Three-Dimensional Topology based on Modified Diagonal Mesh Interconnection Network

Akash Punhani[1], Pardeep Kumar[1] and Nitin Nitin[2]
[1]*Jaypee University of Information Technology, Solan, H.P, India.*
[2]*College of Engineering and Applied Science, Department of Electrical Engineering and Computer Science, University of Cincinnati, Cincinnati, OHIO, USA.*
akashpunhani@gmail.com

***Abstract*—Interconnection Network is the key component of the digital system. The numbers of cores are increasing on the single chip, which led to the introduction of layered based concept in the System on Chips. Various topologies suggested in the past were based on the 3-dimensional layouts. In this paper, we have proposed using the modified Diagonal mesh topology for defining the single layer of the topology. The proposed topology has been tested on the various traffic patterns like a uniform, bit complement, neighbor, tornado, bit traversal and bit reversal traffic. The performance of the proposed topology was better in the bit reversal traffic. The topology was found to be comparable to other three-dimensional topologies on the uniform, and tornado traffic. The performance of the topology was less in comparison to other topologies in the case of other traffic. Based on the analysis of results it can be observed, we can use the topology in the applications where traffic is following the pattern of the form bit reversal.**

***Index Terms*—Latency; Mesh Interconnection Network; Network Traffics; Throughput.**

I. INTRODUCTION

The interconnection network is the part of every digital system. The main components of the interconnection network are topology, routing algorithm and the flow control mechanism used. In past bus-based topology was used to connect the intellectual properties (IP). With the popularity of Amdahl's law, the massively parallel computers come into existence. Using the bus-based topology for these topologies seems to be the bottleneck for the system. So the idea used was to route the wire directly from the source to the destination, this makes the topology complex and difficult to build on the chips. William J Dally and his team suggested [1] the idea of routing the packet in the tile based architecture rather than routing the packet from the source to destination. This topology was a two-dimensional topology. Based on this two-dimensional topology three-dimensional topologies are also constructed the building block of this type of topology, for example, we can create the three-dimensional mesh, and 3-dimensional torus or n-dimensional torus were created in the past. In this paper, we want to extend the two-dimensional topology modified diagonal mesh interconnection network (MDMIN) [2]. The MDMIN topology derived from the diagonal torus topology. The MDMIN has been proven to better in comparison to that of mesh, torus and Diagonal mesh in some of the cases as topology gets divided into two halves when there was an even number of the node. The three-dimensional topologies are preferred in comparison to two-dimensional topologies because of the fact the inter-hop distance between the various nodes gets reduced which means the core property of any node that is the diameter of the topology is also reduced. As the topology design is supporting multiple links as there is the increase in one dimension of the topology the bisection bandwidth of topology will also increase that depends upon the number of nodes in a particular dimension. The increased bisection bandwidth didn't increase the throughput, but will also make the topology more fault tolerant. The 3-D topologies used in the comparison are described in detailed in Section 2 of the paper. Section 3 presents our topology that is the 3D MDMIN. In Section 4, the performance of the topology is compared with the other existing topology. In Section 5, we conclude our results and findings.

II. EXISTING TOPOLOGIES

Many topologies were suggested in the past which are difficult to represent in a plain like a torus topology [3] and X torus topology [4]. The Diagonal neighbour topologies like Diagonal meshes [5], SD torus [6], xx torus [7], xtorus [7] are also tough to be represented in a single plain. N-Dimensional twin Torus [8], dimensional torus and 3D mesh and 3D torus, C2 Mesh [9], [10], CC Torus [11], CCP Torus [12], Diagonal Connected T Mesh [13] and complex graphs like Peterson torus [14] also belongs to the category of multi-layer graphs. An attempt to allocate optimal links is highlighted in [19] and the importance to routing algorithm is highlighted in [18]. In this paper, we will focus mainly on the four topologies that are 3D mesh, 3D torus, 2D torus all other topologies belong to the family of these topologies.

A. 3-D Mesh topology

The 3-D mesh topology is shown in Figure 1.

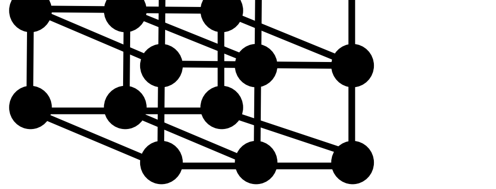

Figure 1: The 3D mesh of 3×3×2 nodes

This topology has multiple layers of the meshes that keep one over the other. In Figure 1, we can see that we have two layers of 3×3 two meshes connected to each other by links. The Layer *0* and Layer *1* are individually 3×3 mesh. The maximum diameter of this topology is five, whereas if we place the same number of nodes in the 6×3 mesh, then the diameter will be 6. In this way, the one hop is reduced and will affect the bandwidth and throughput of the network.

