Center Concentrated X-Torus Topology

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***Abstract*—The topologies are the very important part of the interconnection network. The topologies once decided cannot be further modified in some cases, so we have to design best topology before its use. The regular topologies have been used in various massively parallel computers. In this paper, we have proposed a new variant of X-torus topology which the objective gets the better on the various qualities of service parameter like latency and throughput. The performance the proposed topology has been tested on the four traffic patterns and have been found that the topology is either better or same in the terms of performance. However, it has been found that we were able to get improvement of 85.24% in the terms of average latency than the other topologies similarly the throughput of the topology has improved by 17.86%. The Hop count is also another factor to study as if we can reduce the hop count in a particular topology we will be able to improve the performance and average hop count of our topology has been improved by 9.58%.**

***Index Terms*—Average Hop Count; Average Latency; Average Throughput; Interconnection Networks; Traffic Patterns.**

I. INTRODUCTION

A topology is one of the important design parameters which is used in the network on chip. The performance of Interconnection network depends hardly on the underlying topology. The Interconnection network cannot perform better than the bisection bandwidth even though the other factors that are routing algorithm or the flow control mechanism are improved [1], [2]. This fact has lead to the target the researchers to design the topologies that are having higher bandwidth than the existing topologies. Another key factor for focusing on topology is that it is a design issue that means once the topology is designed we cannot further modify on the chip, but still the other factors like the routing algorithm and flow control mechanism can be updated to some extend so this motivates us to search for the topologies which are based on the simple existing topologies but can give better results than the existing topologies.

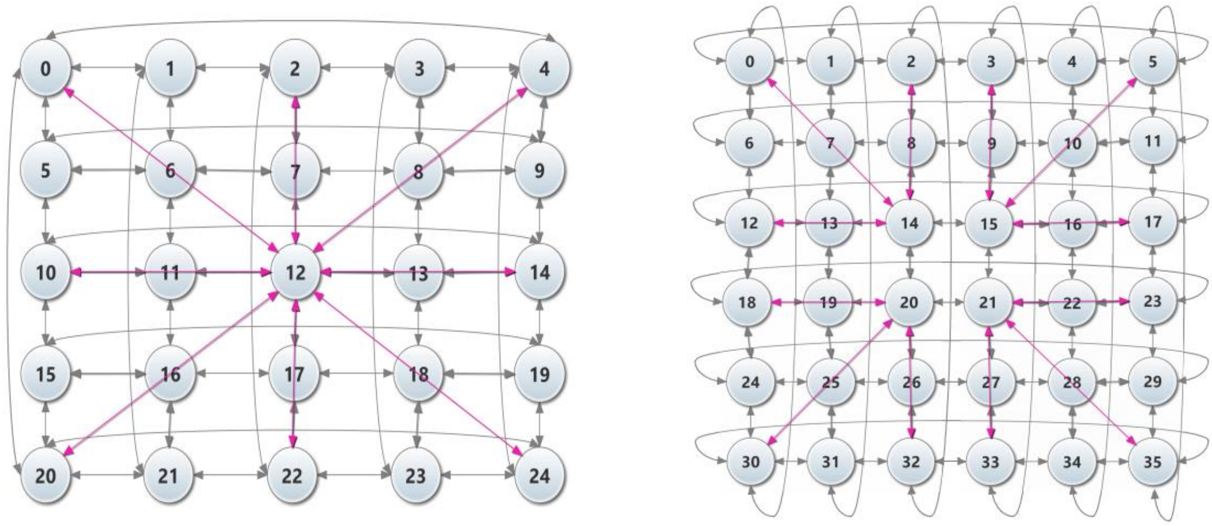
The detailed study of the topologies states that initially we can have two types of topologies for interconnection network that are regular and other one is referred as irregular topology. In our study, we have focused on the regular topology. By the definition of regular topology can say that the regular topology is the topology in which each node is having processing unit and the routing element [2]. The routing unit will be connecting the nodes to other nodes as well as to the current processing unit. In the study of various articles, it has been identified that initially wires we routed to the destination according to the applications so as to boost the performance, but this approach seems to be very costlier and make the design strict to the particular application. This issue was resolved by the suggesting the tile based architecture. This approach has basically stated that route the packets not the wires to a particular node [3]. The main advantage of the tile based architecture was that is has been suited according the design requirement of the chip for the multiple number of cores [16]. Based on this many researcher have worked on the various topologies and had led to the development of various topologies [4]–[10]. Our topology is inspired by the two topologies one is an X-torus topologies which has been refined to get rid of the drawbacks of E topology [8] and the center concentrated topologies the various kinds of center concentrated topologies have been proposed in the mesh and torus topologies [4], [5], [11], [12]. As from the analysis this has been found that center concentration has provided as a great improvement in comparison to existing topologies. In this paper, we will suggest as topology that is designed on the basis of the X-torus topology and is having the center concentrated links as suggested in C^2 Mesh.

