A Dynamic and Mixed Routing Algorithm for 2D Mesh NoC

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***Abstract*—To solve the congestion of NoC caused by overload such as injection rate increase, this paper proposes a novel routing algorithm, that is Dynamic and Mixed Routing(MIXROUT) which is based on XY Routing(XY) and Multiple and Load-Balance Path Routing(MULTI).Although MULTI is an adaptive routing that can relieve traffic congestion state, it has a higher operating power and temperature than other routing mechanism. So a dynamic routing strategy is proposed on the status of the network. It works as follows: MULTI is selected as the routing algorithm when NoC is in heavy load state, otherwise XY is chosen for a lower operating power and temperature. Experimental results show that under the condition of 4*4 topology sizes, MIXROUT is better than XY and MULTI used singly in term of thermal gradient, with a value 1.882°C, 4.116°C and 4.542°C respectively.**

Keywords-Dynamic routing algorithm; Power; Temperature

I. INTRODUCTION

Enjoying better scalability, throughput and lower power consumption when compared to traditional bus architecture, NoC(Network On-Chip) has been looked upon as a method to overcome the drawback of the communication shared bus and is going to be the main stream of the next generation IC design.

With the advance of the semiconductor technology, the feature size of the COMS is shrunk down to the range of nanometer and the delay of the gate has been greatly improved. The number of the functional units integrated on a chip is increasing, which leads to a greater improvement of the system performance. The power density, however, is sharply increasing because of the limited space, which in turn leads to a huge heat propagation and high temperature. As a result, it not only affects the performance of the system but also the life of the chip [1]. So it is necessary to make a trade-off regarding performance while respecting power consumption and temperature in the early of design.In NoC, communications between cores can be implemented by packets. Because the packets' path between source and destination is decided by the routing algorithm, which plays an important role in the performance of the system.

This paper is going to do a design space exploration in different routing algorithms to find a better one with a trade-off between performance and power, temperature.

II. RELATED WORK

Because of its simplicity and easy to implementation of VLSI, XY routing algorithm (XY) has been widely used in NoC. As a deterministic routing, however, it would suffer from a congestion easily when the load of the system beyond of the range it can bear, especially enjoying a wormhole flow-control. To solve congestion, many adaptive routing have been proposed. In [2-3], DyAD and odd-even were proposed respectively. In these two routing algorithms, packets can turn to a different direction depending on the network status when they move toward the destination, but do not consider other factors like power or hotspots. In [4-7], these routing algorithms take power or hotspots into account but not congestion about neighbor nodes. Dynamic and Mixed Routing(MIXROUT), proposed in this paper, thinks about congestion of neighbor nodes and power and temperature factors before making a strategy. And it combines XY routing and Multiple and Load-Balance Path Routing(MULTI) two parts. Although MULTI as an adaptive routing that can solve or relieve congestion has a better performance compared to XY in term of latency and throughput, it has a higher operating power and temperature like other parallel processes such as CMPs(Chip Multi Processors). Considering power and temperature, a module named Router controller(seen in section5) is built in this paper to sample the receiving packets of the network and then judges the status of network in order to decide which routing is used. It works as follow: MULTI is selected to solve or relieve congestion when system is in a heavy load state , otherwise XY is selected to let system work with a lower operating power and operating temperature compared to MULTI, so as not to force system always to work at a higher performance but a power and temperature cost state.

The rest of the paper is organized as follows. Section III is the implementation of MULTI. Section IV is the power and thermal models used in this paper. Section V is the experiments, including the strategy of implementing MIXROUT, and results analysis. And a conclusion is made in section VI.

III. IMPLEMENTATION OF MULTIPLE AND LOAD-BALANCE PATH ROUTING

In this paper, a mesh-based NoC with a variable topology size depending on the need is built, which has two arbitration algorithms, that is round-robin and first come first served(FCFS), and two routing algorithms, namely XY and MULTI discussed later. And the strategy of implementing MIXROUT will be discussed in section V.

Figure.1 is the implementation of the MULTI. Where （Xlocal, Ylocal and（Xdest, Ylocal） are the X dimension coordinate and Y dimension coordinate of the local's node and destination's node respectively. While Xdiff, Ydiff are the the difference of X dimension and Y dimension between destination node and local node respectively. There are two counters, Xcounter and Ycounter, to record the transmitted packets of X dimension and Y dimension respectively for the purpose of selecting a smaller congestion dimension between X dimension and Y dimension. For example, when Xcounter>Ycounter , the Y dimension is selected ,and if Ydiff>0 , the packet turns to the north(N), or the south(S), and Ycounter increases by one.

