

## Comparative Analysis of Cube and Star Based Networks

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**Abstract**— Parallel computing is a variant of computation in which many calculations or execution of many processes are performed concurrently. Large and complex problems can be divided into smaller sub problems, which can be then solved at the same time. Network topology is the key factor of performance for any parallel computer. There are many proposed interconnection network topologies in order to achieve high performance. To trace out the better topology on the basis of standard parameter's performance analysis, we have compared cube based networks and star based networks for the same parameters such as diameter, cost, average distance, message density. In this comparative study various aspects are discussed while designing an efficient multiprocessor interconnection network.

**Keywords**— Topology, Cube Based, Star Based, Average Distance, Message Density, Parallel Computing, Interconnection Network.

### I. INTRODUCTION

In recent years, parallel architecture research provided the ability of solving complex problems which need high computations. A parallel computer is a set of multiprocessor computer which can do parallel processing. Parallel processing is type of computing in which many calculations can be carried out concurrently by many processors. Network topology performs the main role for any parallel computer. Interconnection network is the most practical model of parallel computing[1][2]. In many proposed or existing parallel processing architectures, an interconnection network is used to realize transportation of data between processors or between processors and memory components. In this paper we compared two type of network architectures on the basis of effective parameters. By the analysis of their parameter's graphs and values we conclude which network's performance is better.

The overview of the proposal is to find an optimum solution for highly scalable parallel architecture with desirable properties[3]. For comparison we choose two structure-based networks, such as Cube based networks (CBN) and Star based networks (SBN). In Cube-based network we analysed hypercube, folded hypercube, crossed cube, folded dual cube and folded crossed cube. And in Star-based networks we analysed star varietal cube, star mobius cube, star crossed cube, star cube, and star generalized cube and we choose some networks on the basis of parameters. The parameters we have choose for better comparison are diameter ( $d$ ), cost ( $C$ ), average distance ( $D$ ) and message density ( $\rho$ ). Selection of the better network is on basic requirement as lesser complexity and improved power efficiency.

In this paper study of five CBN and five SBN are carried out. Following section elaborates various parameters taken into consideration to develop better analysis of SBN and CBN on their respective performance scale. The subsequent section (III) comparisons of the parameters used in the analysis of CBN architecture whereas the section following it defined the parameters used for SBN architecture. Section (V) in the proposal accumulates the comparative analysis of CBN & SBN architectures. The final section (VI) of the paper encapsulates the overall analysis as conclusion.

Note: From following cube based network, star based network, cost, average distance, diameter and message density are denoted by CBN, SBN,  $C$ ,  $d$ ,  $D$  and  $\rho$  respectively.

### II. PERFORMANCE PARAMETERS

#### A. Number of Nodes ( $N_t$ )

It is the total number of processing elements attached to a network. It represents the network size.

#### B. Degree ( $d$ )

Degree is the total number of edges associated to a node in a graph. If there is symmetry of nodes in a graph then the degree of any node in the graph is identical or regular. It also represents the complexity of the network.

#### C. Diameter ( $D$ )

The maximum distance between two distinct nodes is the length (in number of edges) of a shortest path between these nodes. In a network maximum of such  $D$  represents the worst case of communication delay between two processors.

**D. Number of Links/Edges (E)**

It is the connection between two vertices/nodes. Edges/links are the source of conversation between nodes. More be the number of edges more will be the complexity of the network.

**E. Average Distance ( $\bar{d}$ )**

It is the ratio between, the distances of all the nodes from a source node take together, to the total number of nodes considered in a particular network.

**F. Message Density ( $\rho$ )**

It is the number of messages transferred from source to the destination. Minimizing the traffic can be achieved by reducing the  $\rho$  which will result in increased communication efficiency.

$$\rho = \bar{d} Nt/E$$

Where:

$\bar{d}$  Average distance

$Nt$  Number of nodes

$E$  Number of edges

**G. Cost (C)**

Cost is depends on two parameters, degree and D of the node as  $C = d * D$ . This factor also plays important role in analysis of performance of any network.

**III. CUBE-BASED INTERCONNECTION NETWORKS**

**A. Hypercube**

Hypercube or N-dimensional cube have  $2n$  number of nodes,  $n 2^{n-1}$  number of edges and D is n. It is the most popular network. Each node is connected point to point by communication links or edges to other node as shown in figure 1. The major performance failure of the network is due to increase number of edges with addition of each node in the system[2][4].