The paper has been organized into various sections. Section II presents detailed discussion about the existing topologies. In Section III, we propose the C^2X-torus topology. In Section IV, we present the experimental setup used for the analysis of the topology. In Section V, a detailed discussion of the results has been presented and finally we conclude the paper in Section VI.

II. X-TORUS AND CENTER CONCENTRATED TORUS

Figure 1 described the X-torus 5x5 topology, the mathematical formulation of the X-torus topologies can be found from the [8]. The topology was having some nodes as the degree of 6 and some are having a less degree in order to make the degree uniform we will add some links to the X-torus topologies so that each node has the degree of six. The X-torus topology utilizes the links to provide the shortest path to the nodes to achieve greater performance against to its counter parts as described in the paper.

Another topology is the Center concentrated torus topology. It is also a modification of the torus topology the torus topology with the uniform degree for four and nodes form the corner edges are incident to the center nodes. The Center concentrated torus is described in the Figure 1(a) and 1(b). From the figure it can be observed that we can have four centers in the case of even topologies and one center in case of odd parity topologies like 5x5 topologies. This topology has been reported to perform better in comparison to the torus topology.



(a) (b)

Figure 1: (a) Odd CC torus and (b) even CC torus

III. CENTER CONCENTRATED X-TORUS TOPOLOGY

This topology is the hybrid topology which has been found with the combination of X-torus topology which has been identified to better regular topology and CC torus topology. The unique difference while designing the CC torus from torus and CC X-torus from X-torus is that in torus it was having the uniform degree, but in the case of X-torus topology we don't have the uniform degree. So the designing the CC X-torus topology can be divided into 2 phases.

A. Introducing New X-torus links

To add the new X-torus links we have to consider the equation as described below and then add the new links based on the equations provided below to the torus topology:

$$C_x = \left\{ \langle (u_a,u_b),(v_a,v_b) \rangle \middle| \left(\left(u_a = v_a \cap u_b = [v_b \pm 1]_{k_x} \right) \cup \left(u_a = \left[v_a + \left\lceil \frac{k_x}{2} \right\rceil \right]_{k_x} \cap u_b = v_b + \left\lfloor \frac{k_x}{2} \right\rfloor_{k_x} \right) \right) \cap \left((u_a,u_b),(v_a,v_b) \right) \in N_x \right\} \quad (1)$$

$$C_y = \left\{ \langle (u_a,u_b),(v_a,v_b) \rangle \middle| \left(\left(u_b = v_b \cap u_a = [v_a \pm 1]_{k_y} \right) \cup \left(u_b = \left[v_b + \left\lceil \frac{k_y}{2} \right\rceil \right]_{k_y} \cap u_a = v_a + \left\lfloor \frac{k_y}{2} \right\rfloor_{k_y} \right) \right) \cap \left((u_a,u_b),(v_a,v_b) \right) \in N_y \right\} \quad (2)$$

$$C = C_x \cup C_y \quad (3)$$

Similarly, the Even parity links can be described by the Equation 4, 5 and 6.

