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REVIEW OF XY ROUTING ALGORITHM FOR NETWORK-ON-CHIP ARCHITECTURE

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Abstract **-** The Network-on-Chip (NoC) is Network-version of System-on-Chip (SoC) means that on-chip communication is done through packet based networks. In NOC topology, routing algorithm and switching are main terminology .The routing algorithm is one of the key factor in NOC architecture. The routing algorithm, which defines as the path taken by a packet between the source and the destination. As XY routing algorithm mainly used in NOC because of its simplicity. This paper basically review of XY routing algorithm in which we study a different type of XY routing algorithm . The classification of XY routing algorithm is totally depend upon the environment and requirement. Such that IX/Y routing algorithm is for less collision in network ,for deadlock-free and livelock-free DyXY is used, for fault-tolerant XYX routing algorithm is proposed and Adaptive XY routing algorithm is used for fully utilization of network resource.

Keywords **-** *Network-on-chip; XY routing algorithm; XYX routing algorithm; IX/Y Routing algorithm ;DyXY Routing algorithm.*

I. INTRODUCTION

Traditionally, System-on-Chips (SoCs) utilize topologies based on shared buses. Dally and Towles proposed replacing dedicated, design specific wires with general purpose, (packet-switched) network [1], hence marking the beginning of network-on-chip (NoC) era. According to NoC design approach, designers use network design technology to analyze and design SoCs. In other words, designers view a SoC as a micro-network of components. SoC interconnection design can be done using the micro-network stack paradigm, which is an adaptation of the protocol stack. NOC can be defined as 'network-on-chip is a communication network targeted for on chip'. The NoC approach was proposed as a promising solution to these complex on-chip communication problems [2][3][4][5]. For the NoC architecture, the chip is divided into a set of interconnected blocks (or nodes) where each node can be a general-purpose processor like a Digital Signal Processing this processor commonly known as processing element (PE). A router is embedded within each node with the objective of connecting it to its neighbouring nodes. The router has four ports (West, South, East and North) to connect with other routers and a local port to connect with PE means have five input and five outputs, as shown in figure 1. Router basically consist of Routing algorithm and switching techniques, where routing algorithm proposed selection strategy which based on the concept of neighbours-on-path, The routing algorithm can be used in order to avoid faulty or congesting ports. Switching techniques determine when and how internal switches connect their inputs to outputs and the time at which message components may be transferred along these path

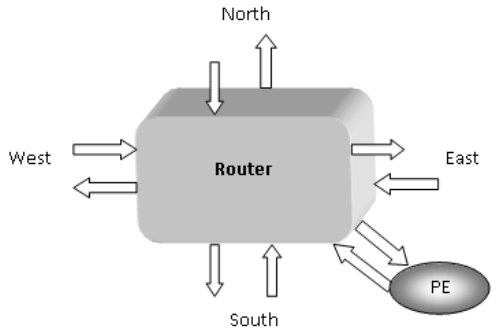

Fig. 1: Generic Router structure

The overall performance of a NoC depends on several network characteristics, such as topology, routing algorithm, flow control, and switching technique [6].

II. OVERVIEW OF NOC DESIGN APPROACH

Switching method, topology and Routing algorithm are three important techniques in the design of a NoC.

A. Switching Technique

There are two major switching techniques: circuit switching and packet switching. Circuit switching establishes a link between source and destination node either virtually or physically before a message is being transferred. The link is held until all the data are transmitted. Major advantages of circuit switching are that there is no contention delay during message transmission and its behaviour is more predictable, so circuit switching is usually employed when Quality of Service (QoS) is considered. Examples of using this technique are discussed in [7] and [8]. Packet switching which transfer messages on a per-hop basis. In packet switching, messages are divided into packets at the source node and then sent into a

network. Packets move along a route determined by the routing algorithm and traverse through a series of network nodes and finally arrive at the destination node. Packet switching is utilized in most of NoC platforms because of its potential for providing simultaneous data communication between many source-destination pairs. It can be further classified into three classes: store and forward (SAF), virtual cut through (VCT), and wormhole switching.

*B. **Topology***

Topology defines how nodes are placed and connected, affecting the bandwidth and latency of a network. Many different topologies have been proposed [9], such as mesh ,torus, mixed and custom topology. Some researchers have proposed the application-specific topology that can offer superior performance while minimizing area and energy consumption [10]. The most common topologies are 2D mesh and torus due to their grid-type shapes and regular structure which are the most appropriate for the two dimensional layout on a chip.