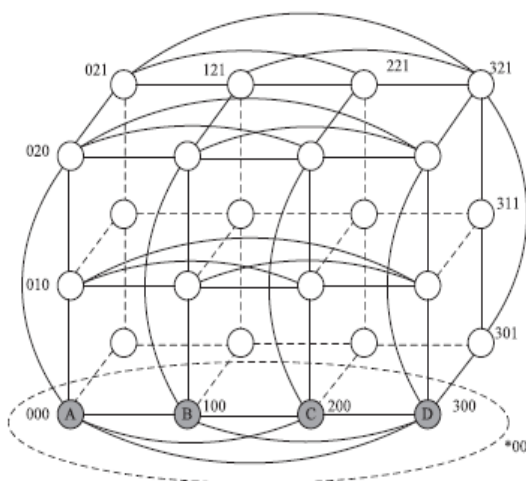


Figure 1. Hypercube of dimension 3

**B. Folded Hypercube**

Folded hypercube is a new type of hypercube which can be constructed by adding some extra links/edges to n-cube as shown in figure 2. This variation makes it better topology than hypercube by half D, less number of links, less C and better d [2][5].

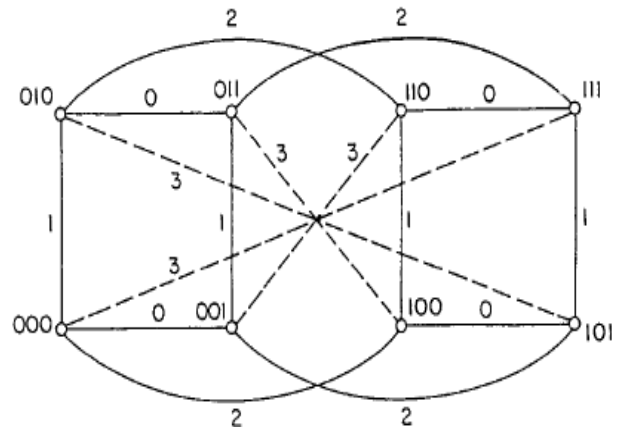


Figure 2. The structure of a Folded Hypercube (3). (Dashed lines represent the complementary links)

**C. Crossed Cube**

The Cross Cube is n dimensional cross cube with almost halved D as hypercube and same C as that folded hypercube.

Disadvantage is number of edges with  $2^{2^n}$  [6]. Some variations of cross cube are also designed as extended crossed cube, folded crossed cube. In figure 3 a crossed cube of dimension n=3 and n=4 is constructed.

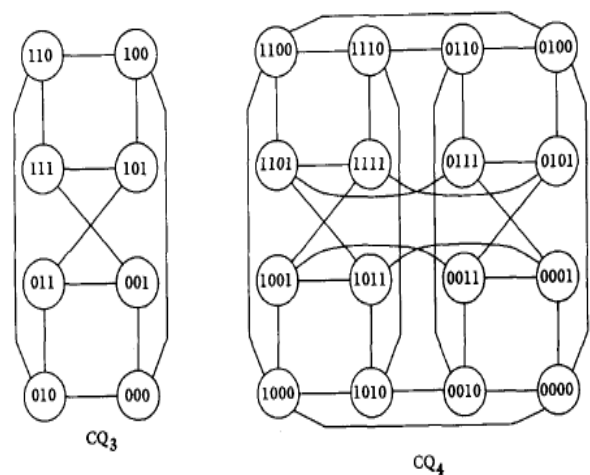


Figure 3. Crossed Cube for the dimension n=3 and n=4.

D. *Folded Dual Cube*

This topology reduces D, C and improves broadcast time in comparison with folded hypercube and dual cube[7]. It is constructed from dual cube  $G_r(V,E)$  by connecting each node to a node farthest from it similar to folded hypercube as shown in figure 4 which is a dimension of three.