$$C_x = \left\{ \langle (u_a,u_b),(v_a,v_b) \rangle \middle| \left(\left(u_a = v_a \cap u_b = [v_b \pm 1]_{k_x} \right) \cup \left(u_a = \left[v_a + \left\lfloor \frac{k_x}{2} \right\rfloor \right]_{k_x} \cap u_b = v_b + \left\lfloor \frac{k_x}{2} \right\rfloor_{k_x} \right) \right) \cap \left((u_a,u_b),(v_a,v_b) \right) \in N_x \right\} \quad (4)$$

$$C_y = \left\{ \langle (u_a,u_b),(v_a,v_b) \rangle \middle| \left(\left(u_b = v_b \cap u_a = [v_a \pm 1]_{k_y} \right) \cup \left(u_b = \left[v_b + \left\lfloor \frac{k_y}{2} \right\rfloor \right]_{k_y} \cap u_a = v_a + \left\lfloor \frac{k_y}{2} \right\rfloor_{k_y} \right) \right) \cap \left((u_a,u_b),(v_a,v_b) \right) \in N_y \right\} \quad (5)$$

$$C = C_x \cup C_y \quad (6)$$

In the above equations the v_a and v_b are the source coordinates from which the coordinates X links are to drawn u_a and u_b are the coordinates of the links that are adjacent the source node in the torus topology. The K_x and $K_y$are the number of nodes in the x dimension and number of nodes in y dimension or simply we can say the number of rows and columns the existing topology. The Resultant topology will have uniform degree.

B. Introducing CC links

The CC links can be added using the basic equations as follows:

For odd number of nodes, the topology will have only a single center so we can find the center using the equation given below, here n is the number of rows and columns assuming having same number of rows and columns.

$$Center = \left\lceil \frac{n^2 - 1}{2} \right\rceil \tag{7}$$

For an even number of nodes we can have four centers identified by equation given below:

$$Center = \left(\left\lfloor \frac{n^2 - 1}{2} \right\rfloor \mp 3 \right) \tag{8}$$

On applying the equations, we have got the following resultant topology as described in Figure 2 and 3. Figure 2 is describing the 6X6 topology which is having an even number of node in the x and y dimension. Figure 3 describes the 5X5 topology which is having odd number of nodes in x and y dimension.

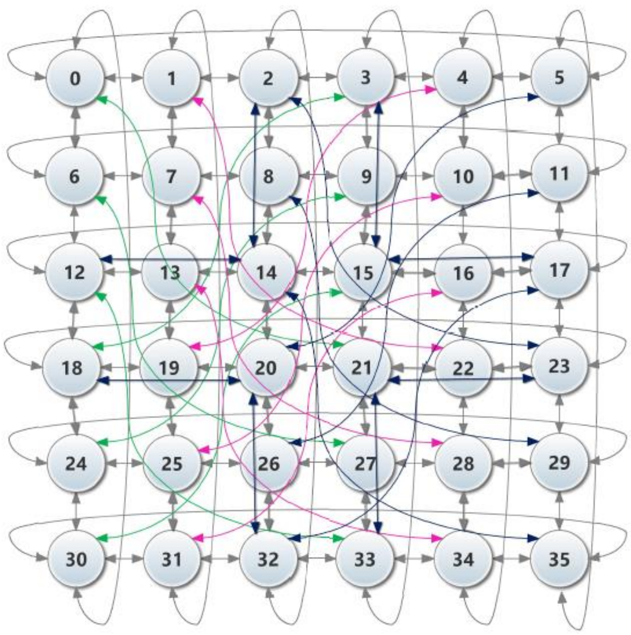


Figure 2: 6x6 center concentrated topology

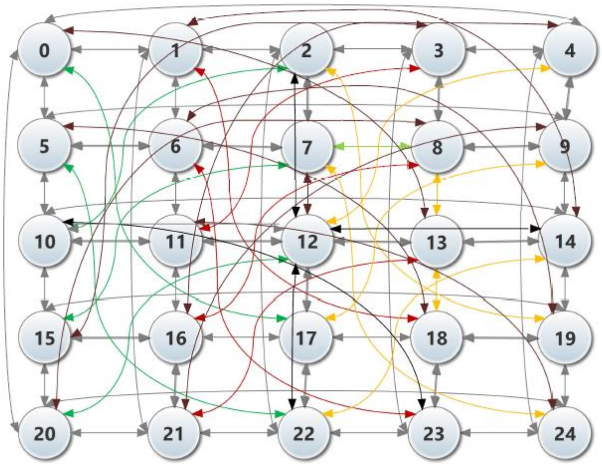


Figure 3: 5x5 center concentrated topology

IV. Experimental Setup

To analyze the performance of the topology the following parameter were select in the configuration of omnet++ [13] as described in the Table 1.