Mesh topology is easy to implement as all nodes are in equally distance as shown in Figure 2 and also makes addressing of the cores quite simple during routing. A mesh topology has four inputs and four outputs from/to other routers, and another input and output from/to the PE.

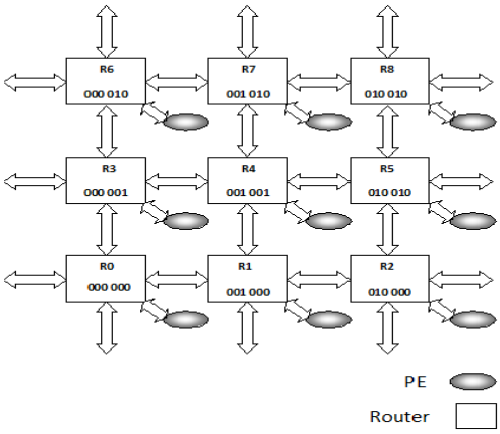

Fig. 2 : 3X3 Mesh Topology

C. Routing Algorithm in NOC

Routing algorithm is a key factor which affects the efficiency of the communication of NoC . The routing algorithm, which defines the path taken by a packet between the source and the destination, is a main task in network layer design of NoC. According to where routing decisions are taken, it is possible to classify the routing in source and distributed routing [11]. In source routing, the whole path is decided at the source router, while in distributed routing each router receives a packet and decides the direction to send it. According to how a path is defined to transmit packets, routing can be classified as deterministic or adaptive. The routing algorithms can be classified based on their adaptability, fault-tolerant capability, a centralized controller controls the data flow in a system and depends on the number of destination .But widely classified as Deterministic routing algorithm always choose the same path between a pair of nodes ,Balance of load is very poor in this case, but they are commonly used due to easy implementation. In Oblivious routing algorithm packets route without considering the network's state. And in Adaptive routing algorithm use information about the network's state (e.g. channel load information, length of queues for resources, etc.) to make routing decisions. A well-designed router should provide adaptive routing to route a packet through the less congested channels. In adaptive routing, each router has congestion information of its surrounding neighbourhood. The channel congestion metric can be based on the number of free virtual channels, the number of free buffers, the demand for switch output or a combination of these parameters [12]. Based on the congestion information, the router routes the packet to its destinations through the less congested channels. Gratz *et al.* propose regional congestion aware routing [13] which abstracts the regional congestion level into four single numbers to determine which direction is more likely to have low congestion. Ascia *et al.* [2] introduce *Neighbors-an-Path* adaptive routing algorithm for a router with no virtual channels. It uses immediate neighbour's congestion level for adaptive routing. Some more classification are possible like Fault-Tolerance-routing Algorithm - in which dynamically detects the faulty components while routing the packets. And Routing Through Reconfiguration - a cycle-free contour around a faulty link to use new unique paths instead of the broken paths.

III. TYPE OF XY ROUTING ALGORITHMS

A. XY

Wang Zhang and Ligang Hou[15] proposed Classic XY(Static XY OR XY) routing algorithm which is one kind of distributed deterministic routing algorithms. In which they used 2-Dimesion mesh topology and router which identified by its coordinate (x, y) for the implementation classic XY routing algorithm. The XY routing algorithm compares the current router address (Cx,Cy) to the destination router address (Dx,Dy) of the packet, stored in the header flit. Flits must be routed to the core port of the router when the (Cx,Cy) address of the current router is equal to the (Dx,Dy) address. If this is not the case, the Dx address is firstly compared to the Cx (horizontal) address. Flits will be routed to the East port when Cx<Dx, to West when Cx>Dx and if Cx=Dx the header flit is already horizontally aligned. If this last condition is true, the Dy (vertical) address is compared to the Cy address. Flits will be routed to South when Cy<Dy, to North when Cy>Dy. If the chosen port is busy, the header flit as well as all