Equation 1 describes the 3D mesh topology. In the above equation, we have considered *m, n, l* as the maximum number of rows, columns and levels, that start the numbering from *0* instead of *1*. This means if there are *m* rows they will be named as row 0 to row *m-1*.

$$E=\begin{cases}(x,y,z+1) & \text{if } x=m-1, y=n-1, z<l-1\\(x,y+1,z) & \text{if } x=m-1, y<n-1, z=l-1\\(x+1,y,z) & \text{if } x<m-1, y=n-1, z=l-1\\(x,y+1,z+1) & \text{if } x=m-1, y<n-1, z<l-1\\(x+1,y,z+1) & \text{if } x<m-1, y=n-1, z<l-1\\(x+1,y+1,z) & \text{if } x<m-1, y<n-1, z=l-1\\(x+1,y+1,z+1) & \text{if } x<m-1, y<n-1, z<l-1\\(x,y,z-1) & \text{if } x=0, y=0, z>0\\(x,y-1,z) & \text{if } x=0, y>0, z=0\\(x-1,y,z) & \text{if } x>0, y=0, z=0\\(x,y-1,z-1) & \text{if } x=0, y>0, z>0\\(x-1,y,z-1) & \text{if } x>0, y=0, z>0\\(x-1,y-1,z) & \text{if } x>0, y>0, z=0\\(x-1,y-1,z-1) & \text{if } x>0, y>0n, z>0\end{cases} \tag{1}$$

B. 3-D Torus topology

Figure 2 shows a *3×3×2* torus topology. Here in this *3D* torus topology, all the nodes in the topology are wrap around which means that the extreme point on each plain is connected to each other. For example, if we consider row, then 0^{th} will be linked to the *n-1*th row, and the *0*th column is connected to the *n-1*th columns, and the layer *0* will be connected to *n-1*th layer.

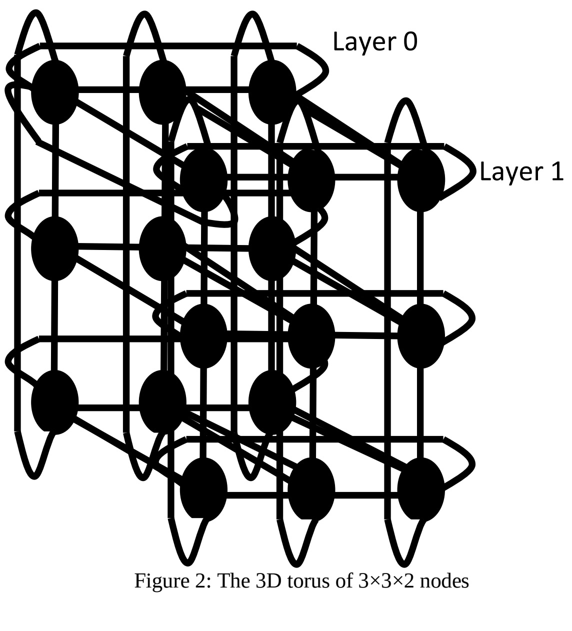

Figure 2: The 3D torus of 3×3×2 nodes

Equation 2 is used to represent the edges of 3D torus topology.

$$E=\{(x\pm 1)\%m,(y\pm 1)\%n,(z\pm 1)\%l\} \tag{2}$$

Here, '*m*', '*n*' is row and columns in the two-dimensional topology and '*l*' define the number of levels.

C. 2-D Torus topology

For the two-dimensional torus has been described in Figure 3. We have selected the torus topology while comparing the three-dimensional topology because it is the simplest two-dimensional topology. The name of the topology itself describes its shape which is the three-dimensional shape. It can be considered as the simplest three-dimensional figure. Torus is one of the most popular topologies and used in many supercomputers. The diameter of the torus topology is 4. Equation 3 describes the equation for the links from the source node to the destination node.

$$E=\{((x+1)\%n,(y+1)\%m)\} \tag{3}$$

where x and y are the source coordinates and n and m are representing the number of nodes in a row and columns respectively. The 2D torus topology is described in the Figure 3.

