The Folded Crossed Cube: A New Interconnection Network for Parallel Systems

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ABSTRACT
Study of parallel computer interconnection network topology has been made along with the various interconnection networks emphasizing the cube based topologies in particular. This paper proposes a new cube based topology called the Folded crossed cube with better features such as reduced diameter, cost and improved broadcast time, better fault tolerance and better message traffic density in comparison to its parent topologies: viz: hypercube and crossed cube. The one-to-one routing algorithm is also designed for the proposed network. The topological properties along with routing time are compared with the parent topologies and found to be better. Performance analysis in terms of cost, reliability is also done for the current network.

General Terms
Parallel Processing, Performance evaluation, Reliability Interconnection networks, Fault tolerance.

Keywords
Folded crossed cube, Topological Properties, Average Node Distance

1. INTRODUCTION
Cube type networks have received much attention over the past few years since they offer a rich interconnection structure with large bandwidth, logarithmic diameter and high degree of fault tolerance[1]. Many interconnection networks such as trees and multidimensional meshes can be embedded in the cube. Extensive research has been done on cube based networks and several variations have been proposed in literature. Prominent candidates among them are Hypercube [2], Folded hypercube [3] crossed cube [4,5], dual cube , meta cube[6] ,folded dual cube [7], star cube[8] and Folded crossed hypercube[12] .

The crossed cube network exhibits better characteristics such as network diameter, mean distance between vertices as compared to Hypercube. Regularity, symmetry, high connectivity, recursive structure are also preserved in Crossed cubes. The Folded crossed hypercube (FCQ_n) is a hybrid hypercube type architecture constructed from a varietal cube, by only adding the new edges (u,v) with $u_{n-1}\ldots u_1u_0 = v'_{n-1}\cdots v'_1 v'_0$ for $0 \leq u \leq (2^n - 1)$.

In this paper a new interconnection network called Folded crossed cube (FCC) is proposed by augmenting the Crossed cube network. Some extra links called complementary links are introduced. The aim is to decrease the diameter. The paper is organized as follows. The proposed hybrid network is defined in Section 2. Its topological properties are derived in Section 3. An optimal one –to –one routing is proposed in Section 4. Performance analysis is done in section 5. Next, Section 6 presents the results and discussions. Section 7 concludes the paper.

2. PROPOSED TOPOLOGY

2.1 Crossed cube
The n-dimensional crossed cube CC_n, is an n-regular graph of 2^n nodes. Every node in CC_n is identified by a unique binary string of length n. The following are the formal definitions of CC_n [5].

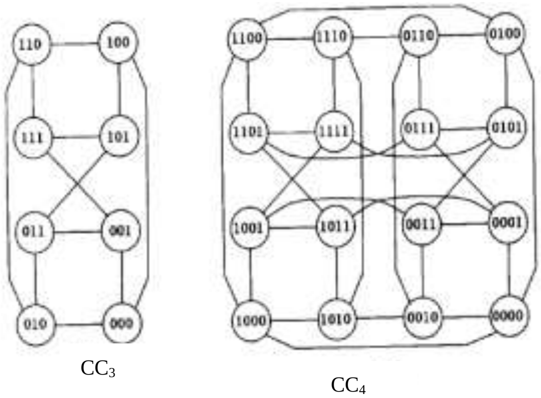
Definition1: Two binary strings $X=X_1X_0$ and $Y=Y_1Y_0$ of length two are said to be pair related if and only If xy ∈ {(00,00) (10,10), (01,11),(11,01)}.