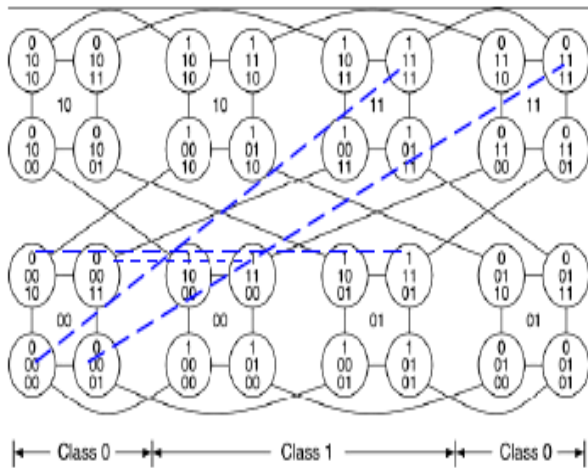


Figure 4. Folded Dual Cube of dimension n=3.

E. *Folded Crossed Cube*

Folded crossed cube is connected through crossed cube network and by adding extra links called complimentary links as shown in figure 5. The folded crossed cube is a graph  $F_r(V,E)$  where v represents a set of vertices and E represents a set of links. The node degree of folded crossed cube is  $(n+3)/3$  with number of nodes  $2^{2n} - 1$  and n-1 as D[8].

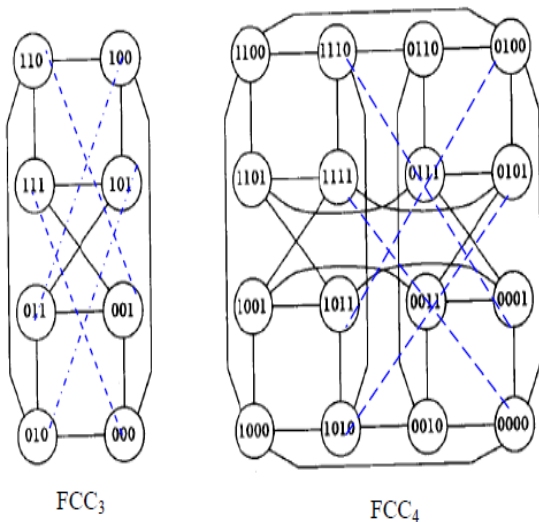


Figure 5. Folded Crossed Cube of dimension n=3 and n=4.

IV. STAR-BASED INTERCONNECTION NETWORKS

A. *Star Cube*

As shown in figure 6(a) the star cube is a combination of Star graph and Hypercube.Star and also known as Cube Star denoted as shown in figure 6(b), having degree as  $(m+n-1)$ . All the common properties of both star graph & hypercube like maximally fault tolerant, vertex- symmetric regularity[9],and shortest path routing are found in star cube network as well. It has large number of node as  $K!2^m$  and less D as  $m + \lfloor \frac{3}{2(k-1)} \rfloor$ .

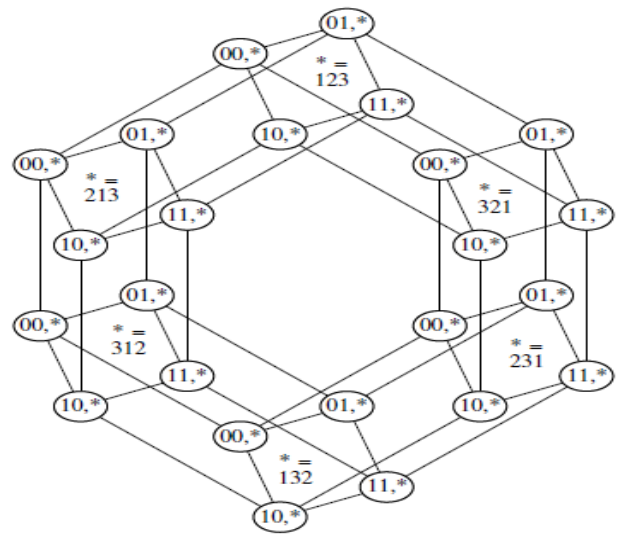


Figure 6 (a). Cube Connected Star of dimension (2-Cube x 3-Star)

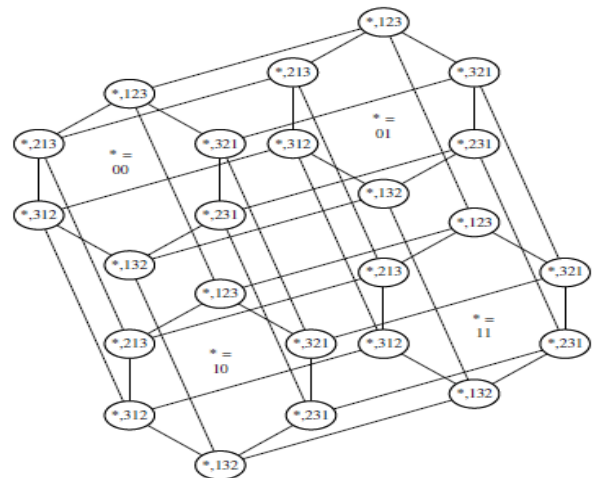


Figure 6 (b). Star Connected Cube of dimension (3-Star x 2-Cube)

