Performance Evaluation, Comparison and Identification of Efficient Hypercube Interconnection Networks

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Abstract

A Multiprocessor is a system with at least two processing units sharing access to memory. The principle goal of utilizing a multiprocessor is to process the undertakings all the while and support the system's performance. An Interconnection Network interfaces the various handling units and enormously impacts the exhibition of the whole framework. Interconnection Networks, also known as Multi-stage Interconnection Networks, are node-to-node links in which each node may be a single processor or a group of processors. These links transfer information from one processor to the next or from the processor to the memory, allowing the task to be isolated and measured equally. Hypercube systems are a kind of system geography used to interconnect various processors with memory modules and precisely course the information. Hypercube systems comprise of 2^n nodes. Any Hypercube can be thought of as a graph with nodes and edges, where a node represents a processing unit and an edge represents a connection between the processors to transmit. Degree, Speed, Node coverage, Connectivity, Diameter, Reliability, Packet loss, Network cost, and so on are some of the different system scales that can be used to measure the performance of Interconnection Networks. A portion of the variations of Hypercube Interconnection Networks include Hypercube Network, Folded Hypercube Network, Multiple Reduced Hypercube Network, Multiply Twisted Cube, Recursive Circulant, Exchanged Crossed Cube Network, Half Hypercube Network, and so forth. This work assesses the performing capability of different variations of Hypercube Interconnection Networks. A group of properties is recognized and a weight metric is structured utilizing the distinguished properties to assess the performance exhibition. Utilizing this weight metric, the performance of considered variations of Hypercube Interconnection Networks is evaluated and summed up to recognize the effective variant. A compact survey of a portion of the variations of Hypercube systems, geographies, execution measurements, and assessment of the presentation are examined in this paper. Degree and Diameter are considered to ascertain the Network cost. On the off chance that Network Cost is considered as the measurement to assess the exhibition, Multiple Reduced Hypercube stands ideal with its lower cost. Notwithstanding it, on the off chance that we think about some other properties/ scales/metrics to assess the performance, any variant other than MRH may show considerably more ideal execution. The considered properties probably won't be ideally adequate to assess the effective performance of Hypercube variations in all respects. On the off chance that a sensibly decent number of properties are utilized to assess the presentation, a proficient variation of Hypercube Interconnection Network can be distinguished for a wide scope of uses. This is the inspiration to do this research work.

1. Introduction

A Multiprocessor is a PC framework with in any event at least two preparing units sharing the access to memory. The basic objective of using a multiprocessor is to process the allotted undertakings simultaneously and lift the framework's exhibition.

An Interconnection Network links multiple caretaking units and has a major effect on the overall framework's presentation. Interconnection Networks, also known as Multi-stage Interconnection

Networks, are node-to-node links between processors or groups of processors. These connections transport data from one processor to the next or from the processor to the memory, allowing the task to be isolated and figured in parallel.

Hypercube networks are a type of network topology that connects different processors with memory modules and routes data in a logical manner. 2^n node(s) are involved in hypercube systems, with $n>0$. Any Hypercube can be viewed as a diagram with no directions, in which a node communicates with a processing unit and an edge represents a link between the processors to be conveyed. Degree, Speed, Node Coverage, Connectivity, Diameter, Reliability, Packet loss, Network cost, and other system scales can be used to evaluate the performance of Hypercube Interconnection Networks. Hypercube Network, Folded Hypercube Network, Multiple Reduced Hypercube, Multiply Twisted Cube, Recursive Circulant, Exchanged Crossed Cube Network, Half Hypercube Network, and so on are examples of Hypercube Interconnection Networks [12].

A Hypercube is an n-dimensional geometrical structure that is geometrically equivalent to a Square (n=2) and a Cube (n=3) in terms of dimensions. The number of nodes grows in proportion to the number of Hypercube elements.

A Hypercube is expressed as a shape with an increased number of measurements:

A point is a zero-measurement dimensional hypercube.

1: If this point is shifted one unit length, a line segment, which is a unit Hypercube of measurement one.

2: A 2-dimensional square is obtained by shifting this line segment's length in the opposite direction from itself.

3: A 3-dimensional Hypercube is formed by shifting the starting point unit length toward the direction opposite to the plane it lies on (a Cube).

4: A 4-dimensional Hypercube is formed by transferring the 3D form one unit length into the fourth measurement (a unit Tesseract).

The quantity of vertices, edges and faces of hypercube geography relies upon the quantity of its measurements. The different components of Hypercubes of 0, 1, 2, 3, and 4 measurements alongside their names are appeared in Table 1

Dimension	Name	Vertex	Edge	Face
0	“Point”	one		
1	“Line Segment”	two	one	
2	“Square”	four	four	one
3	“Hypercube”	eight	twelve	six

Table 1: Components of 0D, 1D, 2D and 3D Hypercubes

Applications of Hypercube Networks:

Hypercube Interconnection Networks are utilized in a differentiated and wide scope of utilizations. A portion of their applications include:

- In Graph Theory, a hypercube is the diagram shaped from the nodes and the links of a n-dimensional hypercube.

Eg: Cubical graph is the diagram shaped by the 8 vertices and 12 edges of a three-dimensional 3D square.

- Hypercubes are extremely intriguing geometric structures which emerge in a wide range of zones of Mathematics including Algebra.

Eg: Finding insignificant types of Boolean (exchanging) capacities, Automation of minimization procedure of Boolean capacities with numerous factors, framework augmentation, and so forth.

- Hypercubes have topological and geometrical properties with applications in a few unique fields, for example, Computer Networks, Parallel Processing, Information Retrieval, Data combination, Social systems, Coding hypothesis, Linguistics and so on.

Eg: Multi entrusting tasks, Computationally Private Information Retrieval (CPIR), Graph shading, phonetic getting the hang of/thinking frameworks for savvy control and recognizable proof.

- Hypercubes are likewise used to perform vector preparing procedure on charts.

Eg: Clustering, Change location, Hypothesis testing with respect to the autonomy of two charts, Feature extraction for neural system, Fuzzy mappings, and so forth.

- The essential calculations for SIMD and MIMD Hypercubes are utilized.

Eg: These incorporate calculations for tackling issues, for example, Data broadcasting, Data aggregate, Prefix total, Shift, Data dissemination, Data gathering, Sorting, Random access peruses and composes and Data change, and so on.

- Hypercubes are pertinent in Image preparing applications.

Eg: These incorporate calculations for picture preparing issues, for example, Image investigation, Image changes, Convolution, Template coordinating, bunching and String altering and so forth. Test results show the adequacy of Hypercubes as a ground-breaking space portrayal both as far as computational time and memory prerequisites.

• And numerous different applications.

Variants of Hypercube Networks

Variants of Hypercube Interconnection Networks include [12]:

- Hypercube Network
- Folded Hypercube Network
- Multiple Reduced Hypercube Network
- Multiply Twisted Cube Network
- Recursive Circulant Hypercube Network
- Exchanged Crossed Cube Network
- Z Cube
- Half Hypercube Network etc...

Hypercube Network:

A Hypercube [13] is an n-dimensional figure that is identical to a shape of cube in three dimensions and a square in two dimensions, according to geometry.

- The base number of steps it takes for one processor to make an impact on the farthest processor is the gap across the interconnection network, termed as the diameter. For example, the diameter of a hypercube with four vertices that resembles a square is two.
- The diameter of a hypercube interconnection network, which is equivalent to an eight-processor cube with each processor and memory module positioned at each vertex of the block, is three.
- For example, if a framework has 2^n processors, each of which is directly associated with different processors, its distance across will be n.

A typical Hypercube Network topology is shown in Fig. 2

Folded Hypercube Network:

Folded Hypercube [13] is an undirected graph that interfaces inverse sets of hypercube vertices and is framed from a hypercube by adding ideal coordinating edges.

- Edges between inverse sets of vertices in a hypercube diagram of request k - 1 may be used to frame the collapsed hypercube graph of request k with 2^{k-1} vertices.
- It can be generated by combining any opposite pair of vertices in a hypercube diagram.
- With 2^{k-1} vertices and 2^{k-2} edges, a collapsed hypercube diagram of request k will be k-customary.
- The chromatic number of request k collapsed 3D shape diagram is two when k is even (that is, for this situation, the chart is bipartite) and four when k is odd. The odd circumference of a collapsed 3D square of odd request is k, so for odd k more noteworthy than three the collapsed 3D shape diagrams give a class of sans triangle charts with chromatic number four and self-assertively huge odd size.
- As a separation ordinary diagram with an odd circumference 'k' and breadth '((k − 1)/2)', the folded cube of the odd number order are instances of summed up odd charts. At the point when the value of k is an odd number, bipartite two fold front of the order k collapsed solid shape is the k-ordered cube from which it was framed.
- When the value of k is an even number, the request k solid shape is a twofold spread yet not a bipartite twofold spread. For this situation, the collapsed solid shape is itself effectively bipartite. Collapsed 3D shape diagrams acquire from their hypercube sub-charts the feature containing the Hamiltonian cycle, and from the Hypercubes that two fold spread them the property of being a separation transitive chart.
- When the value of k is an odd number, the request k collapsed 3D shape consists as a sub-diagram a total double tree with 2^{k-1} nodes. Be that as it may, when k is even, this is beyond the realm of imagination, in light of the fact that for this situation the folded cube is a bipartite diagram with equivalent quantities of nodes on each side of the bipartition, altogether different from the almost two-to-one proportion for the bipartition of a complete binary tree [2].