Definition2: The n-dimensional crossed cube CC_n is recursively defined as follows.
CC_1 is complete graph on two vertices with labels 0 and 1. For n>1, CC_n contains CC^0_{n-1} and CC^1_{n-1} joined according to the following rule: the vertex $u=0u_{n-2}\ldots u_0$ from CC^0_{n-1} and the vertex $v=1v_{n-1}\ldots\ldots v_0$ from CC^1_{n-1} are adjacent in CC_n if and only if

1. $u_{n-2}=v_{n-2}$ if n is even, and
2. for $0<=i<\lfloor (n-1)/2 \rfloor$, $u_{2i+1}u_{2i} \sim v_{2i+1}v_{2i}$

Every vertex in CC_n with a leading 0 bit has exactly one neighbor with a leading 1 bit and vice versa. The network structure of crossed cubes of dimension 3 and 4 are depicted in Figure 1(a) and (b) respectively.

2.2 Folded Hypercube
The folded hypercube [3] of dimension n, FHC(n) is constructed from standard n-cube by connecting each node to the unique node that is farthest from it . Thus FHC(n) is a regular network of degree (n+1). The number of edges is increased by a factor equal to (total number of nodes/2). With increased number of links the diameter is reduced to half as compared to the diameter of general hypercube.



(a) (b)

Figure 1 Crossed cube of Dimension CC_n (a)n=3 and (b)n=4

The hypercube of degree 3 is converted to FHC(3) network as shown in Figure 2.

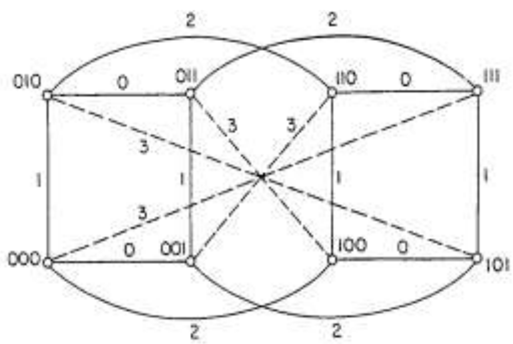


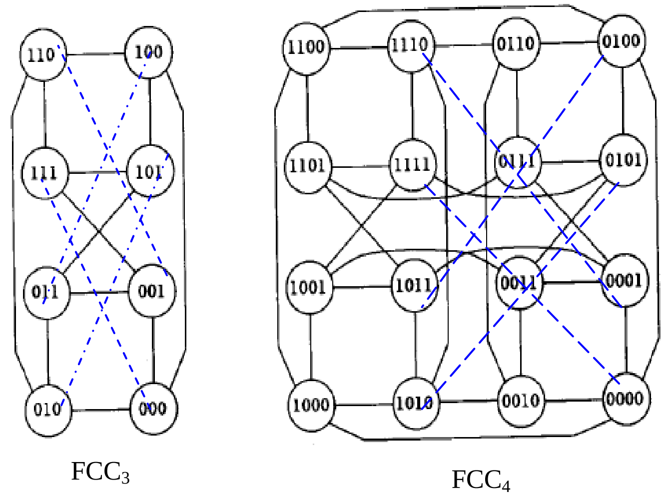
Figure 2. Folded Hypercube FHC(3)

2.3 Proposed Interconnection Network Topology: Folded Crossed cube (FCC)

The Folded crossed cube is constructed by connecting each node to a node farthest from it . Figure 3(a) and (b) respectively depict the structure of Folded crossed Cube of dimension 3 and 4. In figure 3(b) all the complementary links of FCC_4 are not shown for simplicity. The folded crossed cube is a graph F_r (V, E') with the same set of vertices as in CC and with the edge set E' that is a super set of E.

E' =|E| + (Total no of nodes) / 2
= $n.2^{2n-1} + 2^{2n}/2$ = $(n+1)\, 2^{2n-2}$

Now CC is a spanning sub graph of F_r that means FCC(n) and e(u,v) $\in$ E', if u and v are pair related . Also the hamming distance between u and v is either 1 or n that is $\|a(u) \oplus a(v)\|=1$ or n. So every vertex in F_r with a leading 0 bit has exactly one neighbor with a leading 1 bit and vice versa similar to CC.



(a) (b)

Figure 3. Folded Crossed cube of Degree FCC_n (a)n=3 and (b)n= 4.