subsequent flits of this packet will be blocked. The routing request for this packet will remain active until a connection is established in some future execution of the procedure in this router. For simulation they maintain environment as the packet size is 8 bytes with a random destination mode , the percentage load is 50% which mean that 50% of maximum bandwidth is used, the interval between successive flits is 2 clock cycles, the simulation runs 1000 clock cycles and the clock frequency is 1 GHz, Synthetic traffic generators generate traffic in the first 300 clock cycles with warm-up period of 5 clock cycles. After simulation they define an average performance parameter P to evaluate the average performance of the algorithm that is : P= Average Throughput of Network/ Average Latency per packet of Network which is 0.86 for the XY algorithm. So they come to conclusion that the implement of XY routing algorithm is simple as well as the X-direction channel latency is averagely lager than Y-direction channel latency and X-direction channel throughput is averagely all square with Y direction throughput.

B. IX/Y

For less collision Ahmad M. Shafiee, Mehrdad Montazeri, and Mahdi Nikdast developed new routing algorithm called as Intermittent Routing Algorithm[16] in which they used both XY and YX routing algorithm and name it as IX/Y routing algorithm. For study the performance of this routing algorithm they used 4 X 4 mesh topology with NOXIM Simulator in IX/Y routing data would be transferred from source to destination; first packet's Boolean variable is set to 0 and is routed by XY, then next packet's Boolean variable is set to 1 and is routed by YX, again 3rd one is set to 0 and the routing method is XY, and so on. This continuous process from routers in network layer will help to have fewer collisions. While comparing the result delay with respect to injection rate with other routing algorithm like XY, Dyad T, Negativefirst, Northlast, westfirst and oddeven algorithm they found that intermittent algorithm is roughly remained stable below 30 cycles . They also notice that this statistics is approximately the same in a 10*10 mesh-based and is an enduring algorithm in higher injection rates.

C. DyXY

A novel routing algorithm, namely dynamic XY (DyXY) routing algorithm which provides adaptive routing based on congestion condition in the proximity , and ensures deadlock-free and livelock-free routing at same time was proposed by Ming Li, Qing-An Zeng, Wen-Ben Jone [17]. With the DyXY routing algorithm, each packet only travels along a shortest path between the source and the destination If there are multiple shortest paths available, the routers will help the packet to choose one of them based on the congestion condition on the network. The detailed routing algorithm is summarized as follows:

1. Read the destination of an incoming packet.
2. Compare addresses of the destination and the current router.
   2.1. If
   The destination is the local core of the current router, send the packet to the local core;
   2.2. Else
   2.2.1. If
   The destination has the same x (or y-axis) address as the current router, send the packet to the neighboring router on the y-axis (or x-axis) towards the destination;
   2.2.2 Else
   Check the stress values of current router's neighbors towards the destination, and send the packet to the neighbor with smallest stress value.

Where the stress value is a parameter representing the congestion condition of a router, that is the number of occupied cells in all input buffers and each stress value is updated based on an event-driven mechanism. As With static XY routing, the length of a path traveled by packets for a give pair of source and destination is a constant, which equals to shortest path length. For DyXY routing, although the routing path is not static, it is always a shortest path and hence the length is still the shortest path length. Therefore, the average packet path length is only affected by the communication pattern. For the performance calculation author used an event-driven simulator using C++. By injecting more than 140,000 packets into the network in each simulation, and the NoC was warmed up for 20,000 packets before measuring latencies. After that they compared results of XY and DyXY and they found that

1) By size varied from 3X3 to 9X9 with average packet injection rate increasing from 0.1 to 0.3

2) The DyXY routing algorithm achieves better balance in load distribution

3) The average mean response time for all routers can be effectively estimated using the analytical lower bound and upper bound.

D. XYX

For higher traffic load Ahmad Patooghy and Seyed Ghassem Miremadi [18] mention a fault-tolerant routing algorithm called XYX. In the XYX routing algorithm there are two types of packets namely original and redundant packets. Using an indicator bit, embedded in the header flit of the packet, routers can distinguish between original and redundant packets. XYX routers, route the original packets according to XY routing while the redundant packets are routed using YX routing which is inversed version of XY routing. In the YX routing the packet

