NETWORK-ON- CHIPSIMULATION COMPARISON BETWEEN ROUTING TOPOLOGIES

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ABSTRACT: *Network-on-Chip (NoC or NOC) is an approach towards designing the communication system between cores in a System-on-a-Chip (SOC). In this paper a new routing algorithm has been proposed for two dimensional grid NoC which finds the shortest path between the source and destination core in a NoC and also finds the most suitable path in case a node during the data transmission fails. Traditionally bus structure was used as a solution of interconnection between different cores. Because of the advancements in processor technologies, more cores are being placed on a SOC. Bus structure is narrow which does not allow flow of high traffic and causes delay in data traffic. In NoC the bus structure has been ruled out by network topologies which are similar to the Internet and communication happens between each core by transmitting packetized data over the network. Similar to the network of computers, a NoC contains devices like cores and traces which uses the network to communicate and traces are used to connect core with other cores and other devices in a NoC. The most essential thing in the designing of a NoC is the routing algorithm and the topology of the network. Cores route the data traffic according to the routing algorithm they are using. There are many routing algorithms and network topologies which are used according to the requirement. This paper focuses on comparison of all the state of the art routing algorithms with each other and our new proposed algorithm.*

Keywords: Routing topologies, routing algorithms, network-on-chip.

1. INTRODUCTION

Network-on-Chip is the latest procedure [4] adopted for the design for System-on-Chips because of it two properties "*composability*" and "*linear effort*" [5]. Because of the advancements in nanotechnology, the integration of different systems on a SOC is increasing. Large number of devices on a same chip is resulting in a very high data traffic in a very small space. The traditional bus structure which generally has the ability to transmit 8 bits has failed to take the load of such high traffic and started to cause delays and data loss. Apart from the physical limitations a significant role is played by the routing algorithm on the network operations, for data transmission every effort is made to reduce the distance between the source node and the destination node.

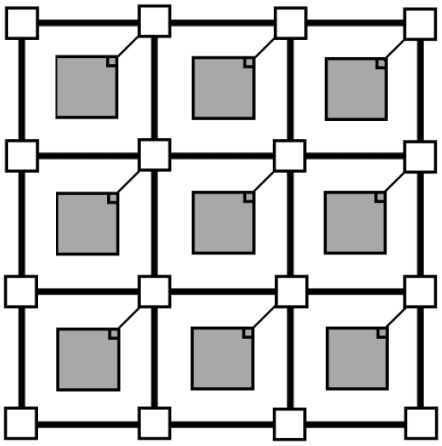

Figure 1A two dimensional grid network

In a NoC different devices have different functionalities, thus different routing algorithms are used according to the requirement of the system.

In NoC there are some requirements in the implementation that every network has to meet. In terms of performance requirement reliable throughput, minimum latency and multiple path diversion [12] are required. In terms of architectural requirements programmability and generality are required. The traffic in NoC network can be categorized into two types, "Best Effort Traffic" and "Guaranteed Throughput Traffic" [12].

Routing in Network on Chip

Routing of packets on network of computers is quite similar to the routing in NoC. The routing algorithm determines the path of data transmission from source to destination. The routing algorithm is further divided into two categories.

1. Oblivious Routing
2. Adaptive Routing

For this paper I have used deterministic oblivious routing which changes its path during run time if it finds a connection break between any two nodes in the path from source to destination.

Network Topologies

Network topologies represent the connection and arrangementof cores/routers in a network. There are many typesof network topologies exist but the most common topologiesthat are used in NoC are mesh, ring and star topologies. Forthese experiments a 4×4 mesh network was simulated asshown in figure 1 having 16 nodes/cores/routers in it.

Mesh Topology

Mesh topology or common known has Manhattan Street Topology [10] is an m row and n column mesh shaped network. The cores/routers are situated at the intersections of traces. Address of each core can be easily defined using their x and y coordinates in the network [12]. A figure of a MSN is shown in figure 1.

Advantages

- Assign line configuration of nodes allows identification and isolation of faults easily.
- Message is not broadcasted to the whole structure like in bus and is only intended for the recipient thus ensuring privacy and security of data.

- If a link between two cores/routers is broken it only effects the communication of only those two cores.

Disadvantages

- If the network area is big then making a mesh network is quite expensive.