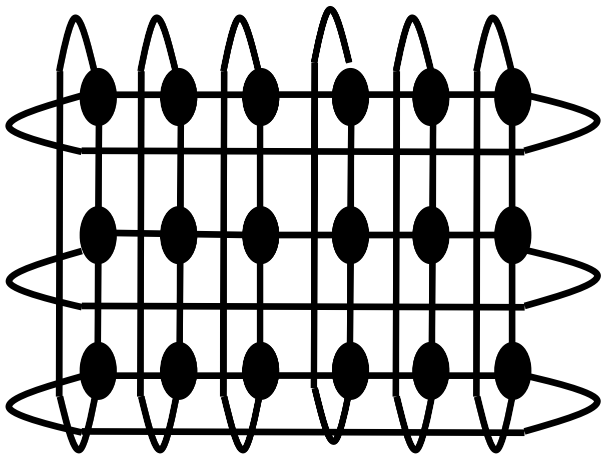

Figure 3: The 2D torus of 6×2 nodes

III. PROPOSED TOPOLOGY

In the proposed topology we suggested using the MDMIN topology [2] at each level. The MDMIN topology has been described in Figure 4 and which will be connected to another layer by the same the mathematical formulation as we have used in the case to 3D mesh. The further modification MDMIN have been suggested in the MDMIN to improve the performance.

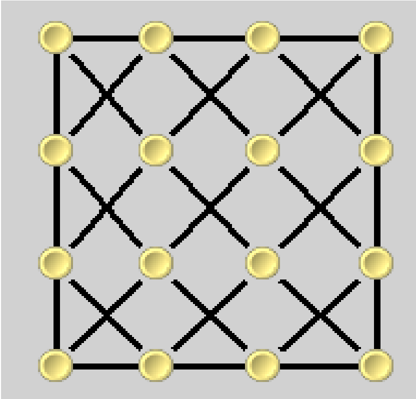

Figure 4: MDMIN of 4×4

Figure 5 describes the proposed topology. The mathematical formulation of the MDMIN has been described in [2].

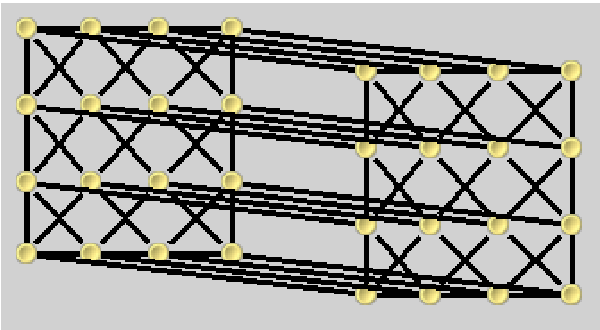

Figure 5: Proposed Topology Based on 3D MDMIN 4×4×2

The links are described by the simple Equation 4.

$$E = \begin{cases} (x, y, z \pm 1) & if\ z < l - 1 and\ z > 0 \\ (x, y, z - 1) & if\ z = l \\ (x, y, z + 1) & if\ z = 0 \end{cases} \quad (4)$$

In the above equation, 'l' is representing the level of the topologies for 3D MDMIN.

IV. RESULTS AND DISCUSSIONS

To analyse the performance of the proposed topology, we have used the two parameters they are the average throughput and average end to end latency. We have designed the topology in the OMNeT++ simulator [14], [15]. The topology has been tested on the six traffic patterns and compared with the other three existing topologies. Table 1 describes the hardware used for the testing the performance of the topology.

Table 1
The hardware used to create simulation

No	Hardware Configuration	Specification value
1	Processor	Intel®core™2 CPU T5200@1.6 GHZ
2	RAM	3 GB
3	Operating System	Windows 7 32 Bit
4	OMNeT++ Simulator version	4.4.1

The OMNeT++ configuration parameters for the 32 nodes in each topology have been described in Table 2.

Table 2
The parameter used for the testing of topology

No	Parameter Name	Parameter Value
1	Simulation Time	0.5 s
2	Warm-up Period	50 ms
3	Traffic Patterns	Uniform Traffic Bit Complement Traffic Neighbor Traffic Tornado Traffic Bit Transpose Traffic Bit Reversal Traffic
4	Inter-Packet Arrival Delay	163.84 µs,81.92 µs 54.61 µs,40.96 µs 32.77 µs,27.31 µs 23.41 µs,20.48 µs 18.20 µs,16.38 µs
5	Topologies	2DTorus (4X8) 3D mesh (4X4X2) 3D Torus (4X4X2) Proposed Topology
6	Channel Data Rate	1Gbps

A. Uniform Traffic

The uniform traffic sends the traffic to every node with equal probability. The average end to end latency graphs has been described in Figure 6 and 7. From the results, it can be observed that the even though the average throughput was almost the same, but the latency of the proposed topology was better in comparison to other topologies under consideration.