A Folded Hypercube Network topology and Folded Hypercubes of different dimensions are shown in Fig.3

Multiple Reduced Hypercube Network:

- The nodes of a Multiple Reduced Hypercube MRH(n) [13] are communicated as n bit strings Sn, Sn-1, ... Sj ... S2, Sl comprising of double numbers {0,1} (i<i<n).
- The edges of MRH (n) are communicated in three structures. In view of the procedure of association, they are named as Hypercube edge, Exchange edge and Complement edge.
- These are shown as h-edge, x-edge and c-edge separately.
- Each edge is characterized into when n is a much number and n is an odd number [3].

<u>Case 1:</u> When n is an even number, it is assumed that for edge definition, (s_n, s_{n-1}, ...s_{i+1}) is α and a bit string (s_i...s_2 s_1) is β in the bit string of a node U(= s_n, s_{n-1}, ..s_i...s_2, s_1). Therefore the bit string of a node U(= s_n, s_{n-1},..s_i ...s_2, s_1) can be simply expressed as αβ. Assuming that the nodes U and V are adjacent with each other, adjacent edges are as follows [11] [13] [21].

a) **Hypercube edge:** This edge indicates an edge linking two nodes U(=s_n, s_{n-1},..s_i ...s_2, s_1) and V(=s_n, s_{n-1}, ...s_{i+1}, s_i...s_2, s_1) of MRH(n) (n/2≤j≤n).

b) **Exchange edge:** This edge indicates an edge linking two nodes U(=αβ) and V(=βα) of MRH(n) if α≠β in the bit string of the nodes.

c) **Complement edge:** This edge indicates an edge linking two nodes U(=s_n α'β') and V(=s_n α'β') of MRH(n) if α≠β in the bit string of the nodes [11,13, 21].

Case 2: When n is an odd number. It is assumed that for edge definition, (s_{n-1}...s_{i+1}) is α' and a bit string (s_n, s_i...s_2, s_1) is β' in the bit string of a node U(=s_n, s_{n-1},..s_i ...s_2, s_1). Then the number of bit strings of α' and β' is each n /2 . Therefore a node U can be indicated as U (=s_n α'β') [11,13, 21].

a) **Hypercube edge:** This edge indicates an edge linking two nodes U (=s_n, s_{n-1}....s_j...s_{i+1}, s_i...s_2, s_1) and V(=s_n, s_{n-1}... s_j....s_{i+1}, s_i...s_2, s_1) of MRH(n)

b) **Exchange edge:** This edge indicates an edge linking two nodes U(=s_n α'β') and V(=s_n β'α') of MRH(n) in the bit string of a node.

c) **Complement edge:** This edge indicates an edge linking two nodes U(=s_n α'β') and V(=s_n α'β') of MRH(n) if α'= β' in the bit string of a node [11,13, 21].

- Node/edge availability is minimal number of nodes/edges that are required to be wiped out to partition an interconnection network into at least two sections without normal nodes. Regardless of whether k-1 or less nodes are wiped out from a given interconnection network, an interconnection network is connected, and once the interconnection network is isolated when legitimate k nodes are killed, availability of the interconnection network is called k. An interconnection network having a similar node connectivity and degree implies that it has maximal adaptation to non-critical failure [3, 11].
- A Multiple Reduced Hypercube Network is shown in Fig. 4

Multiply Twisted Cube Network:

An n-dimensional Multiply Twisted Cube 'Q_n' [13, 22] has a similar basic unpredictability as n-dimensional Hypercube Q. That is, it has a similar number of nodes and joins, and every node has a similar degree n, as Q. In any case, past examinations demonstrate that because of a portion of its properties better than hypercube, the Multiply Twisted Hypercube is a decent option for developing multiprocessor systems [4].

- The Multiply Twisted Hypercube is recursively characterized, and it has a relative structure. It is seen that the distance across of Q_n is [n+1]/2, which is about portion of the breadth n of the n-dimensional Hypercube Q. Moreover, the normal separation between nodes in Q_n is around 3/4 of the normal separation between nodes in Q.

- In combination with the consistency, these properties can be utilized to plan straightforward information correspondence calculations for Q_n that are more effective than those for traditional hypercube Q. Additionally, numerous effective hypercube calculations can be straightforwardly adjusted to fit the contorted hypercube [13, 22].
- A Multiply Twisted Cube Network is shown in Fig.5

Recursive Circulant Hypercube Network:

Recursive Circulant Hypercube Network like Recursive Circulant Graph G(N, d) [23, 24] is characterized to be a Circulant chart with N nodes and jumps of powers of d, $d \geqslant 2$. Here each d_i is known as a hop. G(N, d) additionally can be characterized as a circulant chart with jumps of powers of ‘d’[5].

- Since Recursive Circulant Graphs are a subclass of Circulant Graphs, they are vertex-symmetric. Recursive Circulant Hypercube Network is node symmetric, and subsequently standard.
- G(N, d) has a Hamiltonian cycle unless $N \leqslant 2$, and can be recursively constructed when N=cd, $1 \leqslant c \leqslant d$ [23, 24].
- Sample Recursive Circulant Hypercube Graphs G(8,4) and G(16,4) are shown in Fig.6

2. Analysis

Degree is considered to be the connectivity of different nodes of a network and Diameter is defined as the maximum shortest path between any two nodes. Degree and Diameter are considered to compute the approximate Network Cost. It is considered as the product of degree and diameter.

These properties are used to analyze the performance of Hypercube Interconnection Network variants and shown that Multiple Reduced Hypercube (MRH) exhibits better performance as it involves lower Network Cost when compared to that of other variants.

For Interconnection Networks where number of nodes i.e., n=3, the approximate Network Cost of various variants is as shown below:

As shown above, Multiple Reduced Hypercube (MRH) has Lower Network Cost when compared to that of the other variants.

In this paper, the following properties are considered and analyzed to propose a new metric to evaluate the performance of above mentioned variants of Hypercube Interconnection Networks [12] .

- Degree
- Diameter
- Network Cost
- Speed
- Packet Loss

- Node Coverage

a) Degree: It is relationship among different nodes of a network. Node availability infers the intricacy of network. More noteworthy number of connections in the network implies more noteworthy is the multifaceted nature. It is availability among various nodes in a network.

b) Diameter: It is characterized as the maximal briefest way between any two nodes of the network. Lower diameter is alluring as the diameter puts a lesser bound on the criticality of equal calculations that require association between any pair of nodes subjectively.

c) Network Cost: It can be considered as the consequence of degree x diameter. This property is broadly utilized in assessing the presentation of a network.

d) Speed: Speed can be considered as the hugeness of speed of an item. The mean speed of a packet in a period span is the separation voyage/length of time stretch. The more speed enhances progressively number of packets transmission.

e) Packet Loss: Packet Loss is estimated as the extent of packets lost to the packets sent over the network. The more packet loss the less reliable transmission and the less packet loss the more proficient transmission.

f) Node Coverage: It is the level of goal nodes secured out of complete accessible nodes of the network.

3. Implementation

The following variants of Hypercube Interconnection Networks are considered for research to evaluate the performance [12, 13]

- Hypercube Network
- Folded Hypercube Network
- Multiple Reduced Hypercube Network
- Multiply Twisted Cube Network
- Recursive Circulant Hypercube Network

1. **Hypercube Interconnection Network**

The simulated image of Hypercube Interconnection Network is shown in Fig. 7

2. **Folded Hypercube Network**

The simulated image of Folded Hypercube Network is shown in Fig.8

3. **Multiple Reduced Hypercube Network**

The simulated image of Multiple Reduced Hypercube Network is shown in Fig.9

4. **Multiply Twisted Cube Network**

The simulated image of Multiply Twisted Cube Network is shown in Fig.10

5. **Recursive Circulant Hypercube Network**

The simulated image of Recursive Circulant Hypercube Network is shown in Fig.11

As a piece of beginning examination and to survey the presentation of considered Hypercube Interconnection Networks, the investigation of the properties, for example, number of nodes, degree, diameter, and network cost is performed. Degree and Diameter are investigated to evaluate the Network cost.

At various time frames, 60, 90, and 120 units, the normal estimations of speed, packet loss, and node coverage are determined alongside degree and diameter by actualizing the considered Hypercube Interconnection Networks.

The created dataset is then arranged as far as event, time, source node, destination node, type of packet, size of packet, fid, address of source, address of sink and the sequence number to compute the normal estimations of recognized properties of all the considered Hypercube variations at various referenced time spans.