**B. Star Varietal Cube**

Star varietal cube  $SVC(n,m)$  is for large scale multiprocessor system. It is the combination of  $n$ -star and  $M$ -varietal hypercube[10]. It holds most desirable properties of star and varietal hypercube as recursive structure, partitionability, and strong connectivity as shown in figure 7.

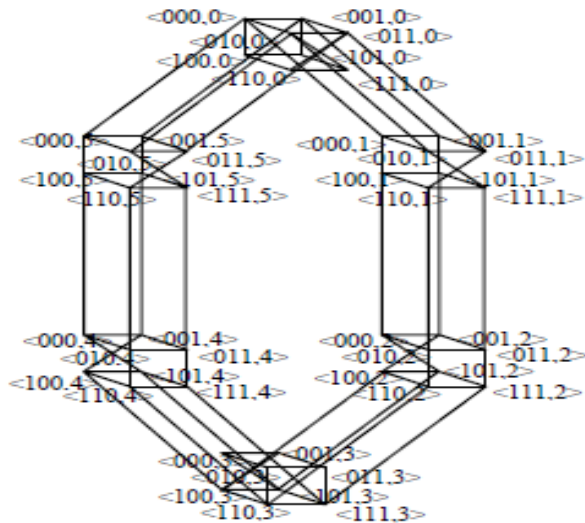


Figure 7. Star Varietal Cube of dimension 3

**C. Star Crossed Cube**

It is constructed by a star graph and crossed cube structure as shown in figure 8. It contains the characteristics of both star as well as crossed cube. As Compared to other hybrid networks, it holds better characteristics, such as regularity, degree,  $D$ ,  $C$ ,  $d$ , and  $\rho$  [11].

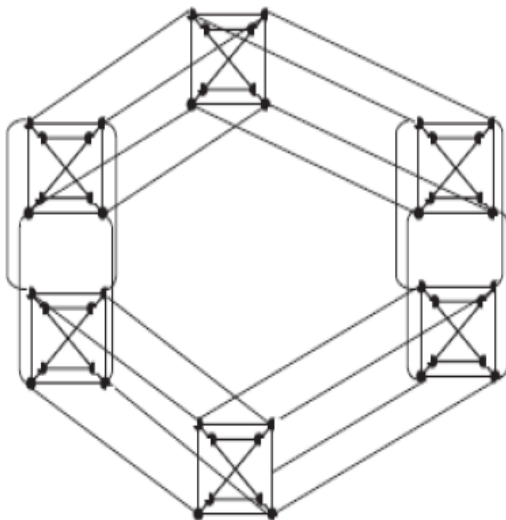


Figure 8. Star Crossed Cube of dimension 3

**D. Star Mobius Cube**

Star graph and  $m$ -star are combined together to construct Star mobius cube as shown in figure 9. Here, each node of star graph is substituted by mobius cube[1]. It is used for very large-scale multiprocessors system.

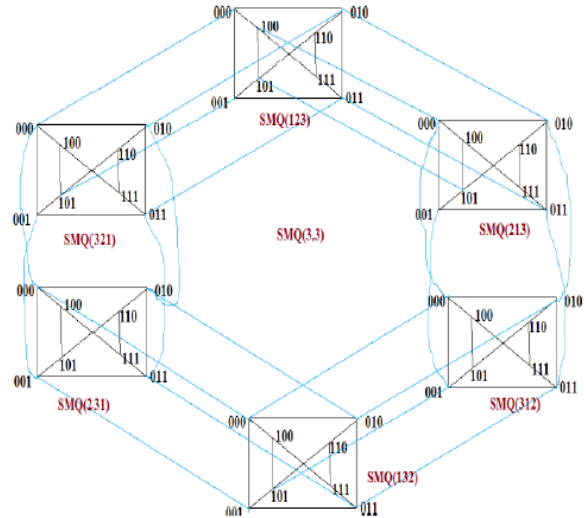


Figure 9. Star Mobius Cube of dimension 3

**E. Generalized Star Cube**

Star graph and Cube used to form hybrid network named as Generalized Star Cube. It is constructed by replacing each node in an  $m$ -Cube with Star graph or by replacing each node in an  $(n,k)$ -Star graph with an  $m$ -Cube[9] as shown in figure 10. Generalized Star Cube size is more flexible in comparison with its composition graphs.