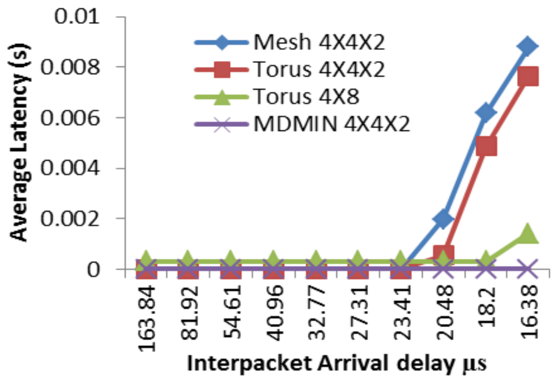

Figure 6: Average Latency at Uniform Traffic

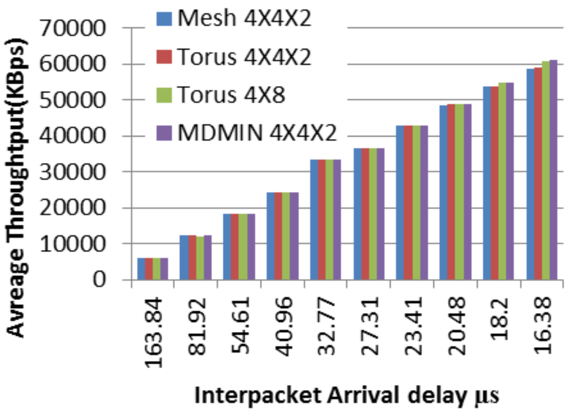

Figure 7: Average Throughput at Uniform Traffic

B. Bit Complement Traffic

On bit complement traffic it has been found that the 2D torus will be the best topology in comparison the three-dimensional topologies. The proposed topology proved to be identical to that of 3D torus topology. The graphs of latency and throughput are described in Figure 8 and 9.

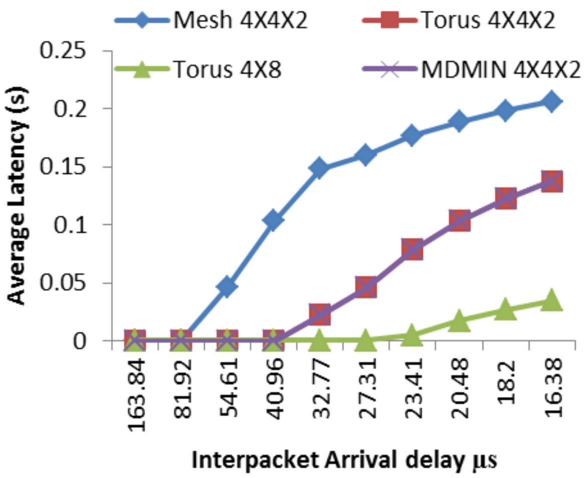

Figure 8: Average Latency at Bit Complement Traffic

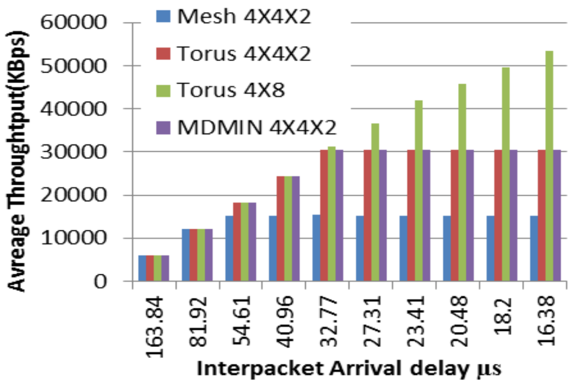

Figure 9: Average Throughput at Bit Complement Traffic

C. Neighbour traffic

In the case of neighbour traffic, there are two assumptions on which we can decide our neighbour; one is the neighbour that may be situated on the diagonals which are the case of proposed topology, and other may be the horizontal and vertical adjacent nodes. For doing the analysis, we have selected the horizontal or vertical neighbour that is against our designed topology. Still the results show that the proposed topology has shown better performance than the other two 3-Dimesional topologies, but it is slow in comparison to torus topology. The results have shown in Figure 10 and 11 respectively.