For instance, on execution of Folded Hypercube Network for 30 units of time span, the organized information comprises of the necessary data as tabulated in Table 2

Event	Time	From Node	To Node	Packet type	Packet size	fid	Source address	Sink address	Sequence number
+	0.1	7	3	cbr	1000	2	7	3	0
-	0.1	7	3	cbr	1000	2	7	3	0
d	0.1	7	3	cbr	1000	2	7	3	1
+	0.1	7	6	tcp	40	1	7	6	0
-	0.1	7	6	tcp	40	1	7	6	0
d	0.1	7	6	tcp	40	1	7	6	1
+	0.108	7	3	cbr	1000	2	7	3	1
-	0.108	7	3	cbr	1000	2	7	3	1
d	0.108	7	3	cbr	1000	2	7	3	1
r	0.11016	7	6	tcp	40	1	7	6	0
+	0.11016	6	7	ack	40	1	6	7	0
-	0.11016	6	7	ack	40	1	6	7	0
d	0.11016	6	7	ack	40	1	6	7	1
r	0.114	7	3	cbr	1000	2	7	3	0

Table 2: Sample organized information of Folded Hypercube Network for 30 units of time frame

As performed with folded hypercube network, all other considered variants of hypercube networks are actualized for various time units of 30, 60, 90, 120 units of time span and gigantic information is created. To dissect the properties of speed, packet loss, node coverage, degree, diameter and network cost, the generated data is formatted in terms of event, time, source node, destination node, type of packet, size of packet, fid, address of source, address of sink and the sequence number as shown above.

For example, on implementation of Folded Hypercube Network for 30 units of time interval, the average values for the required parameters are calculated as tabulated in Table 3

Parameter Metric					
S. No	**Parameter**	**ack**	**cbr**	**tcp**	**Average**
1	Degree	4	4	4	4.000
2	Diameter	2	2	2	2.000
3	Network Cost	8	8	8	8.000
4	Speed	15.07739	15.04949	15.0630483	15.063
5	Packet Loss	0.099	0.099	0.099	0.099
6	Node Coverage	37.5	37.5	37.5	37.500

Table 3: Parameter Metrics and Average Values

4. Proposed Metric Parameter

A justified Weight Metric is designed to be mapped on the various parameters to calculate a new proposed metric parameter **Performance Index** to examine the performance of various Hypercube Interconnection Networks as shown below [11].

Weight Metric					
W1	**W2**	**W3**	**W4**	**W5**	**TOTAL**
20	20	20	20	20	**100**

Table 4: Weight Metric

Mapping Metric		
	Parameter	**Weight**
A	Speed	W1
B	Packet Loss	W2
C	Coverage	W3
D	Degree	W4
E	Diameter	W5

Table 5: Parameter & Weight Mapping Metric

With the justified metrics as shown above, the proposed metric parameter **Performance Index** is calculated as shown below [11]:

Performance Index
{(Avg. Speed * w1) - (Avg. Packet Loss * w2) + (Avg. Coverage * w3) + (Avg. Degree * w4) + (Avg. Diameter*w5) + (Avg. Network Cost * w6)}/100

Thus, as shown above mathematically, Performance Index can be calculated for every variant of hypercube network at any specified time interval.

5. Results And Comparison

From the above calculation, the Performance Index for Folded Hypercube Network at 30 units of time interval is calculated as shown below.

Performance Index
11.692

Similarly, The Performance Index of Folded Hypercube Networks is evaluated at different time intervals of 30, 60, 90 and 120 units and tabulated in Table 6 to identify the variations in its performance.

TYPE/TIME	30	60	90	120
FOLDED HYPERCUBE	**11.692**	**13.412**	**16.412**	**19.412**

Table 6: Performance Index of Folded Hypercube at 30 units of time

With the same mathematical calculations, by considering the properties of Speed, Packet Loss, and Node coverage along with Degree, Diameter, and Network cost, the Performance Index of various considered Interconnection Networks at 30, 60, 90, and120 units of time is shown in Table 7.

TYPE/TIME	30	60	90	120
FOLDED HYPERCUBE	**11.692**	**13.412**	**16.412**	**19.412**
HYPERCUBE NETWORK	**10.442**	**13.412**	**16.412**	**19.412**
MULTIPLE REDUCED HYPERCUBE	**10.642**	**13.612**	**16.612**	**19.612**
MULTIPLY TWISTED CUBE	**11.999**	**19.469**	**22.469**	**25.469**
RECURSIVE CIRCULANT	**8.962**	**8.9629**	**14.962**	**17.962**

Table 7: Performance Index considering the properties speed, packet loss, node coverage, degree, diameter and network cost at different time intervals

The Performance of Hypercube Variants at 30, 60, 90, and 120 units of time considering the properties Degree, Diameter, Network Cost, Speed, Packet Loss and Node Coverage is compared in Fig. 12 [11].

Comparison

The Performance Index of various Hypercube Interconnection Networks at time intervals of 30, 60, 90 and 120 units considering the properties Degree, Diameter, Network cost, Speed, Packet Loss and Node Coverage [11].

TIME/TYPE	FOLDED HYPERCUBE	HYPERCUBE	MULTIPLE REDUCED HYPERCUBE	MULTIPLY TWISTED CUBE	RECURSIVE CIRCULANT
30	11.692	10.442	10.642	**11.999**	8.962
60	13.412	13.412	13.612	**19.469**	8.962
90	16.412	16.412	16.612	**22.469**	14.962
120	19.412	19.412	19.612	**25.469**	17.962

Enhancement in Performance		
MTC	Folded	**30.32 %**
	Hypercube	**47.92 %**
	MRH	**31.29 %**
	RC	**56.15 %**

Table 8: Enhancement in performance of MTC over other variants considering Performance Index

Thus, as clearly shown, MTC exhibits much more efficient performance over other variants based on proposed metric of Performance Index. Thus, the improvement in Performance of Multiply Twisted Cube Network (MTC) is **5.41** times considering the property of proposed metric Performance Index. The Performance of Hypercube Interconnection Networks Variants at 30, 60, 90 and 120 units of time based on Performance Index is depicted in Fig. 13 [11].

6. Conclusion

The Performance of a set of multiprocessor interconnection networks is assessed utilizing a novel metric “Performance Index”. Variations in the exhibiting performance of various hypercube interconnection networks are watched and analyzed at various time stretches. The results and the perceptions show that out of all the five considered variations of hypercube interconnection networks i.e., Hypercube Interconnection Network, Folded Hypercube Network, Multiple Reduced Hypercube, Multiply Twisted Cube, and Recursive Circulant, Multiply Twisted Cube (MTC) displays productive execution over different variations based on new property metric Performance Index at expanded Time Intervals. Along these

lines, it shows its most suitability for enormously Parallel Processing Applications dependent on the factor of Node Coverage. Multiply Twisted Cube Network displays upgraded execution of 30.32% over Folded Hypercube, 47.92% over Hypercube Network, 31.29% over Multiple Reduced Hypercube and 56.15% over Recursive Circulant Network and an improved exhibition of 5.41 times.