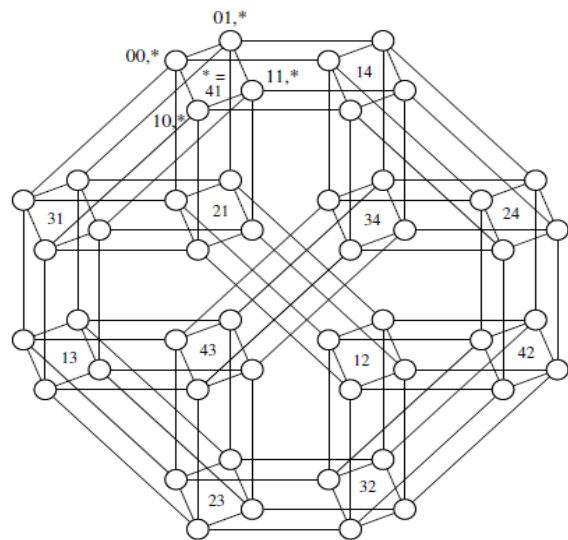


Figure 10. Generalized Star Cube of dimension  $((4,2)\text{-Star} \times 2\text{-Cube})$

Table.1 summarizes important parameters such as D, C, d, and  $\rho$  for all five CBN explained in section III.

Network	Parameters			
	Diameter	Cost	Average distance	Message Density
Hypercube	n	n <sup>2</sup>	n/2	1
Folded Hypercube	$\lceil n/2 \rceil$	$(n+1)\lceil n/2 \rceil$	$\sum_{i=0}^n (\lceil n/2 \rceil) \binom{n+1}{\lceil n/2 \rceil} / 2^n - 1$	$\frac{\sum_{i=0}^n (\lceil n/2 \rceil) \binom{n+1}{\lceil n/2 \rceil} 2^n}{(n+1)(2^{n-1})(2^n-1)}$
Crossed Cube	$\lceil (n+1)/2 \rceil$	$n\lceil (n+1)/2 \rceil$	$\{\sum_{i=0}^n (\lceil (n+1)/2 \rceil) \binom{n}{\lceil (n+1)/2 \rceil}\} / 2^n$	$\{\sum_{i=0}^n (\lceil (n+1)/2 \rceil) \binom{n}{\lceil (n+1)/2 \rceil}\} / 2^{2n}$
Folded Dual Cube	$(n+3)/2$	$(n-1)(n+3)/2$	$\left\{ \left( \frac{n(n-1)(n^3+9n^2+26n)}{6} \right) \sum_{i=0}^n \left( \frac{1}{(5-n)^i} \right) \right\} / 2^{2n-1}$	$\left( \frac{n(n-1)(n^3+9n^2+26n)}{6(n+3)2^{n-2}} \right) \sum_{i=0}^n \left( \frac{1}{(5-n)^i} \right)$
Folded Crossed Cube	$(n+1)$	$(n+1)(\lceil n/2 \rceil)$	$\left\{ \sum_{i=0}^n (\lceil n/2 \rceil) \binom{n+1}{\lceil n/2 \rceil} \right\} / 2^n$	$2 \left\{ \sum_{i=0}^n (\lceil n/2 \rceil) \binom{n+1}{\lceil n/2 \rceil} \right\} / (n+1)$

Table 2. Summarizes same parameters such as D, C, d, and  $\rho$  for all five Star based network explained in section IV.