Table 1
Parameter of Simulation on Omnet++

S.No.	Parameter Name	Value
1	Nodes in each Row	5
2	Nodes in each Columns	5
3	Routing Algorithm	Table based Shortest Path(Static)
4	Simulation Time	0.5 s
5	Channel Data Rate	1 Gbps
6	Link Delay	0.1 ms
7	Traffics patterns	Random, Neighbor, tornado, bit complement and Hot Spot

The traffic pattern used for the analysis have described in [14], [15]. The topology have been tested on hardware configuration equipped with intel® Core™ i3 CPU M330@2.13 GHZ with 4.00 GB and 2.99GB usable.

V. Results and Discussion

The results obtained from the various traffic patterns were analyzed on the three parameters and the result have been presented below

A. *Performance on Uniform Traffic*

Figure 4 describes the latency of the four topologies on the various traffic patterns. From the figure, it is clear that the proposed topology is better than all the other three topologies.

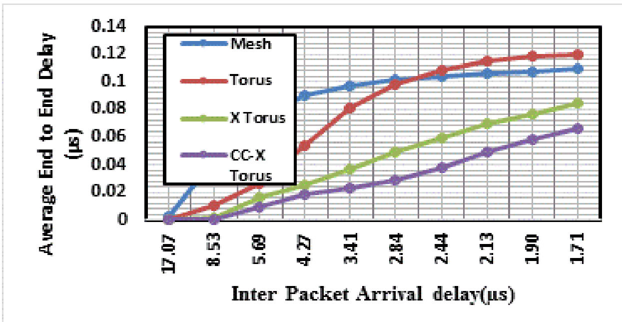


Figure 4: The average end to end latency on uniform traffic

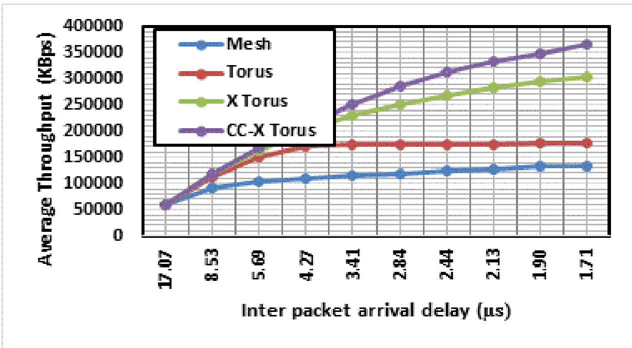


Figure 5: The average throughput on uniform traffic

Figure 5 described the throughput of the topology on the traffic patterns under observation. From the figure, it is clear that the throughput of the CC-X-torus is better in comparison to the other topologies.

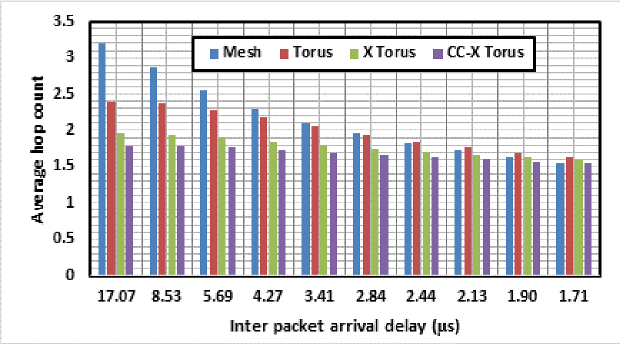


Figure 6: The average Hop Count on uniform traffic

B. Performance on Bit Complement Traffic

Figure 7 describes the average end to end latency of the various topologies in the case of this topology has performed same as that of the X-torus topology but is betterthan the remaining topologies. The reason for such performance is that the extra links has not exploited the pattern of bit complement traffic.