3. TOPOLOGICAL PROPERTIES OF FCC:

This section describes the topological properties of the proposed network.

Lemma1: For all $n \geq 1$, $(u_{n-1}..u_0, v_{n-1}\ldots v_0)$ is an edge in FCC if and only if there exist an l with (i) $u_{n-1}\ldots u_l = v_{n-1}\ldots v_l$.
(ii) $u_{l-1} \neq v_{l-1}$
(iii) u and v are pair related.
Or $u_{n-1}\ldots u_0 \neq v_{n-1}\ldots v_0$ that is all bits are complemented. So $v_0 = u'_0, \ldots v_{n-1} = u'_{n-1}$

Lemma 2: Let (u,v) be an edge in FCC. When u and v have a left most differing bit at position d then v is said to be d neighbor of u and edge (u,v) is an edge of dimension d. Here the farthest node is an adjacent node by complementary link so it will be the *(d+1)th* dimension edge.

Theorem 1: The node connectivity of FCC is *(n+1).*

Proof : Every node with n bit address a(u) in FCC is connected to n nodes at hamming distance 1 and one node at hamming distance n. The address of latter node is a(u)' that is complement of all bits in a(u). So degree of FCC is $d_F(u)$ = *n+1* and FCC is a regular graph of degree *(n+1)*

Theorem 2: The number of node disjoint paths between any two nodes of FCC is *(n+1).*
Proof : Since every node has *(n+1)* neighbours so it is necessary to remove at least *(n+1)* nodes to disconnect FCC.

3.1 Diameter

It is defined as the maximum distance between the nodes of the network.

Theorem 3: The Diameter of FCC is $\lceil n/2 \rceil$.

Proof : As discussed in [3] , consider any two nodes u,v ∈ V, the node set with ||a(u) ⊕ a(v)||= $\lceil n/2 \rceil$ + i, where -$\lceil n/2 \rceil$ < i ≤ $\lfloor n/2 \rfloor$. Both the nodes u and v can communicate in at most $\lceil n/2 \rceil$ hops by correcting the differing bits in their n bit node id one at a time. When the hamming distance is less than n, a path can always be established between u and v by using the complementary edge which connects u to its farthest node u'. The hamming distance between u' and v is clearly $\left\lfloor \frac{n}{2} \right\rfloor - i$. Therefore the distance

D(u,v)=1+$\left\lfloor \frac{n}{2} \right\rfloor - i$. Hence the diameter is $\left\lceil \frac{n}{2} \right\rceil$.

3.2 Bisection Width

It is defined as the number of edges whose removal will result in two distinct sub networks.

Theorem 4: The bisection width of FCC*(n)* is 2^n.

Proof: From the construction it is clear that two identical (n-1) –dimensional crossed cubes CC_{n-1}^0 and CC_{n-1}^1 are connected by dimension(n-1) edges of CC_n . Next $\frac{|V|}{2}$ number of edges called complementary links are introduced to make FCC(n). So, now removal of 2^{n-1} and $\frac{|V|}{2}$ number of edges will disconnect FCC(n) into two equal halves. So the bisection width becomes $2^{n-1} + 2^{n-1} = 2^n$ as $|V| = 2^n$.

3.3 Cost

For a symmetric network the cost factor is defined as the product of the diameter and the degree of the node. This factor is widely used in performance evaluation.

Theorem 5: Cost of FCC(n) is $(n+1)\left(\left\lceil \frac{n}{2} \right\rceil\right)$.

Proof: Cost = degree * diameter

The degree of FCC is *(n+1)*. The diameter of FCC(n) is $\left\lceil \frac{n}{2} \right\rceil$.

Hence cost = $(n+1)\left(\left\lceil \frac{n}{2} \right\rceil\right)$

3.4 Mean Internode Distance

The mean internode distance in a regular network is defined as the ratio of the sum of distances between a node and all other nodes to the total number of nodes. In a hypercube there are $\binom{n}{i}$ nodes at distance *i*. The same is derived for FCC(n) as follows.