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Figures

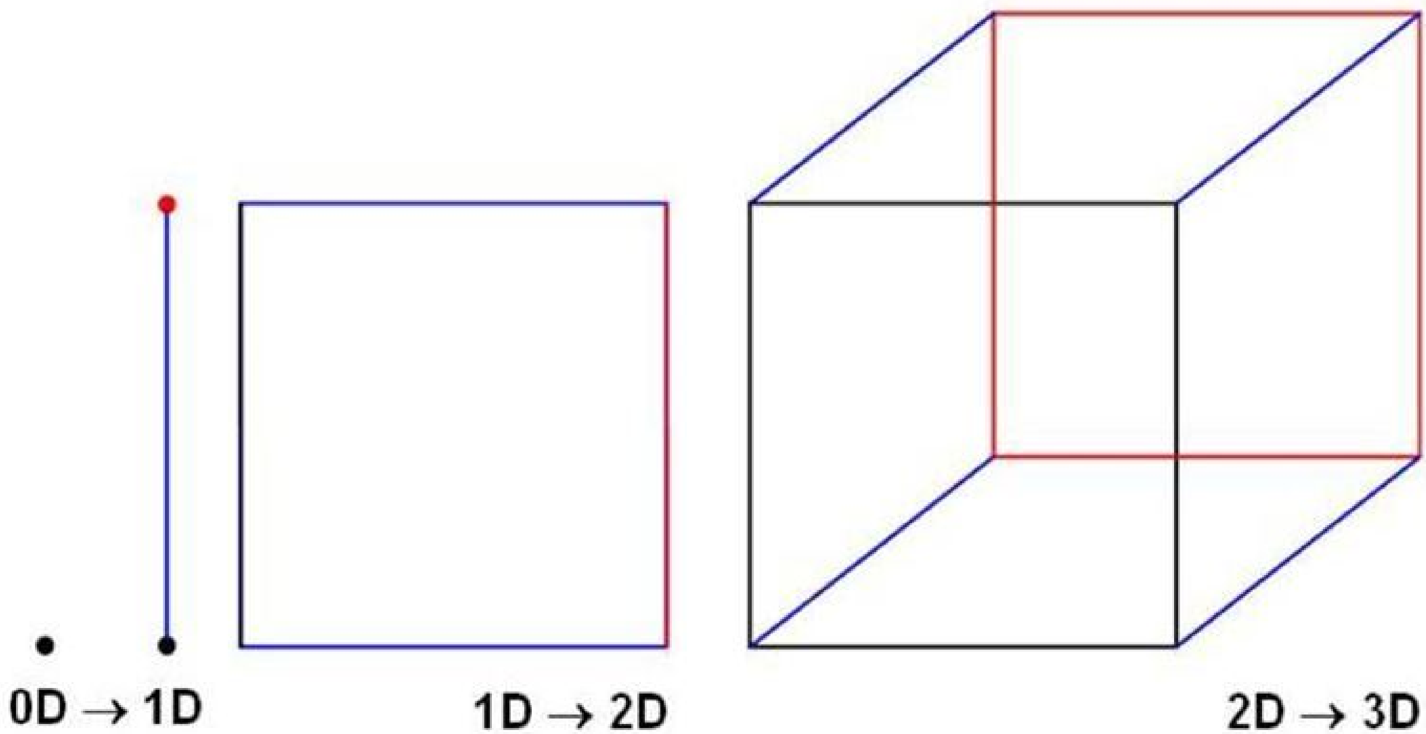

Figure 1

Hypercubes with different number of nodes and dimensions

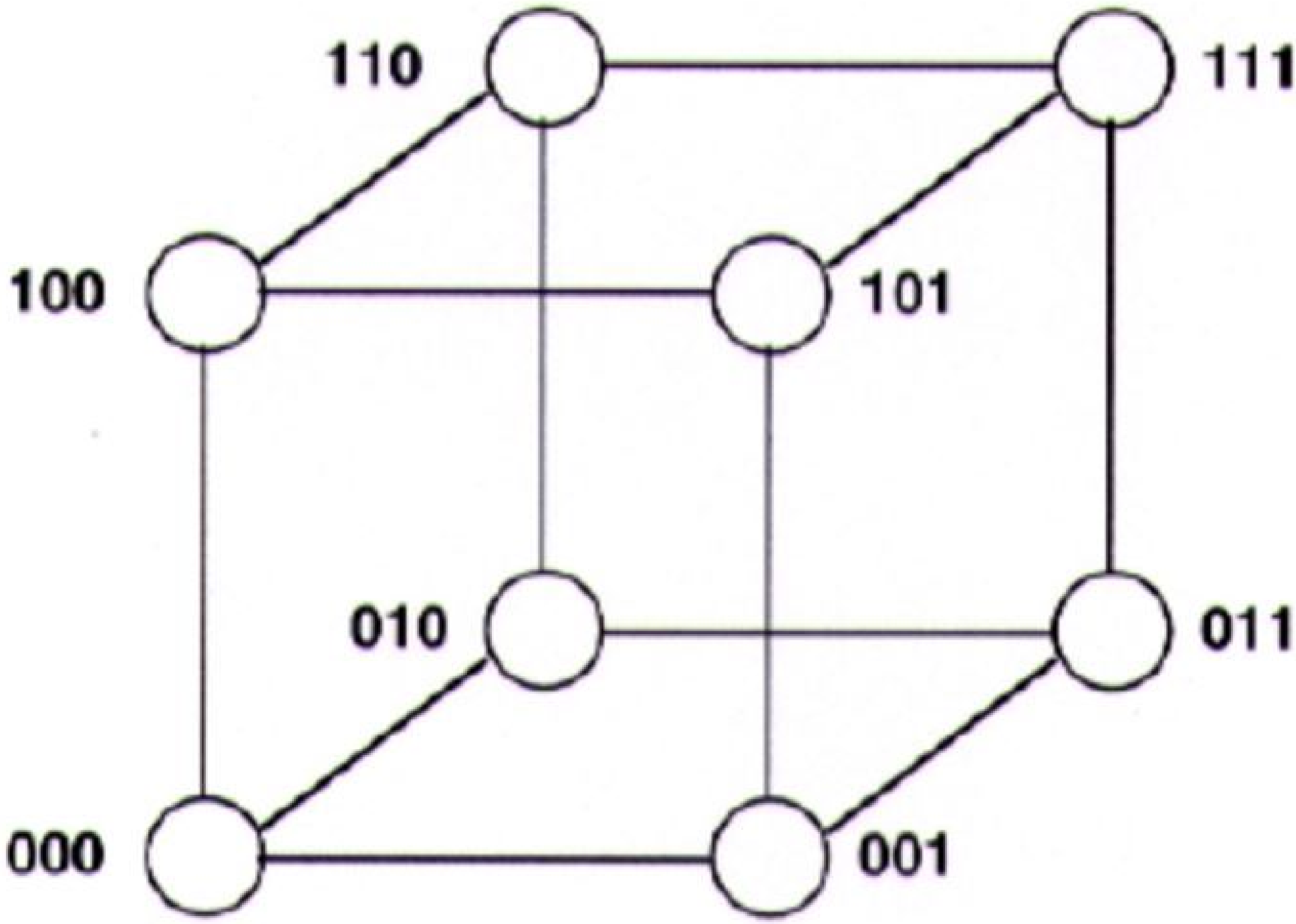

Figure 2

Hypercube Network

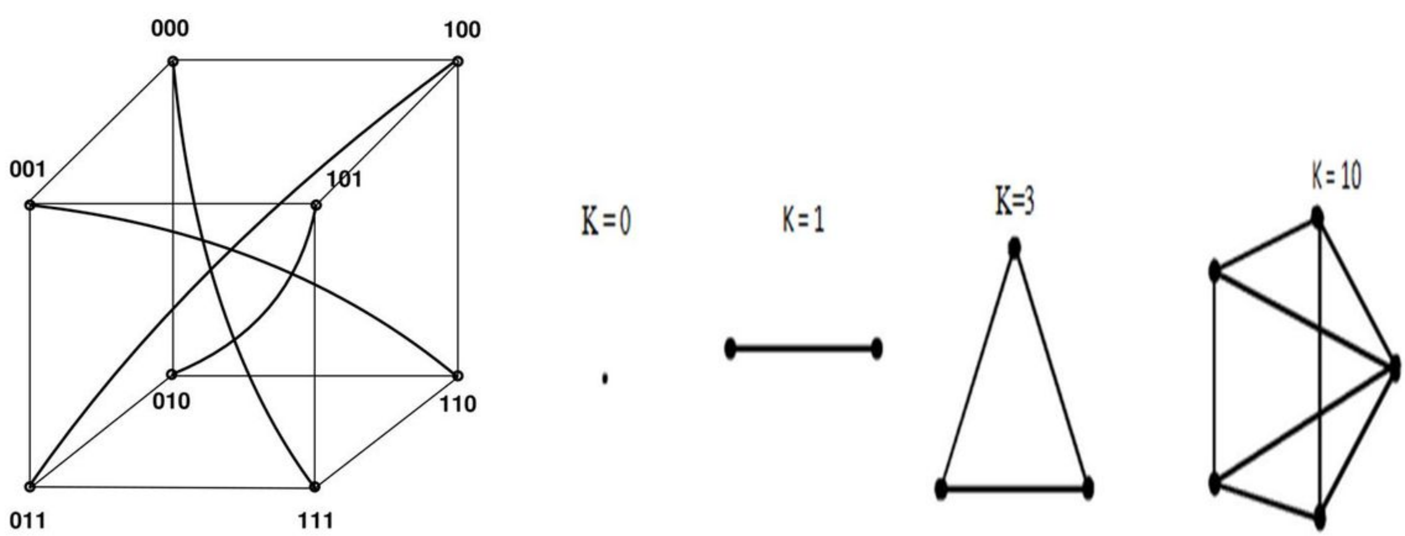

Figure 3

a. Folded Hypercube Network. b. Different types of Folded Hypercubes.