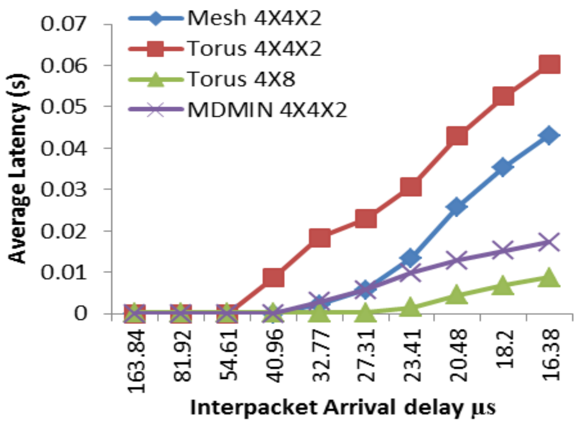

Figure 10: Average Latency at Neighbour Traffic

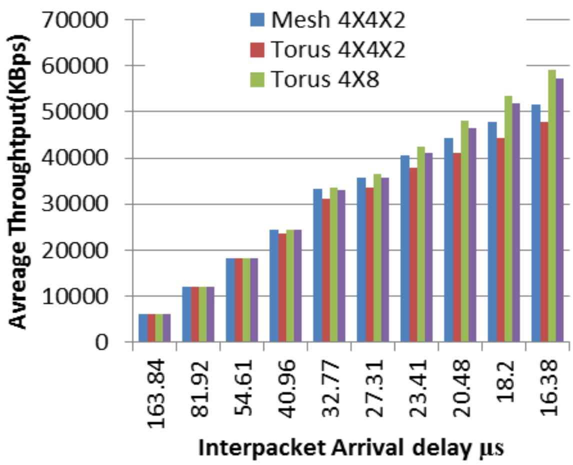

Figure 11: Average Throughput at Neighbour Traffic

D. Tornado Traffic

The tornado traffic is supposed to be a kind of traffic, which assumes to have the values to be shuffled by at least of the bits. It is considered to be worst digital permutation traffic. The performance of the proposed topology was almost the same of that of the other three-dimensional topologies. Figure 12 and 13 also described that the two-dimensional torus is having poor performance in comparison to other topologies.

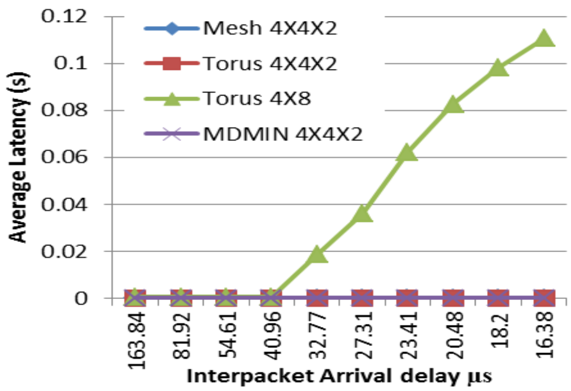

Figure 12: Average Latency at Neighbour Traffic

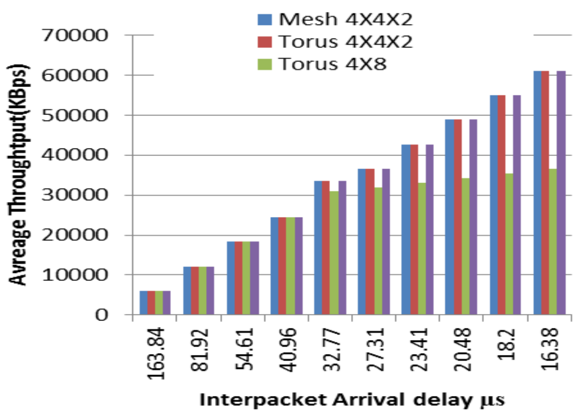

Figure 13: Average Throughput at Neighbour Traffic

E. Bit Transpose Traffic

This traffic is also based on the bit permutation and also guarantees that at least half of the nodes are affected by the performance. The performance of our topology is not okay in this traffic. It is again dominated by 2D and 3D torus topologies as described in Figure 14 and 15.