Lemma 3: The number of nodes at distance *i* from any node in FCC(n) is $\binom{n+1}{i}$, for *0< i<*$\left\lceil \frac{n}{2} \right\rceil$. For *i=*$\left\lceil \frac{n}{2} \right\rceil$, this is $\binom{n+1}{\frac{n}{2}+1}$, for even *n* and is $\binom{n}{\left\lceil \frac{n}{2} \right\rceil}$ for odd *n.*

Proof: For *0< i<*$\left\lceil \frac{n}{2} \right\rceil$ and any node *u* in FCC, there are $\binom{n}{i}$ nodes at Hamming distance *i* from u according to hupercube properties. Next u is connected to the node u' by the complementary link. Then there exist $\binom{n}{i-1}$ at distance *(i-1)* from u'. The distance of such nodes from *u* via u' is *i-1+1=i*. Then the number of nodes is given by

$$|Z_i| = \binom{n}{i} + \binom{n}{i-1} = \binom{n+1}{i}$$

For *i=*$\left\lceil \frac{n}{2} \right\rceil$, there are two cases:

Case i) n is even then

$$|Z_{n/2}| = \binom{n}{n/2} + \binom{n}{\frac{n}{2}+1} = \binom{n+1}{\frac{n}{2}+1}$$

Case ii) n is odd then

$$|Z_{\lceil n/2 \rceil}| = \binom{n}{\lceil n/2 \rceil}$$

Theorem 6: The mean internode distance of FCC(n) is given by

$$\bar{d} = \left(\frac{\sum i\,|Z_i|}{N}\right)$$

.

Proof : In FCC network , the nuber of nodes at a distance i from a given node is given by Z_i will be calculated as discussed in *Lemma* 3.

The total number of nodes is given by *N=2*^{n}.

So the average distance is given by

$$\bar{d} = \left(\frac{\sum i\,|Z_i|}{N}\right)$$

3.5 Message Traffic Density

This factor is defined as $\rho \equiv \frac{\bar{d}N}{E}$

where N is the total number of links, $\bar{d}$ is the average node distance and E is the total number of links. It is assumed that each node is sending one message to a node at distance d on the average. ρ is a good measure to estimate the traffic in the network.

Theorem 7: In FCC network, the message traffic density is given by $2\frac{\left(\frac{\sum i|z_i|}{N}\right)}{n+1}$

Proof: As per the definitions,

$$\rho = \frac{\bar{d}N}{E}.$$

For FCC_n

$\bar{d} = \left(\frac{\sum i|Z_i|}{N}\right)$ and *E =(n+1)N/2.*

$$\text{So} \quad \rho = \frac{\frac{\sum i|z_i|}{N}N}{(n+1)N/2} = 2\frac{\left(\frac{\sum i|z_i|}{N}\right)}{n+1}$$

3.6 Mean Internode Distance Rate

The absolute mean internode distance rate denoted by γ_a and the relative one is denoted by γ_r for any network X is defined as

$$\gamma_a(X) = \frac{\bar{d}(X)}{\bar{d}(Q_n)} \quad \text{and} \quad \gamma_r = \frac{\bar{d}(Q_n)-\bar{d}(X)}{\bar{d}(Q_n)}$$

For FCC network these two parameters are derived as follows:

$$\gamma_a(FCC) = \frac{(\sum_{i=1}^{n} i|Z_i|)/(2^n-1)}{n2^n/2(2^n-1)},$$

and

$$\gamma_r(FCC) = \frac{\frac{n2^n}{2(2^n-1)} - \frac{\sum_{i=1}^{n} i|Z_i|}{2^n-1}}{n2^n/2(2^n-1)}$$

4. ROUTING

This section proposes a routing algorithm for FCC(n).