Network	Parameters			
	Diameter	Cost	Average distance	Message Density
Star Cube	$m + \lfloor \frac{3}{2(k-1)} \rfloor$	$(m+k-1)(m + \lfloor \frac{3}{2(k-1)} \rfloor)$	$\frac{m}{2} + k - 4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i}$	$2(\frac{m}{2} + k - 4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i})(m+k-1)$
Star Varietal Cube	$\lfloor 2m/3 \rfloor + \lfloor 3(k-1)/2 \rfloor$	$(m+k-1)(\lfloor \frac{2m}{3} \rfloor + \lfloor \frac{3(k-1)}{2} \rfloor)$	$k - 4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i}$	$\frac{2(k-4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i})}{(m+k-1)}$
Star Crossed Cube	$\lfloor \frac{3(k-1)}{2} \rfloor + \lfloor (m + \frac{1}{2}) \rfloor (m+k-1)$	$(11x + \frac{y}{2}) + k - 4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i}$	$\frac{(11x + 4y)}{8} + (k - 4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i})$	$2[\frac{(11x+4y)}{8} + (k - 4 + \frac{2}{k} + \sum_{i=1}^k \frac{1}{i})](m+k-1)$
Star Mobius Cube	$\lfloor \frac{3(k-1)}{2} \rfloor + \lfloor \frac{(m+2)}{2} \rfloor$	$(m+k-1)(\lfloor 3(\frac{k-1}{2}) \rfloor + \lfloor \frac{(m+2)}{2} \rfloor)$	$\frac{m}{3} + \frac{[1-(-1/2)^m]}{9} + k - 4 + 2/k + \sum_{i=1}^k 1/i$	$2(\frac{m}{3} + \frac{[1-(-1/2)^m]}{9} + k - 4 + 2/k + \sum_{i=1}^k 1/i)/(m+k-1)$
Generalized Star Cube	$m + 2k - 1$	$(m+n-1)(m+2k-1)$	$(\frac{m}{2}) + k - 1 + \sum_{i=1}^k \frac{1}{i} - 2 \frac{(k-1)}{n} - k! \frac{(n-k)!}{n!}$	$2[\frac{m}{2} + k - 1 + \sum_{i=1}^k \frac{1}{i} - (2 \frac{(k-1)}{n}) - \frac{(k(n-k)!)}{m+n-1}]$

**V. COMPARITIVE ANALYSIS OF CUBE BASED AND STAR BASED NETWORKS**

Architectural comparative analysis was done to make overall conclusion. We have considered four parameters namely D, C, d, and ρ which are evaluated and compared between hypercube based and SBN. The curve plotted between CBN namely crossed cube, folded crossed cube, folded dual cube, folded hypercube and hypercube. While for SBN generalized star cube, star crossed cube, star cube, star mobius cube and star varietal cube are analysed.

D is an important factor which affects the complexity of the network. Figure 11 depicts hypercube has highest D and folded hypercube has the lowest D as number of level increases. Folded dual cube has higher D than folded hypercube, crossed cube and folded crossed cube.

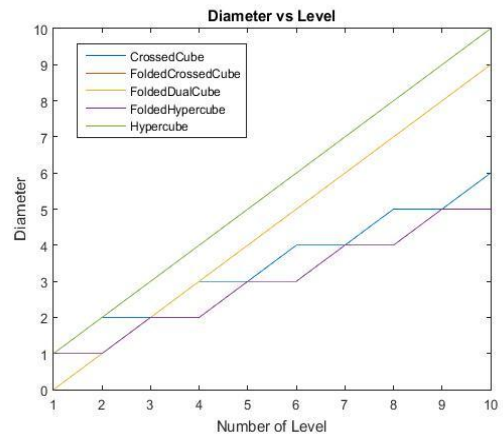


Figure 11. Diameter Vs Level for Cube Based Network

In all the cases exponential expansion was obtained as shown in Figure 12. Hypercube has the highest value of C while folded hypercube has lowest and slightly less in comparison with crossed cube, folded cube and folded dual cube.

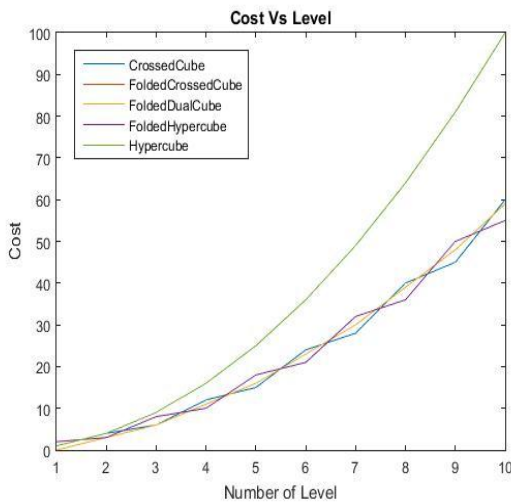


Figure 12. Cost Vs Level for Cube Based Network

The main factor  $d$  which helps in evaluating the actual performance of a network. The curve in the figure 13 illustrates folded dual cube has highest  $d$  and hypercube has lowest. While folded hypercube has almost same value variation with number of nodes and higher than crossed cube & lower than folded dual cube.