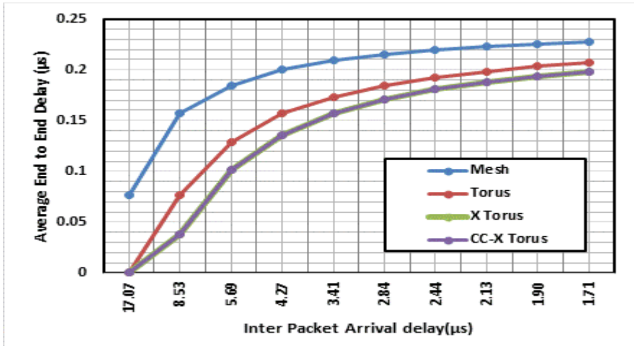


Figure 7: The average end to end latency on bit complement traffic

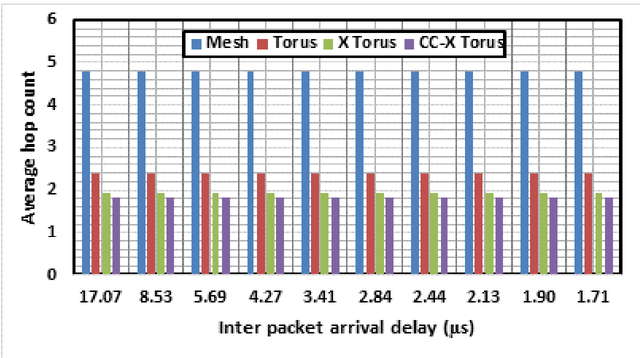


Figure 8: The average Hop Count on bit complement traffic

Figure 8 and 9 are describing the average hop count and the average throughput of the topologies under comparison and as we have discussed in the case of average end to end latency the CC –X topology has not exploited the pattern of bit complement traffic so it is almost the same as that of X-torus topology.

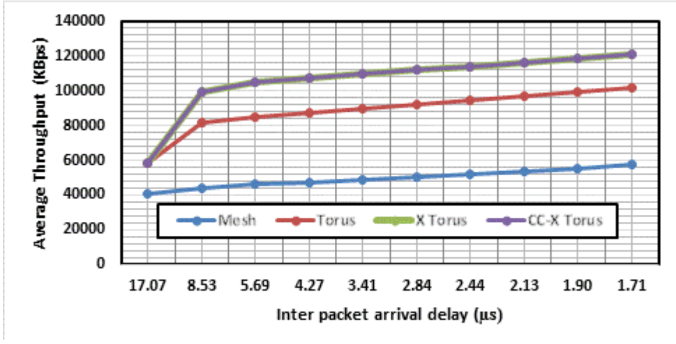


Figure 9: The average throughput on bit complement traffic

C. Performance on neighbor traffic

Figure 10 to 12 describe the average end to end latency, average hop count and the average throughput respectively on the neighbor traffic. As we know that the neighbor is always a single hop count.