4.1 Routing Algorithm

The routing in a network depends upon shortest path, the Hamming distance. In F_r the hamming distance is 1 or n. Algorithm for one-to-one communication is proposed below.

One-to-one Routing:

This algorithm performs the routing between any pair of nodes namely $u(u_{r-1}u_{r-2}\ldots u_0)$, $v(v_{r-1}v_{r-2}..v_n) \in V$ of F_r.

Algorithm One-to-one (a(u),a(v),r)
Begin

a(w)=(a(u) $\oplus$ *a(v);*

If $||a(w)|| < \left\lceil \frac{n}{2} \right\rceil$

Route the message sent from u via a path composed of links with labels corresponding to bit position which are 1's in a(w)

Else

send the message to u' via the complementary link, route the message via a path composed of links with labels corresponding to bit positions that are 0's in a(w).

end;

Here $a(w)=(w_{r-1},w_{r-2}\ldots w_0)$. So $\|a(w)\| = r$. If $r \le \left\lceil \frac{n}{2} \right\rceil$, then path formed between u and v will be composed of any one of r! permutations of w_i's. If $r > \left\lceil \frac{n}{2} \right\rceil$, then a complementary edge must be used somewhere along the path.

So length of shortest path in Folded Crossed cube is at most $\left\lceil \frac{n}{2} \right\rceil$, the diameter of the network.

5. PERFORMANCE ANALYSIS

It is very much necessary to do Performance analysis of a parallel interconnection network as it reflects important aspects of a multiprocessor system that is the total cost of a system. To make the parallel interconnection network more attractive, more emphasis is given to fault tolerance and reliability analysis. All these factors are evaluated in this section.

5.1. Fault Tolerance

In parallel computing environment fault tolerance of a network is an important characteristic. For a graph, it is defined as the maximum number of vertices that can be removed from it provided that the graph is still connected. Hence the fault tolerance of a graph is defined to be one less than its connectivity. As discussed in [9], a system is said to be k-fault tolerant if it can sustain up to *k* number of edge faults without disturbing the network.

For symmetric interconnection networks the connectivity is equal to the node degree. For FCC, the node degree is (*n+1*). So FCC can tolerate up to *n* faults.

5.2 Fault Diameter

Fault diameter estimates the impact on diameter when fault occurs, that is removal of nodes from the network [10]. Fault diameter d_f of the graph G with fault tolerance *f* is defined as the maximum diameter of any graph obtained from G by deleting at most *f* vertices. The fault diameter should be close to the original diameter.

Theorem 8: The fault diameter of FCC(n) is given by

$$f_d = \left\lceil \frac{n}{2} \right\rceil + 1.$$

Proof: In FCC(n) a message originating at any node can travel through (n+1) paths. In case a link failure occurs then the message travels through one more node. This results in increase in diameter by unity.

So the diameter of the fault network

$$= \text{original diameter} + 1 = \left\lceil \frac{n}{2} \right\rceil + 1.$$

5.3 Cost Effectiveness Factor

While calculating the cost of a multiprocessor network; along with the cost of the processing elements the cost of the communication link is also considered [11]. In cube based networks the number of links is a function of the number of processors. The cost effectiveness factor takes this into account and gives more insight to the performance of the multiprocessor system.

Theorem 9: The cost effectiveness factor of FCC(n) is $\frac{1}{1+\rho\left(\frac{n+1}{2}\right)}$; where ρ is the ratio of link to processor cost.

Proof: The total number of processors in FCC is 2^n=p.
The total number of edges is

$= (n+1)\ 2^{n-1} = (n+1)p/2 = f(p)$

So g(p)= f(p)/p= (n+1)/2.

Hence CEF(p)= $\dfrac{1}{1+\rho g(p)} = \dfrac{1}{1+\rho\left(\dfrac{n+1}{2}\right)}$.

5.4 Time Cost Effectiveness Factor

Time cost effectiveness factor considers time for solution of a problem as a parameter for evaluating the performance. This factor considers the situations where a faster solution is more rewarding than the slower solutions.