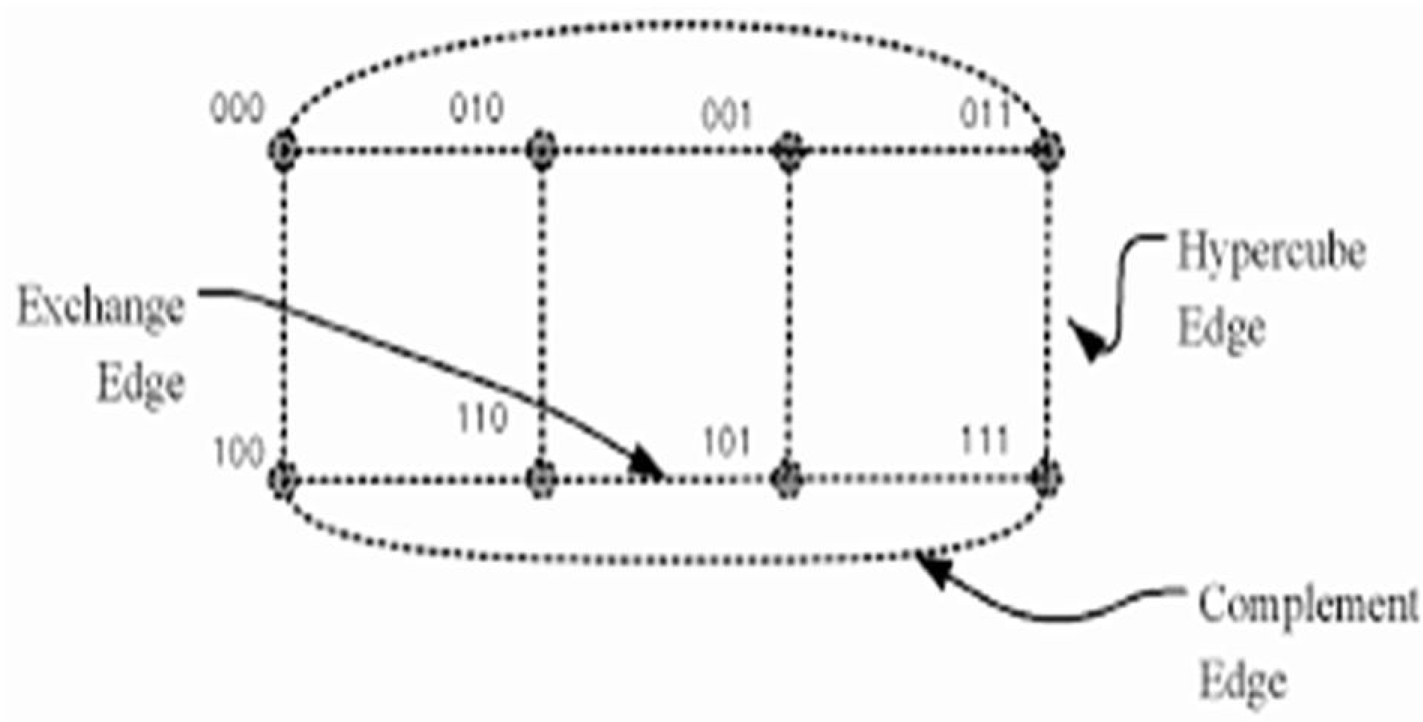

Figure 4

Multiple Reduced Hypercube Network

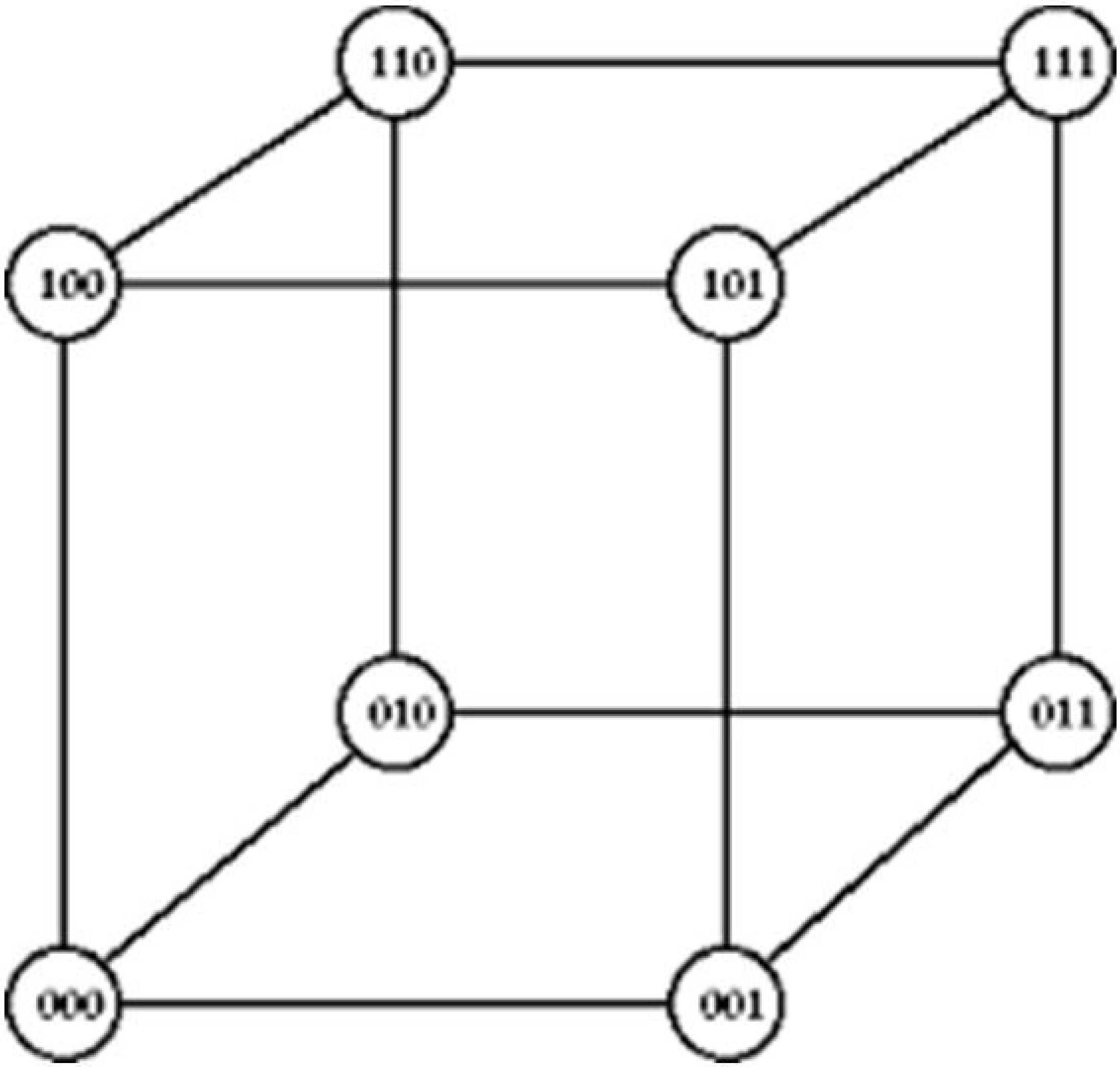

Figure 5

Multiply Twisted Cube

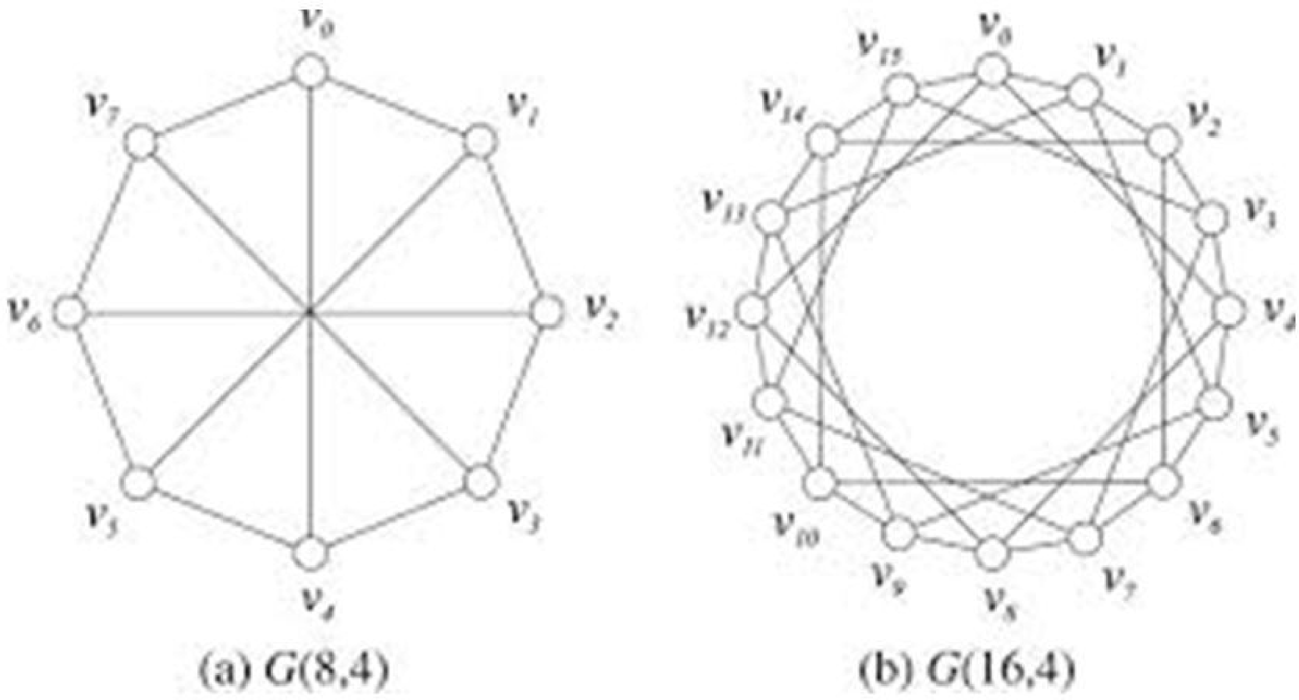

Figure 6

Recursive Circulant Hypercube Graphs

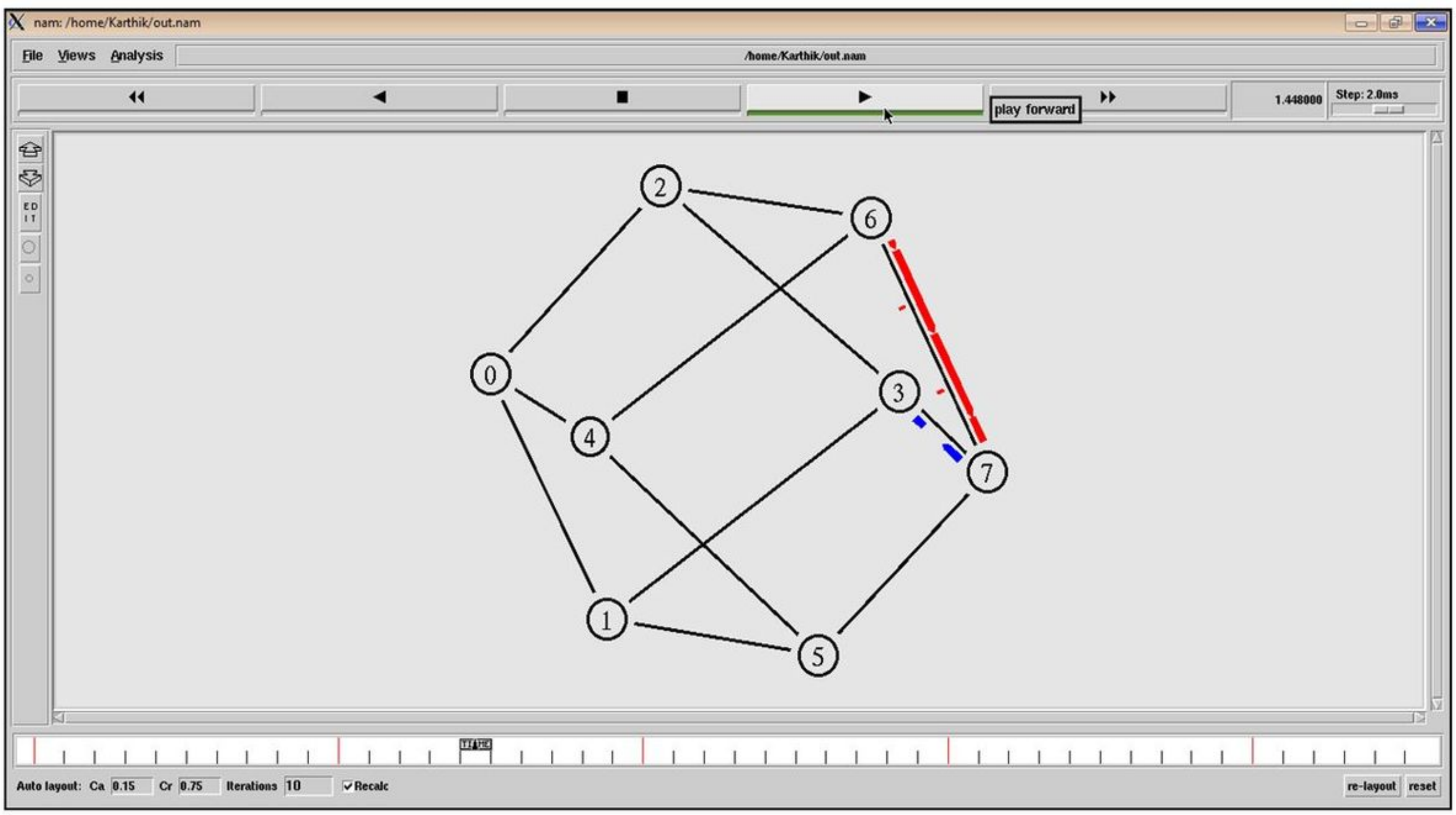

Figure 7