Ring Topology

Ring topology is form of network topology which takes aform of a ring. In this topology every node is connected withexactly 2 other nodes, one at the left and the other one at theright thus making a continuous path for data transmissionfrom node to node. A ring topology network is shown infigure 2.

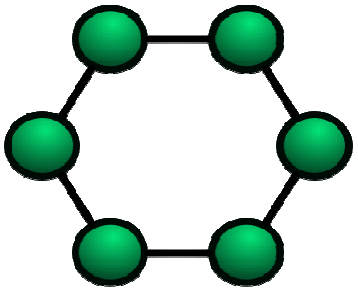

Figure 2 A ring topology

Advantages

- Performance is better than bus structure.
- Every node has the opportunity to transmit the data as the network is in order.
- No central node is required to monitor the network like used in star topology.

Disadvantages

- If the link between any two nodes is broken, complete network crashes.
- Increase in the number of nodes increases the communication delay.

Star Topology

Star topology is form of network topology which takes a form of a star. In this topology every node is connected with a central node which means that the central node is behaving as a master so if any communication between two nodes happen. It always passes through the master node.

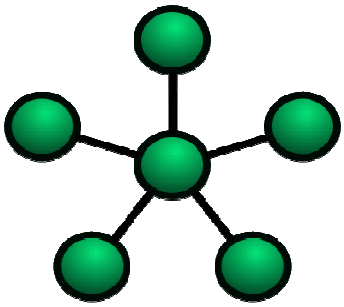

Figure 3 A star topology

Advantages

- Performance is better than bus structure [3].
- Every transmission maximum passes from only 3 nodes "source, master and destination".
- Fast data transmission.
- Easy fault and error detection.
- Addition of new nodes is easy.
- If any link between a node and the master breaks, the whole network doesn't crash.

Disadvantages

- If the master fails complete network crashes.

3. Routing Algorithm

The most important factor in any network, whether it is a network of computers or NoC is the routing algorithm that decides the path of the data transmission from source to destination. In networks there are two types of routing algorithms.

- Oblivious Routing
- Adaptive Routing

Oblivious Routing

Oblivious routing introduced by [13] has no information about the status of the network like whether any links are broken or there is any congestion in the network. The path of the transmission is decided by the nodes/routers [3]. Minimal turn routing [1] is considered to be the simplest routing algorithm which tries to route the packet using minimal turns.

Adaptive Routing

In adaptive routing, every node/router is aware of the condition of the network such as traffic condition, congestion and adopt the routing path accordingly. This happens to avoid fault tolerance and traffic congestion [2] which means that some routing algorithm misroute the traffic from the destination to avoid high traffic. In case of low traffic, the adaptive algorithm should ideally find the shortest route to destination [11].

4. Network Flow Control

Network flow control which is also called routing mode [12] decides how packets travel inside a network. Flow control is not dependent on the routing algorithm but many of the routing algorithms are designed to use some given mode [12]. Some of the network flow control algorithms are briefly described below.

Store and Forward

Store and forward packet switching [7] is the simplest form of the routing mode. Data as we know is transmitted in the form of packet is completely stored in the buffer of the node which means that unless the whole packet is arrived in the current node from the previous node, it will not start transmitting the packet to the next node, so for this purpose the size of the buffer of the node should be large enough to hold the largest packet in the network. Delays in the transmission occurs because of receiving the whole packet before transmitting it. A store and forward switching can be seen in figure 4

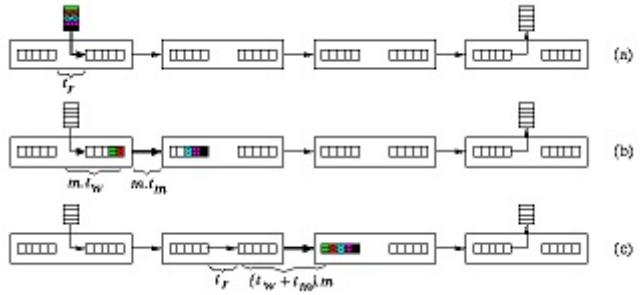

Figure 4 Store and forward switching

Virtual Cut Through

The cut through switching [6] is quite similar to the message switching but the only difference is that it starts to transmit the data when the head of the packet arrives at the intermediate node. The node starts to transmit data as soon as the succeeding node allows to transmit. It is quite similar to the store and forward as this method requires same amount of memory as store and forward requires but the latency is low here. A virtual cut through can be seen in figure 5.