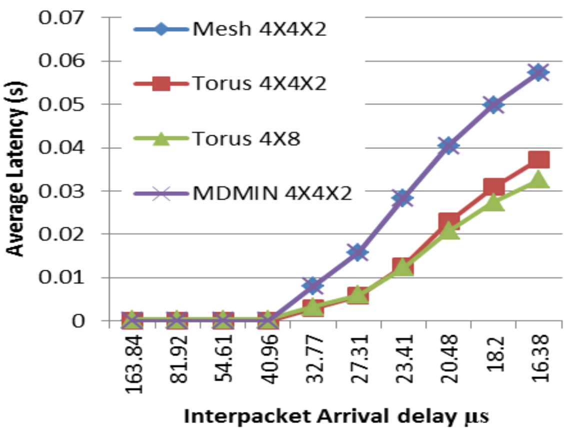

Figure 14: Average Latency at Bit Transpose Traffic

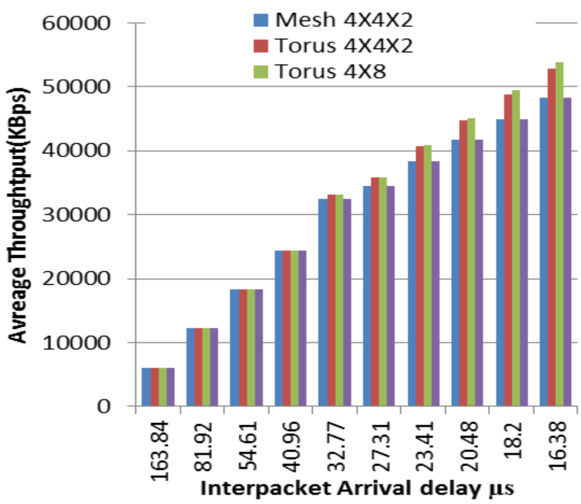

Figure 15: Average Throughput at Bit Traversal Traffic

F. Bit Reversal Traffic

This traffic based on the bit permutation and guarantees that all the bits in the source and destination are changed from their positions. It is also considered to be one of the worst traffic patterns. From the details described in Figure 16 and 17, it is clear that proposed topology is best in the case of the Bit Reversal Traffic.

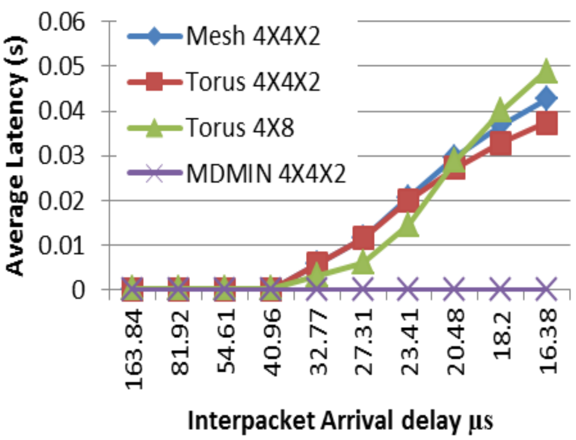

Figure 16: Average Latency at Bit reversal Traffic

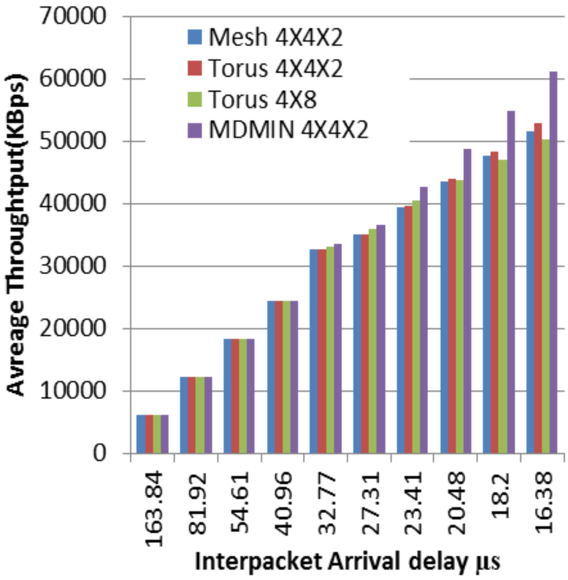

Figure 17: Average Throughput at Bit Reversal Traffic

V. CONCLUSION

By the results described in the previous section on the various topology and traffic patterns, it can be observed that topology has behaved poorly on neighbour and bit traversal traffic. It has almost the same performance on the uniform and tornado traffic. Proposed topology has performed better in the case of bit reversal. We can also observe that in the case of neighbour traffic even though the selection of the neighbour is made horizontally still the performance of the topology is at the second best. At last, we can conclude our topology can be substituted with the existing 3 Dimensional topologies. In the future, we can suggest the higher level topologies which can outperform the other existing topologies.

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