queue is set to \( \xi_i(n) \), the state of the entire system at the moment is: \( (\xi_1(n), \xi_2(n), \ldots, \xi_N(n)) \). Afterwards, after inquiring in parallel whether there is any information grouping waiting in the i+1th queue, at time \( t_{n+1} \), the arbiter starts to provide threshold services to the i+1 queue, and the system status is: \( (\xi_1(n+1), \xi_2(n+1), \ldots, \xi_N(n+1)) \).

According to the change law of the system state with time in the above process, the paper gives the following system state transition equation:

\[
\begin{align*}
\xi_j(n+1) &= \xi_j(n) + \mu_j(u_i) \\
\xi_j(n+1) &= \eta_j(v_i) + \xi_j(n)
\end{align*}
\]  
(1)

The variables in the state transition equation are set as follows: \( u_i(n) \) is the time for the arbiter to transfer from the ith queue to the next queue; \( v_i(n) \) is the service time of the arbiter for each queue. \( \mu_j(u_i) \) is the number of information grouping entering the jth queue within \( u_i(n) \) time, \( \eta_j(v_i) \) is the number of information grouping entering the jth queue within \( v_i(n) \) time, \( \xi_j(n) \) is the number of information packets in the jth queue at time \( t_n \); \( \xi_j(n+1) \) is the number of information packets in the jth queue at time \( t_{n+1} \).

When the system is in a stable state, the system is a complex N-dimensional random process and has a unique stable distribution. Therefore, the probability generating function of the system state variable at time \( t_{n+1} \) is:

\[
G_{i+1}(z_1, z_2, \ldots, z_i, \ldots, z_N) = G_i(z_1, z_2, \ldots, B_i[z_j], \ldots, z_N) - G_i(z_1, z_2, \ldots, z_i, \ldots, z_N) |_{z_j = 0} + R_i[z_j] G_i(z_1, z_2, \ldots, z_i, \ldots, z_N) |_{z_j = 0}
\]  
(2)

3. System Analysis Process

3.1. Average Queue Length

According to the operating principle of the system, when the arbiter starts to process information packets in the ith queue at time \( t_n \), the number of information packets that already exist in the ith queue can be represented by \( g_i(i) \).

\[
g_i(i) = \frac{Ny_i}{1-N\rho+N\nu_i}
\]  
(3)

3.2. Average Query Cycle

For this system, the time for the arbiter to query each queue once is the average query cycle of the system, and its average value reflects the sensitivity of the system, which can be obtained from the mathematical relationship between the average queue length and the average query cycle.

\[
E(\overline{\theta}_i) = \frac{N\nu_i}{1-N\rho+N\nu_i}
\]  
(4)

4. Arbitration Algorithm Performance Analysis

Based on the above algorithm analysis, the simulation model of traditional RR scheduling algorithm and
the simulation model of improved arbitration algorithm are established by MATLAB platform, and the system performance indicators of the two algorithms are analyzed by statistical analysis method. Under the same conditions, each queue arrives at the queue with a Poisson distribution with arrival rate $\lambda$, the service time of the arbiter to process information packets in the queue is $\beta = 10$, the transition time between queues is $\gamma = 1$. The system works under stable conditions. The following comparison chart shows that the theoretical calculation values of the system model proposed in this paper are consistent with the experimental results and can represent the first-order characteristics of the system.

![Figure 3](image1.png)

**Figure 3.** The average queue length of the new algorithm.

![Figure 4](image2.png)

**Figure 4.** Average queue length comparison chart.

![Figure 5](image3.png)

**Figure 5.** Average query cycle comparison chart.

(1) Figure 3 shows the first-order characteristic index change curve of the system, the curve in the figure reflects the reasonable trend that the first-order system characteristic index increases with the increase of the arrival rate of information packets. The curve calculated by the theoretical formula is basically consistent with the statistical analysis of the simulation experiment, which shows that the key index analysis of the system and the simulation result have good rationality and consistency.

(2) As shown in Figure 4 and Figure 5, the optimized algorithm has a significant improvement in the average queue length and average query cycle compared with the traditional RR scheduling algorithm. This is because after the two processes of system service and query transfer are processed in parallel, the service efficiency of the entire system is improved, thereby reducing the number of queues of information packets in the buffer, and reducing the energy consumption of the entire system, at the same time, the average query cycle of the system is shortened, and the response speed of the system is improved. These improvements have very high use value in Network-on-chips applications.

5. **Conclusion**

Nowadays, the development of VLSI technology is changing with each passing day, new scenarios and new applications are constantly emerging, all of which put forward higher requirements for the Network-on-chips. The Network-on-chips has always adopted the traditional RR scheduling algorithm, the traditional RR scheduling algorithm can no longer meet the system service requirements of low energy consumption and fast response under high load conditions. Therefore, based on the in-depth analysis of the RR scheduling strategy, the paper optimizes the two processes of the arbiter transfer query and service processing in parallel. The algorithm model is established using mathematical tools such as
embedded Markov chain and multi-dimensional probability generating function, and the average queue length and average query period of the algorithm are mathematically analyzed, and an accurate solution is obtained. The simulation model of the algorithm is established based on the simulation platform to verify the accuracy of the precise solution. System performance analysis shows that the parallel optimized RR scheduling algorithm reduces the key performance indicators of the system in the service process, improves the system service response speed, and makes the network-on-chip arbitration mechanism more efficient.

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