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-------------------------------------------
  Multi routing Arogrithm
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Xdiff=Xdest-Xlocal;
Ydiff=Ydest-Ylocal;
ToLocal=((Xdiff==0)&(Ydiff==0));
ToNorth=((Ydiff>0)&(Xcounter>Ycounter));
ToSouth=((Ydiff<0)&(Xcounter>Ycounter));
ToEast=((Xdiff>0)&(Xcounter<Ycounter));
ToWest=((Xdiff<0)&(Xcounter<Ycounter));

 if(ToLocal)
     turn to L;
else if(ToNorth)
    turn to N;
    Ycounter++;
else if(ToSouth)
    turn to S;
    Ycounter++;
else if(ToEast)
    turn to E;
    Xcounter++;
else if(ToWest)
    turn to W;
    Xcounter++;
endif
-------------------------------------------
```

Figure.1 Multiple and Load-Balance Path Routing Algorithm

IV. POWER AND THERMAL MODELS

Router as the main part of NoC is the subject when we study the power and thermal of NoC, including the main parts of the router , such as buffers and crossbar et al. In this section power and thermal model will be discussed.

A. Power Model

Power consumption can be classified as static power and dynamic power. And dynamic power is calculated according to the equation (1):

$$P = aCV_{dd}^{2}f \tag{1}$$

where a , C , V_{dd}^{2} , f are switching activity with a range from 0 to 1, load capacitance, voltage and frequency respectively. Under the condition of the fixed voltage and frequency, how to estimate the value of a is the key to calculate dynamic power of the router in this paper. In [8],volume-based models as a function of total transmitted data were proposed to estimate average power . Although they were simple, high-level, and fast, but not accurate. Because they did not capture low-level effects, such as congestion and burstiness. In [9],gate-based models were used to evaluated power ,but very time-consuming due to the complexity of NoC's components and the huge signals to be counted. To make it worse, there are many schemes concern with topology, routing, and flow control in early design. As a result, many signals to be counted are different. In [10], a rate-base model was proposed ,which took the average load of the router as the switching activity of the router . It enjoyed a fast and accurate performance. In [11], a router power simulator called Orion2.0 was proved to be feasible .The result based on it was different less than 7% compared to that based on a real chip, Intel 80-core Teraflops chip.

The power of router is calculated through the rate-based model and Orion2.0 simulator together.

B. Thermal Model

The thermal of the router, can be calculated by simulator HotSpot. HotSpot is an accurate and fast thermal model suitable for use in architectural studies. The model has been validated using finite element simulation [12]. It is based on an equivalent circuit of thermal resistances and capacitances that correspond to microarchitecture blocks and essential aspects of the thermal package.

HotSpot can calculate the temperature of units in a specific layout chip with corresponding power.

V. EXPERIMENTS AND RESULTS ANALYSIS

A. Metrics of Performance

Latency of a packet, throughput are used as the main metrics of NoC as well as power and temperature. Latency and throughput are defined in equations (2) and (3) respectively .

where $TotalLatency$, $TotalPackets$, $TotalFlits$, $TotalCycles$ are the total latency of packets, total packets received by system, total flits received by system, and total cycles of simulation respectively.

$$Latency = \frac{TotalLatency}{TotalPackets} \tag{2}$$

$$Throughput = \frac{TotalFlits}{TotalCycles} \tag{3}$$

B. Strategy of implementing MIXROUT