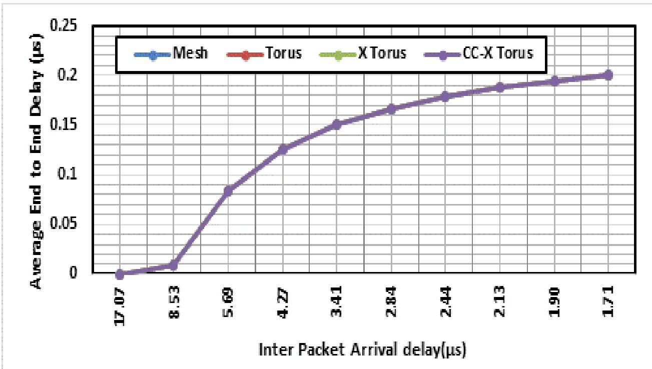


Figure 10: The average end to end latency on neighbor traffic

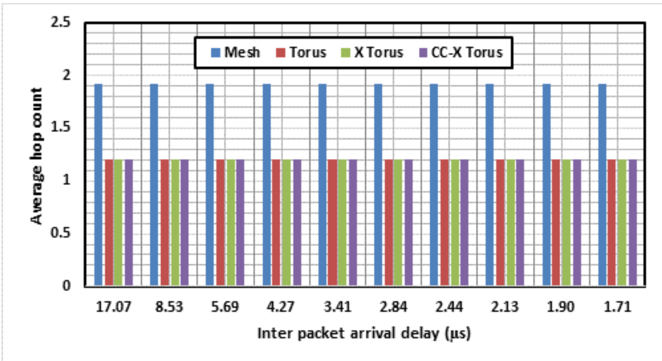


Figure 11: The average hop count on neighbor traffic

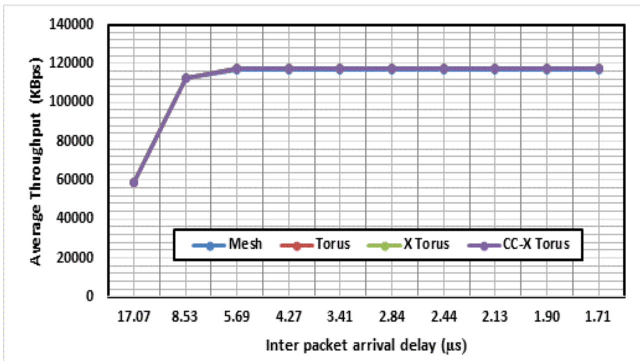


Figure 12: The average throughput on neighbor traffic

All the topologies will show almost the same performance the mesh is showing a jump in the hop count because of the fact in the torus topologies the extreme nodes are also the neighbors but mesh this is not the case.

D. Performance on tornado traffic

Figure 13 to 15 describe the performance on the tornado traffic on the factors average end to end latency, average hop count and average throughput. The average latency of CC-X-torus is less than all the other topologies. Similarly, in Figure 14, the average hop count is least for the CC-X-torus topology and throughput is best among the topologies mentioned.

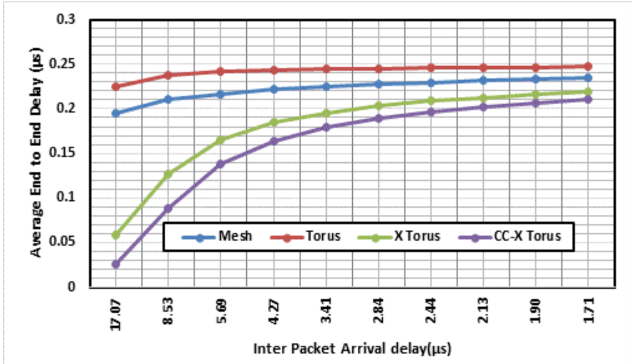


Figure 13: The average end to end latency on tornado traffic

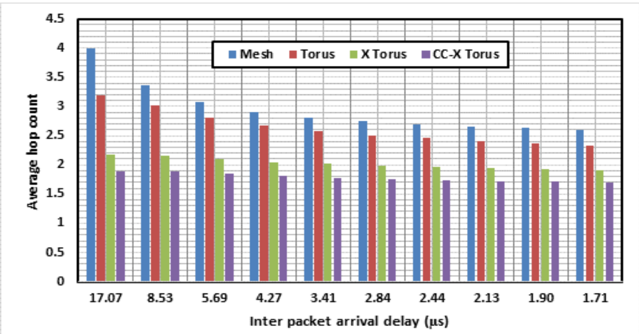


Figure 14: The average hop count on tornado traffic

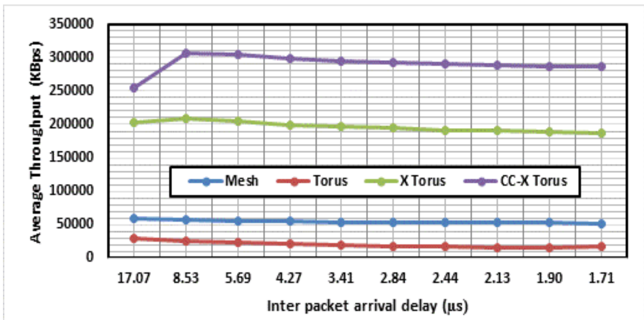


Figure 15: The average throughput on tornado traffic

E. Performance on hot spot traffic

The hotspot analysis is performed in most of the cases to test the performance of the network when it has been loaded at certain part of the nodes. From Figure 16 to 18, it can be observed that the hotspot effect is easily handled by ourtopology and the CC-X-torus topology has performed better in all the cases.