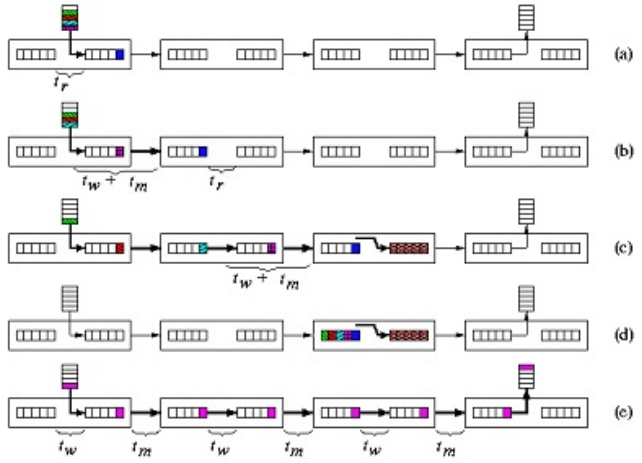

Figure 5Virtual Cut Through Switching

Wormhole

In wormhole [15] switching packets are divided into equal size. "A first flit of a packet is routed similarly as packets in the virtual cut-through routing. After first flit the route is reserved to route the remaining flits of the packet. This route is called wormhole" [12]. The advantage of wormhole switching is that it requires far less memory for the buffer than the other two stated. The other advantage of the wormhole switching is that the latency time is much less than cut through and store and forward as data transmission starts without waiting for the whole packet. A wormhole can be seen in figure 6

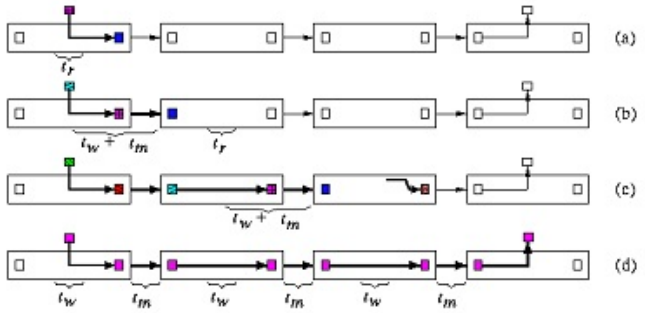

Figure 6Wormhole Switching

.Problems in Routing

Problems begin to appear in the network when the traffic in the network starts to block because of high data rate. Solution of this problem is to try again when the amount of traffic in the network decreases. This happens usually when oblivious routing is used when nodes are unaware of the network traffic condition. Common problems that happen in both oblivious and adaptive routing are deadlock, livelock and starvation [9].

Deadlock

Deadlock in the network happens when two packets wait for each other to move ahead in the network this happens because both packets are reserving some resources and they are waiting for each other's resources to get free as in network nodes does not free the previous resource until they get a new resource. Deadlocks block the communication thus may lead to the failure of the network.

Solutions of deadlock are provided in [8] and [14] uses minimal turn routing in irregular topologies but these methods have to be used during the construction of the network. For regular topologies deadlock can be avoided by making restriction on the routing function.

Livelock

Livelock happens in the network when the packet keeps wondering into the network without reaching the destination ever. This usually happens when the path given by the routing algorithm is not usually the shortest path.

Starvation

Sometimes during the transmission of the data on the network, packets are assign priorities, Starvation occurs when low priority packets never reach their destination. This can be avoided by allocating some portion of bandwidth for low priority packets.

5. Methodology

For this paper 3 network topologies were implemented and experiments were performed to measure the performance of each network topology given a certain number of nodes in a network.

The topologies that are implemented in this project are

1. Star
2. Ring
3. Grid

The routing mode that was implemented for the network flow control is store and forward and the assumption made that throughput is guaranteed unless the packet goes in the state of livelock or deadlock. The routing algorithm that is

chosen for this paper is oblivious routing algorithm as the nodes are unaware of the state of the network.