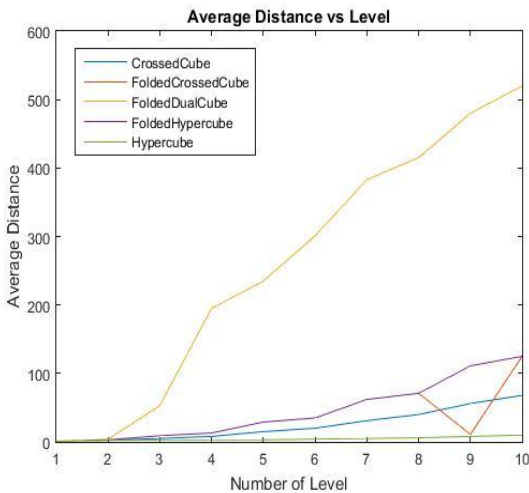


Figure 13. Average Distance Vs Level for Cube Based Network

$\rho$  correlate the number of messages sent from source to the destination. As figure 14 curve shows folded dual cube has very high  $\rho$  in comparison with other networks. While crossed cube has lowest  $\rho$ . Hypercube has a constant value 1 which is independent of variation in number of levels.

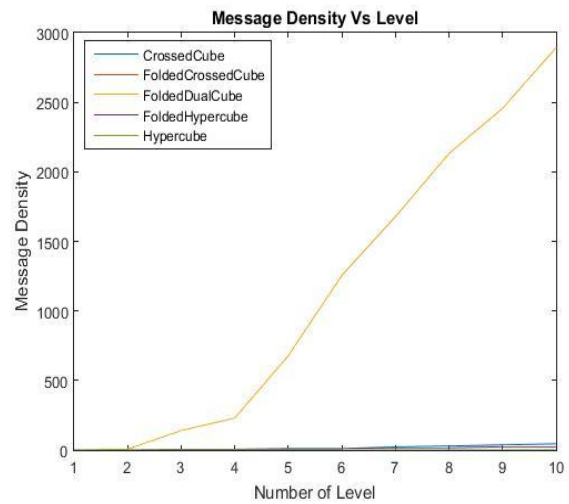


Figure 14. Message Density Vs Level for Cube Based Network

In the next phase of our analysis we have plotted the curve for SBN for the same parameters used for hypercube networks.

The curve in the figure 15 depicts star varietal cube has the lowest  $D$  whereas star crossed cube has the highest exponential  $D$ . Star mobius cube has slightly higher  $D$  than star varietal cube but less than star cube. Generalized star cube has greater  $D$  than star cube but very less than star crossed cube.

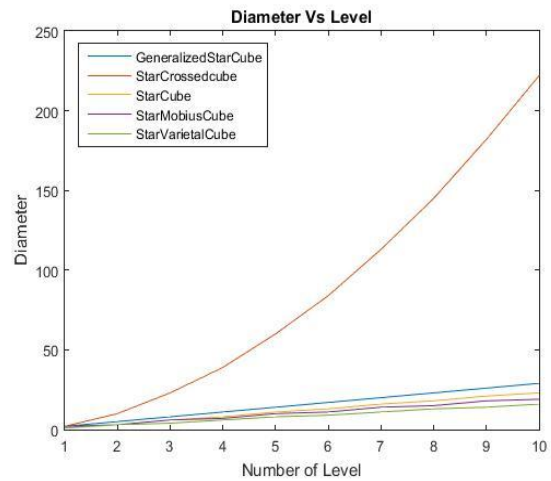


Figure 15. Diameter Vs Level for SBN

The curve in figure 16 depicts star crossed cube has the lowest  $C$  as level increases and generalized star cube has the highest cost with exponential nature. Star varietal cube has slightly higher  $C$  at level 10 as 380 in comparison with star mobius cube which is 361 but very less  $C$  than generalized star cube which is 551. Whereas star crossed cube has the lowest cost value as 121.38.