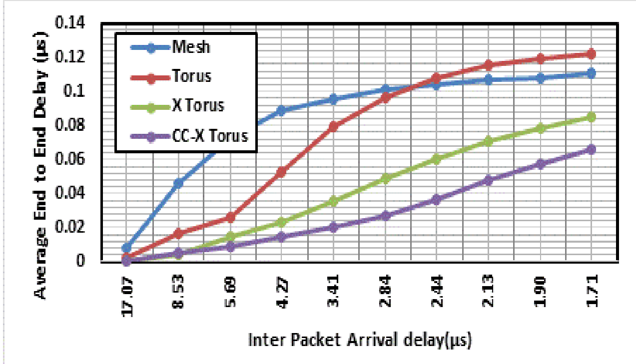


Figure 16: The average end to end latency on hot spot traffic

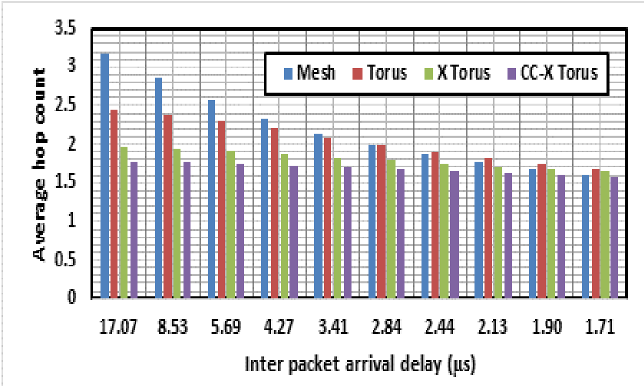


Figure 17: The average hop count on hot spot traffic

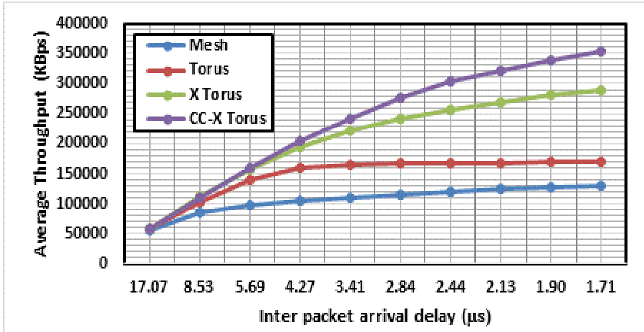


Figure 18: The average throughput on hot spot traffic

Summary of Improvement on various traffics on all the parameters have been presented in the Table 2.

Table 2
The Comparison Of Various Parameters

Traffic→ Parameter↓	Random	Bit comple-ment	Neigh-bor	Tornado	Hot Spot
Average Latency	85.24%	4.15%	0%	55.64%	45.64%
Average Hop Count	8.40%	4.16%	0%	13.78%	9.58%
Average throughput	16.95%	0%	0%	34.38%	17.86%

VI. CONCLUSION

From the results discussed in above section, we can observed that the topology proves to better in comparison to all the three topologies. In the case of bit complement traffic and neighbor traffic the performance has been achieved almost equal to that of the X-torus topology. The best improvement is 85.24% in the case of latency for the random traffic and 9.58% in the case of the hot count for the hot spot based traffic and improvement of 17.86% was observed in the case of throughput in the case random hotspot traffic. With the basis of the result we can conclude that the topology is better substitute than all the remaining counter parts. In future, we can further explore the topology to get the high performance in various quality of service parameter.

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