Hypercube Interconnection Network

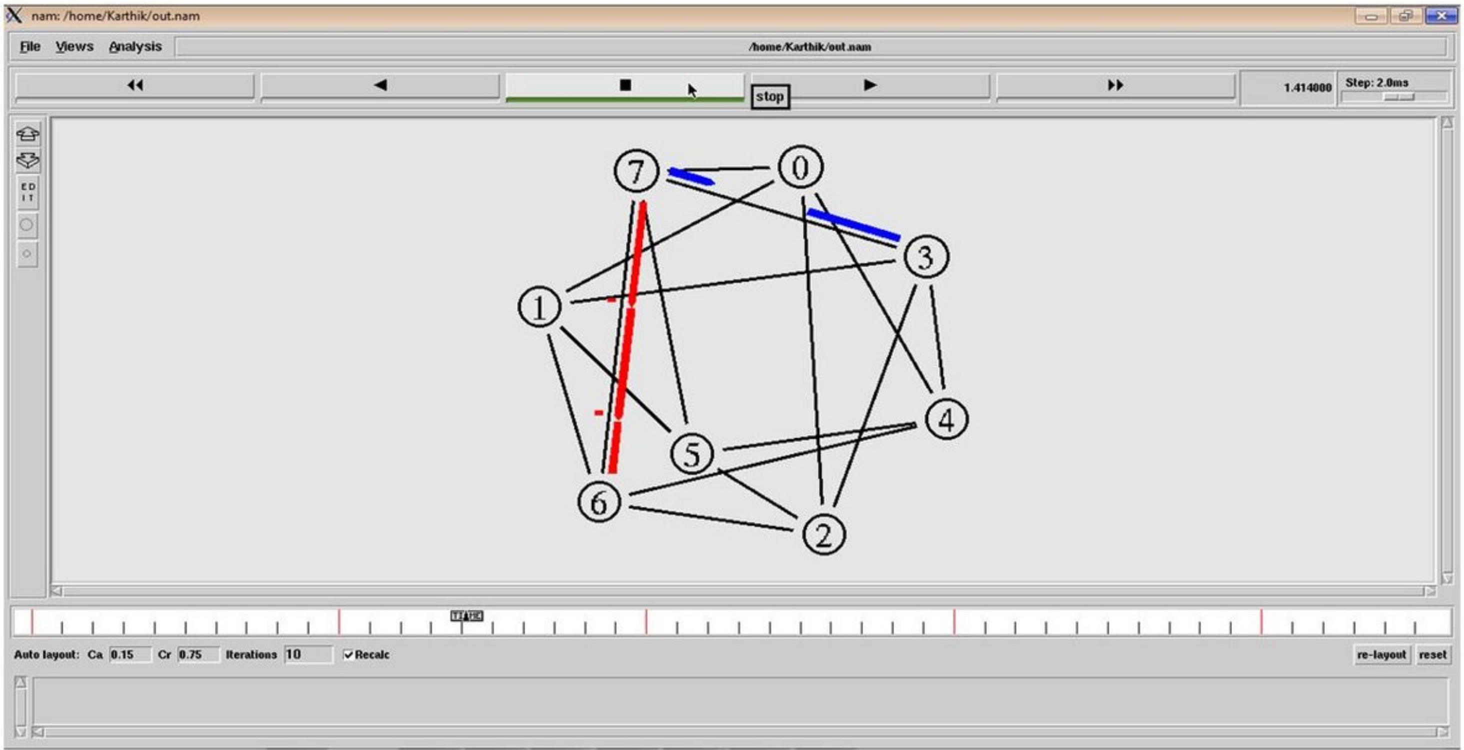

Figure 8

Folded Hypercube Interconnection Network

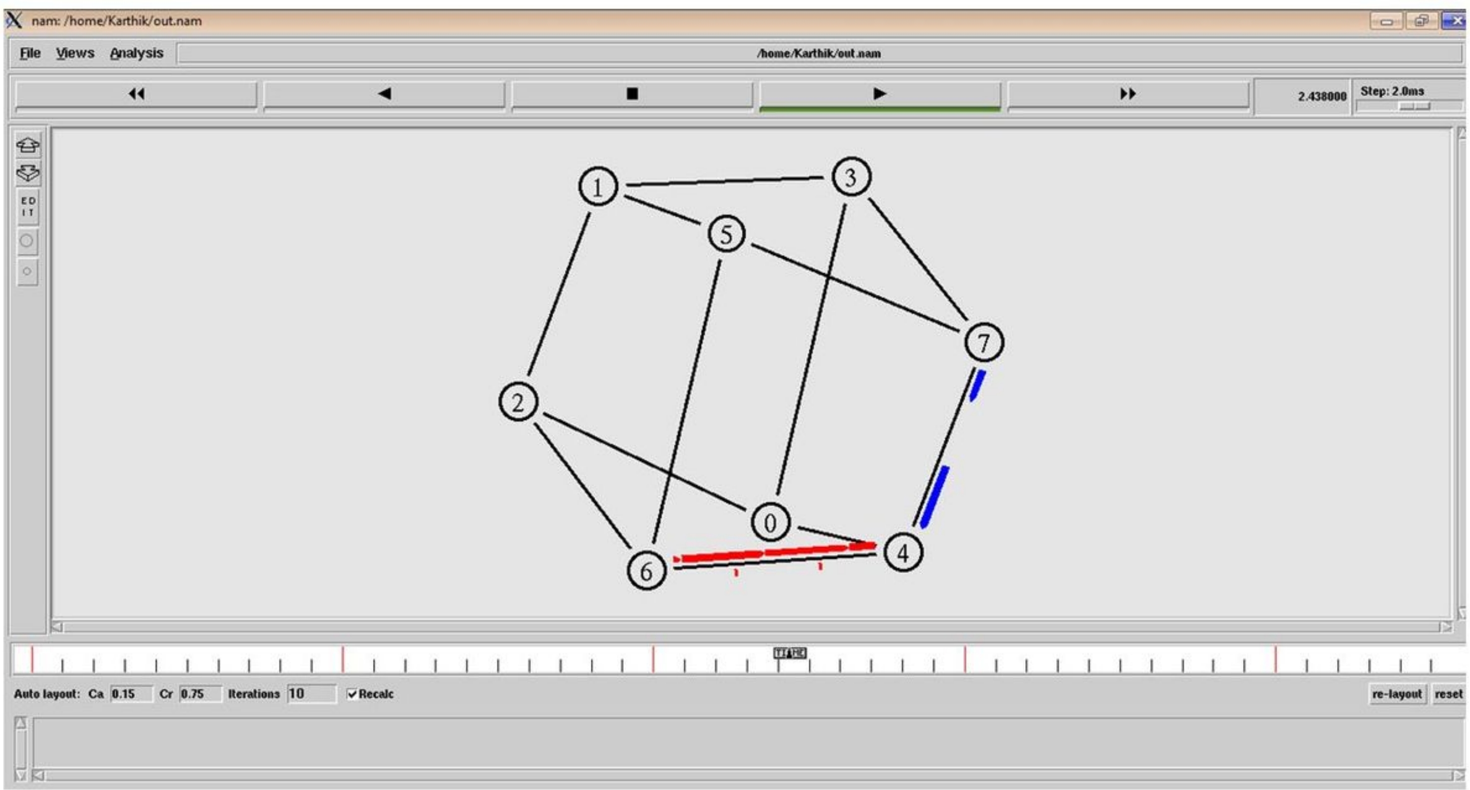

Figure 9

Multiple Reduced Hypercube Network

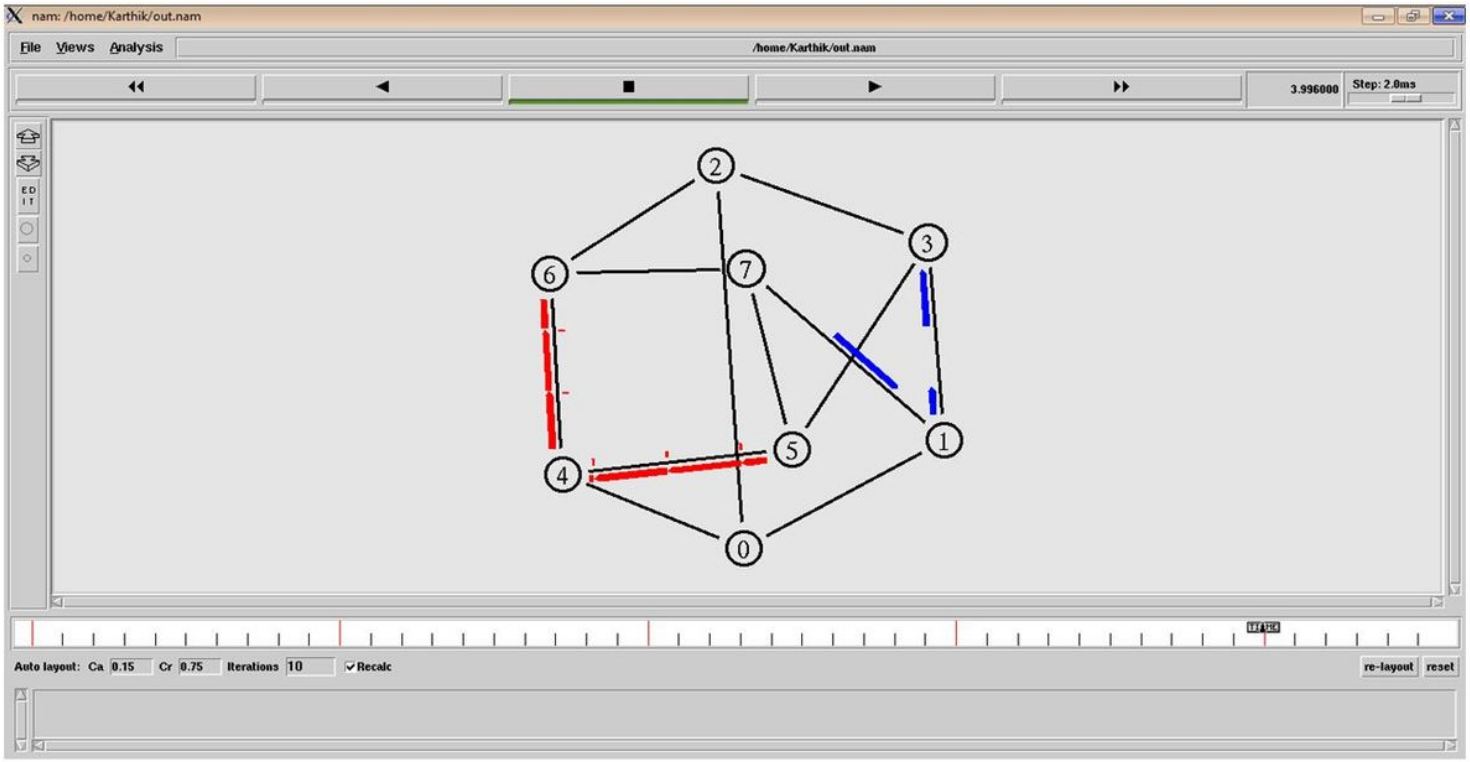

Figure 10

Multiply Twisted Cube Network