Minimal Path Routing Algorithm

The new routing algorithm which is proposed in this paper is described in this section. An assumption has been made that every node in the grid is assigned a self-index which is different from the index of the node in the gridi.e. node that have the grid index [0,0] has self-index of 1 similarly if the node having grid index of [3,3] has self-index of 16. This is done because self-index can tell how linearly far the destination node is from the source node. Every node also maintains the self-index of its neighbouring nodes.

Algorithm

Repeat

- Check neighbours.
- Subtract the self-index of all neighbours from the self-index of destination.
- Find the neighbour with minimum self-index subtractionanswer, move data to its buffer

Until

This algorithm not only gives the shortest path from sourceto destination but also it gives the minimum turn path. Moreoverthis algorithm can change the path during runtime if it finds that the link between two nodes is broken or the bufferof the neighbouring node does not have sufficient space inbuffer

The drawback of this algorithm is that packet does not pass through the node once it has passed from, so if the packet reaches at a node and finds that the path between the next nodes is broken then it cannot go back to the previous node to find an alternate path.

6. EXPERIMENTS AND RESULTS

Shortest Path Test

First experiment that was performed was to verify the claim of the finding the shortest path in a grid through proposed routing algorithm. The results can be seen in table 1.

The assumption that was made during the experiment was that no link in between any node is broken and buffers are empty. The table is explained as "Source" means the self-index of the source node, "Destination" means the self-index of the destination node and "Nodes" means the number of nodes a packet has travelled to reach the destination, the source and destination nodes are also included into the outcome.

Table 1 Shortest paths for mesh network

Source	Destination	Nodes	Shortest path
1	4	4	Y
1	5	2	Y
1	16	7	Y
1	16	9	Y
16	2	6	Y

Rerouting

In networks mostly happens that when a packet moving from source to destination, a link is broken between two nodes in the way, so the nodes has to re-route the packet so that it can reach the destination keeping the minimal path. This experiments shows that the algorithm that is explained before has the ability to re-route or not. The results from Table 1 are used to draw new results that are shown in Table 2. In this experiment a grid of 4 × 4 is used.

Table 2Shortest Paths for Mesh Network with Broken Links

Source	Destination	Previous Path	Broken Links	New Path
1	15	1,5,9,13,14,15	5,9	1,5,6,10,14,15
1	5	1,5	1,5	1,2,6,5
2	15	2,6,10,14,15	6,10	2,6,7,11,15
4	5	4,3,2,1,5	3,2	4,3,7,6,5

From the experiments we can see that if some links between nodes from source to destination were broken, the algorithm rerouted the traffic to new path so that it can reach the destination using minimal path.

Ring Vs Mesh

In this experiment ring topology is compared with mesh in terms of node traversal i.e. in which topology data has to travel more nodes than the other. In case of ring topology, before transmitting data, the nodes looks on both right and left side that from which side the destination is nearest. After finding the direction the source node starts transmitting the data in which the distance between the source and the destination is minimum. In this experiment a 4 × 4 mesh has been compared with a 16 node ring. Results of the experiment can be seen in table 3.

Table 3 Ring Vs mesh

Source	Destination	Number of nodes data travelled in ring	Number of nodes data travelled in mesh
1	16	2	7
1	5	5	2
1	8	8	5
15	6	8	4
4	14	7	6

By the experiments we can conclude that usually mesh works better than ring because packets have to travel more in ring than in mesh.

Star Topology: 3 Node Test

In star topology, it is claimed that for every transmission a packet has to move only to 3 nodes to reach the destination from its source. This experiment is carried out to verify this claim. This experiment also verifies the claim that adding new nodes in the star network is easy and the organization of the previous topology is not changed. The result of this experiment can be seen in table 4.

Table 4 Star topology

Source	Destination	Master node	Number of nodes data travelled
1	16	2	3
1	5	8	3
1	8	4	3
15	6	1	3
4	14	7	3

From the experiments we can see that the claim that every packet passes only through 3 nodes is true. In ideal

conditions when there is no congestion, star topology performance better than mesh and ring topologies.

7. CONCLUSION

The conclusion of this paper is that the routing topologies and the routing algorithm used to design a network are very much important and are requirement dependant, some applications in which low traffic with high speed is required, star topologies works better as packet always to 3 nodes only. A new shortest path routing algorithm was also introduced that takes minimal memory and resources. Some application like gaming consoles where is high traffic, ring topology works better similarly in applications where broadcasting of data is not required mesh topology works best.

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