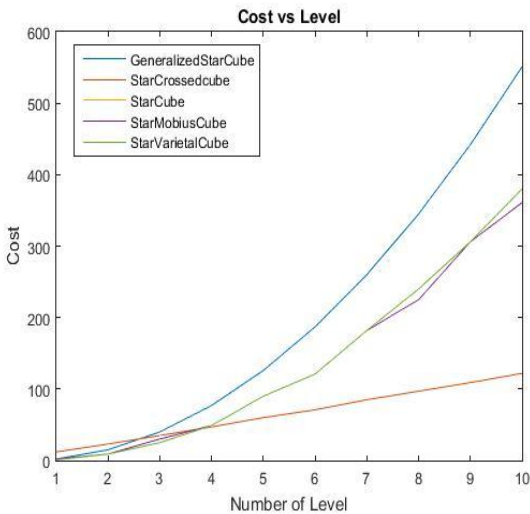


Figure 16. Cost Vs Level for Star Based Network

Figure 17 curve illustrates star varietal cube has the lowest  $d$  whereas star crossed cube has the highest value. Generalized star cube and star cube has almost same  $d$  values but very less than star crossed cube. Comparatively generalised star cube and star cube have higher average node distance followed by star Mobius cube and star varietal cube respectively.

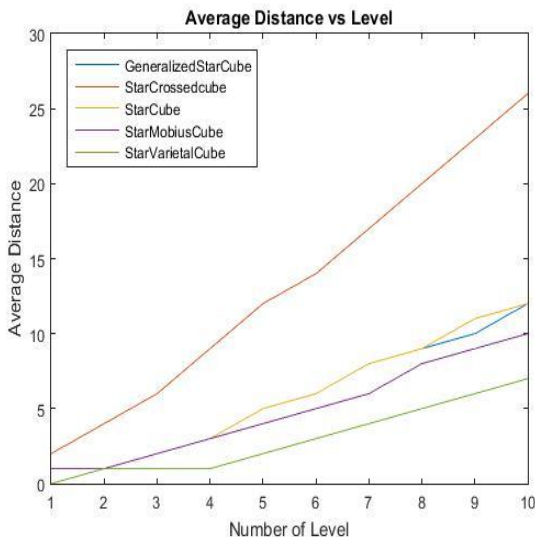


Figure 17. Average Distance Vs Level for Star Based Network

Figure 18 represents a curve for  $\rho$  and generalized star cube has the lowest  $\rho$  whereas star cube has very high  $\rho$ . Star crossed cube has very less  $\rho$  as 47.15

In comparison with star cube which has nine times higher value as 432.50, but slightly higher than star varietal and star mobius cube.

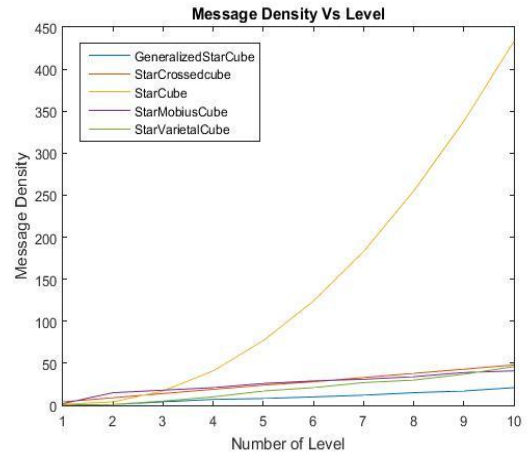


Figure 18. Message Density Vs Level for Star Based Network

### VI. CONCLUSION

In this paper, we analysed and described topological properties of two different network architectures star and cube. CBN we compared are hypercube, folded hypercube, crossed cube, folded dual cube and folded crossed cube networks. While we choose generalized star cube, star cube, star mobius cube, star varietal and cube star crossed cube for SBN.

Our analysis concluded that in case of  $D$  and  $C$  CBN folded hypercube perform best while hypercube perform worst. In case of  $d$  hypercube was found to be effective and folded dual cube was least effective. In  $\rho$  cross cube was more productive and dual cube is least.

In the next phase we found that best performances for  $D$ ,  $C$ ,  $d$ , and  $\rho$  in case of SBN were varietal cube, star crossed cube, star varietal cube and generalized star cube respectively. Whereas star crossed cube, generalized star cube, star crossed cube and star cube has worst performances than other networks on  $D$ ,  $C$ ,  $d$ , and  $\rho$  respectively.

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