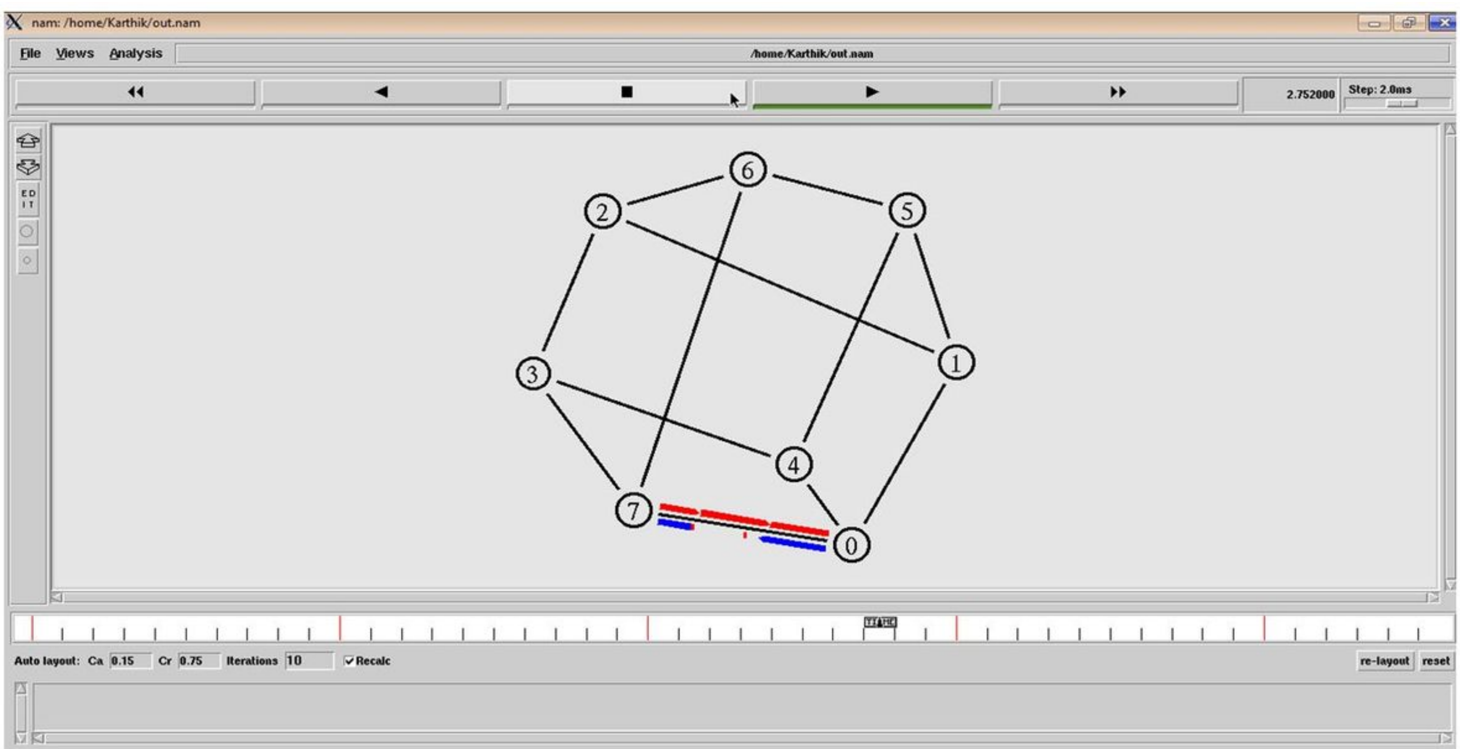

Figure 11

Recursive Circulant Hypercube Network

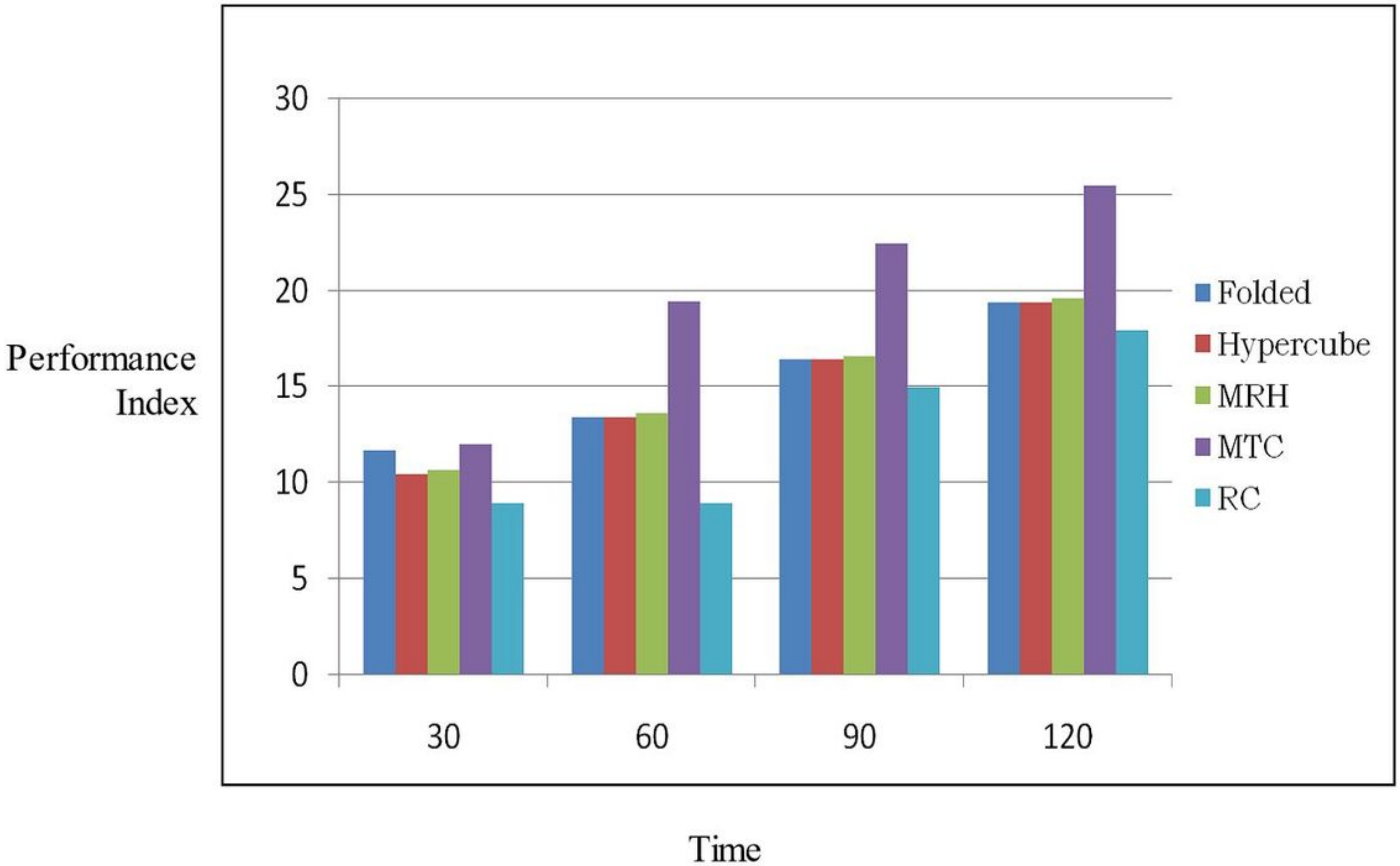

Figure 12

Performance comparison considering the properties of degree, diameter, network cost, speed, packet loss and node coverage at different time intervals for different variants of hypercube networks