is routed in Y dimension at the first phase, when the packet reaches the row where destination node is located, the second phase starts and the packet will be routed in X dimension to reach the destination node. While the XY routing leads the original packets to some corners of the network, the YX routing leads the redundant packets to the other corners. To route the redundant and the original packets through different paths, indicator bit of the redundant packet is set to "1" while it is set to "0" in the original packet. Each flit of the original packet at the source node is equipped with one bit parity code. Consequently, the XYX routing algorithm routes the original and the redundant packets in opposite directions and the traffic distribution on the network channels tends to uniform distribution. Comparison shows that traffic distribution of XYX routing is very close to uniform distribution; hence all of the network channels have the same contribution in passing network traffic. At the destination node when a new original packet is received the parity bit will be regenerated and checked with those embedded in the packet. If two parity sets are equal, the packet will be accepted otherwise it will be dropped and the destination node waits to receive the redundant copy of the packet. For experimental analysis they create simulation platform as, 6×6 mesh topology, a minimum of 20000 packets have been delivered, a fixed length of 32 flits per packet, mean rates of spanned from 0.001 to 0.02 packet per cycle per node, and in the reliability evaluation experiments, a wide range of error rates have been also injected to the network to precisely investigate the reliability improvement of the proposed routing algorithm. In this experiment the network has been simulated with error injection rate approximately 0.5, 1, 2, 5, 10, 20 and 50 percent of all flits experience a bit flip error. In result Ahmad Patooghy *et al*. found that at lower traffic rate XYX and other algorithms like S2S have correctly delivered more than 90% of the packets and their behavior are almost the same, In high error rate condition, the XYX routing could tolerate more than 60% of errors while it imposes lower performance and power consumption overheads. The XYX routing has the best performance almost in all working conditions.

E. Adaptive XY Routing

For fully utilizing network resources Mohsen Nickray, Masood Dehyadgari and Ali Afzali-kusha [19] proposed Adaptive XY Routing in which they used a context aware agent which route packets based on the entire network status and other members of society. Adaptive XY routing algorithm is a derivative of classic XY routing algorithm. This algorithm could operate as a deterministic or adaptive routing depends on neighbor agents'(switches) load condition. When congestion becomes high, agent tries to route packets through less congested path. The agents find less congested paths using 2-bits quantized load value. As showed in Table 1.

Table 1

alue	DESCRIPTION
00	Port is free and ready to receive
01	Threshold0(Initial value= 50% of buffer is full)
10	Threshold1(Initial value= 75% of buffer is full)
11	Port is quite busy and can't receive

Emergence of a new route containing two parts: Firstly packets are routed by XY routing, when the destination port determined by XY routing is congested (a threshold is defined for each port of switch which is a criterion in order to realize a port is congested or not. This threshold involves the position of a switch for example switches are located in the center of mesh have threshold0 and the others have threshold1) they do not route packet to the destination where declared by XY routing rather then they compare quantized load value of neighbors and select the path that its quantized load value is minimum. This algorithm causes user don't have to wait until the crowded route release. Author also perform study the other routs which do not have any heavy load. Simulation perform on 3X3 mesh topology using SystemC language in which they keeping base class as SystemC . For results use two mode of load generation random test and test using multi media applications . Tables 2 and 3 compare simulation results which show better results for context-aware agent based algorithm and the proposed algorithm shows more improvement when number of packets increases that is in higher loads. When sent packets in a period are

Table 2 : Conventional XY routing

	500	2000	10000
Send Packet	450	3200	25000
Latency(Avg.)	17	30	43
Max Latency(Avg.)	34	70	93

Table 3: Context-aware agent based routing changed from 500 to 25000, the improvement of latency is changed from %11 to %25 and the improvement of max latency is changed from 0% to 33%.

	500	2000	10000
Send Packet	450	3200	25000
Latency(Avg.)	15	25	33
Max Latency(Avg.)	34	49	62

IV. CONCLUSIONS

A different type of XY routing algorithm is used in different network condition. The selection of XY routing algorithm it totally depends upon the application and the traffic of packet in the network. As simplicity in implementation is important in all architecture so an XY routing algorithm widely used . For fewer collisions Intermittent Routing Algorithm is preferred. The DyXY routing algorithm achieves better balance in load distribution as well as provide deadlock-free and livelock-free facility. Were we can't compromised with accuracy of received data , we go for the fault-tolerant routing like XYX .If application is focused on network resources utilization the Adaptive XY routing algorithm is best choice. Finally we can say that choice of XY routing algorithm is totally depends upon environmental condition of NOC architecture.

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