There is a 2D Mesh NoC network with 3*3 topology sizes, as shown in Figure.2. The Router Controller can calculate the receiving packets of the system within a period of sampling in order to judge the status of the system load and then decide which routing algorithm to be selected，namely MULTI is selected when system is in a heavy load state, otherwise XY .

The load of system is defined as equation(4):

$$Load = \frac{Packets * Length * Size}{SampleCycles * CoresNumber} \tag{4}$$

Where *Load* ranges from 0 to 1 and *Packets*, *Length*, *Size*, *SampleCycles*, *CoresNumber* are the number of system receiving packets, the length of the packet, the width of the flit, the period of each sampling, the topology sizes of network respectively.

When *Load* exceeds Load_Threshol, the system is in a overload state, and MULTI is selected ,otherwise XY is selected to let system work at a lower power and temperature cost state. Load_Threshol is set as 0.3, in this paper, which is a derivate reference deduced from Fig.3 and Fig.4.

From Figure.3, the throughputs of three topology sizes , namely 4*4, 5*5, 6*6, increase sharply enjoying MULTI routing when injection rate are bigger than 0.3, while smoothly enjoying XY.

From Figure.4, the latencies with XY increase rapidly from 0.3, while smoothly with MULTI. It means that 0.3 can be thought as a threshold of congestion.

So we take 0.3 as a reference of Load_Threshol to decide which routing to be selected.

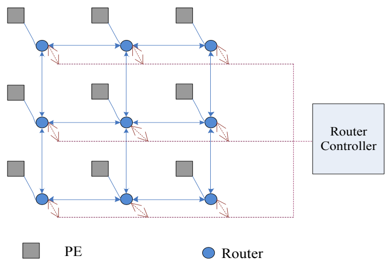

Figure.2 3*3 2D Mesh NoC

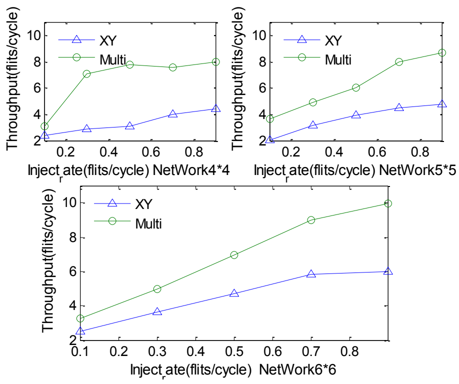

Figure.3 The Throughputs of different topology sizes

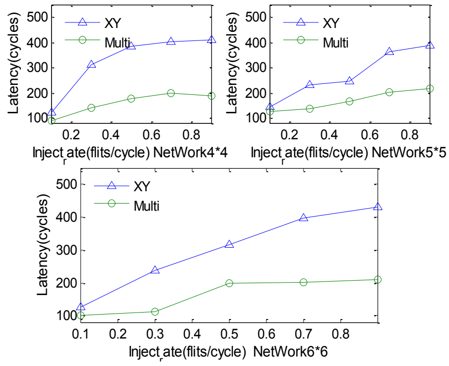

Figure.4 The Latencies of different topology sizes

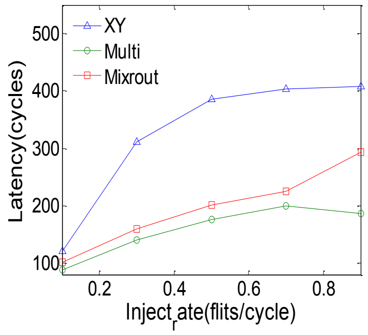

Figure.5 The average Latency

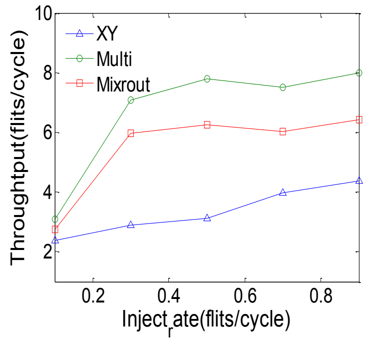

Figure.6 The average Throughput

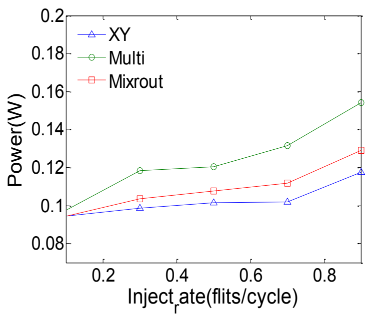

Figure.7 The average Power

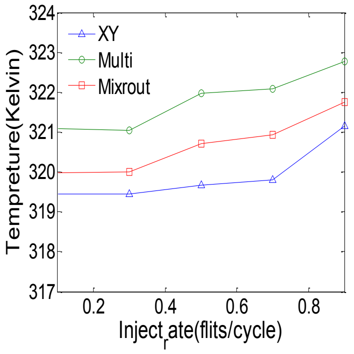

Figure.8 The average Temperature

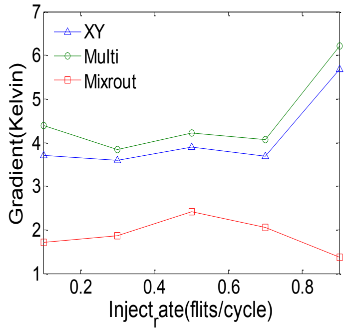

Figure.9 The thermal Gradient

C. *Experimental Conditions*

To explore the relations of performance with different routing algorithms while respecting power and temperature, the rest of experiments is based on a Mesh NoC(4x4) network. And the period of clock and the arbitration algorithm are 2ns and FCFS respectively. A packet contains 30 flits and the width of flit is 38. As a case of study , six traffic flows are set, that is (0,0)->(3,3),(0,2)->(3,0),(0,3)->(3,0),(1,0)->(2,3),(1,3)->(2,0) and (3,2)->(0,0). Each source sends 20 packets to corresponding destination and each simulation with corresponding routing runs 20000 cycles.

D. *Experimental Results*

From Figure.5~Figure.8, results show that the performances of MIXROUT are the trade-offs between XY and MULTI in term of the average latency of a packet, average throughput, average power, average temperature. As far as average latency, it has been reduced more than that with XY and MULTI by 39.7% and -24.1% respectively. Average throughput, is improved by 61.8% and -19.1% respectively. Average power, is reduced by -6.2% and 12.1% respectively. Average temperature , is reduced by -0.7764°C and 1.1108°C respectively. While ,based on Figure.9,the thermal gradients of these routings, that is MIXROUT, XY, and MULTI, are 1.882°C, 4.116°C and 4.542°C respectively, that is to say MIXROUT has a better performance in term of thermal-balance of the system.

VI. Conclusion

MIXROUT is proposed in this paper to solve the congestion caused by overload. The results indicate that MIXROUT has a better thermal balance than XY and MULTI and the thermal gradient values of these three routing are 1.882°C, 4.116°C and 4.542°C respectively. And it has trade-offs between XY and MULTI in term of the overall system performance including throughput, latency, power, and temperature.

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