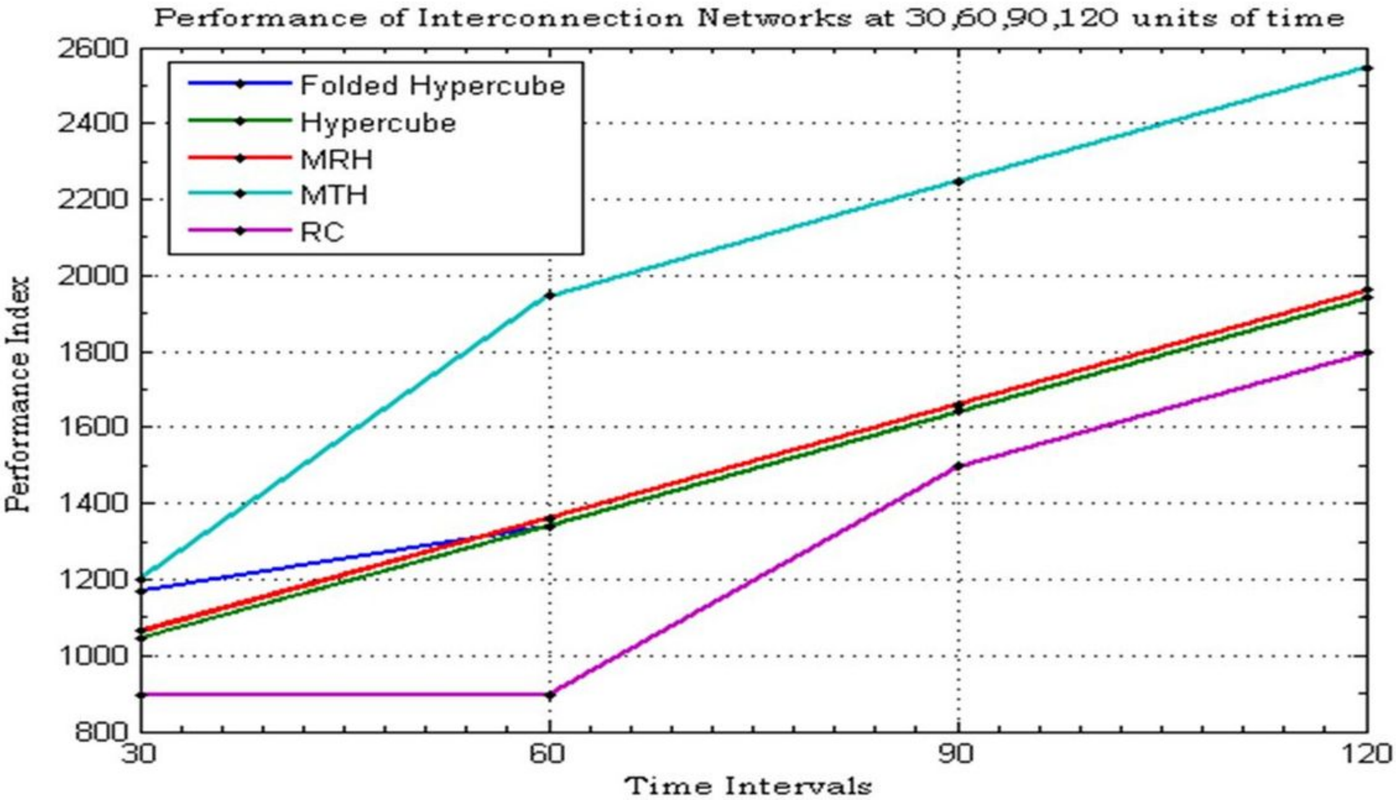

Figure 13

Comparison of Performance Index for different variants of hypercube interconnection networks at different time intervals

Supplementary Files

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- suppfig.jpg