When speedup of parallel algorithms is known ,the above two factors characterize the profitable use of multiprocessor systems.

For FCC(n), the TCEF is given by

TCEF(p,T_p)= $\dfrac{1+\sigma T_1^{\alpha-1}}{1+\rho g(p)+\dfrac{T_1^{\alpha-1}\sigma}{p}}$;

where T_1 is the time required to solve the problem by a single processor using the fastest sequential algorithm , T_p is the time required to solve the problem by a parallel algorithm using a multiprocessor system having p processors and ρ is the cost of penalty / cost of processors.

5.5 Reliability Analysis in FCC

Two reliability measures are of particular interest: Terminal Reliability and Broadcast Reliability [13]. Terminal reliability is generally used as a measure of the robustness of a communication network, is the probability of the existence of at least one fault free path between a source and destination nodes.

Two nodes A and B are considered with n number of node disjoint paths lying between them. Let r_i be the number of links involved in path i, where $1 \le i \le n$. Thus there are r_i-1 number of nodes in path i.

Let $P(E_i)$ be the probability of successful route through the i^{th} path.

Then R_l be the link reliability with link failure rate is 0.0001 and

R_n is the node reliability with processor failure rate is 0.001.

$R_l = e^{-\lambda t}$, where λ= 0.0001 and t=1000 and $R_n = e^{-\lambda t}$, where λ= 0.001 and t=1000.

Theorem 10: For FCC network the two terminal approximate reliability is given by

$$TR= 1-\prod_{i=1}^{n}(1-R_l^{r_i}R_n^{r_i-1}).$$

Proof : All nodes and links are considered to be identical with their failure rates statistically independent and exponentially distributed.

Now the probability of existence of a successful connection between the source and destination can be given by

$$P(E_i)= R_l^{r_i}R_n^{r_i-1}$$

So

$$TR= P(E_1 \cup E_2 \cup E_3 \cup ... \cup E_n)$$
$$= 1-\prod_{i=1}^{n}(1-R_l^{r_i}R_n^{r_i-1})$$

6. RESULTS AND DISCUSSIONS

This section evaluates different parameters of FCC and a comparison is made with other networks.

Different topological parameters are compared in Table 1. The degree, diameter and cost, average node distance, message traffic density of FCC has been compared with that of HC, CC and FHC as shown in Fig. 4,5,6,7 and 8. The degree is increased due to addition of complementary links. But the diameter and cost of FCC(n) both are appreciably reduced as compared to hypercube. The average node distance is evaluated in Table 2 and compared against that of hypercube and crossed cube and found to be quite reduced as shown in Figure8.

The average message density is also evaluated for FCC, HC and CQ. The comparison is done as shown in Figure 7. It is close to 0.75 where as it is 1 for HC. It never exceeds 0.8 for large value of n. In Table 4 the computed values of mean inter node distance rates both absolute and relative are shown.

Table 5 and 6 present the computed values of cost effectiveness and time cost effectiveness of FCC(n). In both the cases FCC exhibits better cost effectiveness and time cost effectiveness in comparison to hypercube and crossed cube as evaluated in [11].

Table 7 and 8 show computed values for reliability of FCC network. The proposed network is more reliable than the parent networks as it has more node disjoint paths with increasing values of n as shown in Figure 9. Figure 10 depicts the superiority of the proposed network in terms of reliability while keeping n the node degree fixed at 10 but varying t from 1000 to 10,000.

Table 1 : Comparison of parameters of FCC, CC, FHC,HC

Networks	**Degree**	**Diameter**	**Cost**	**Bisection width**
HC	n	n	n^2	2^{n-1}
FHC	$n+1$	$\lceil \frac{n}{2} \rceil$	**(n+1)*** $\lceil \frac{n}{2} \rceil$	2^n
CC	n	$\lceil \frac{n+1}{2} \rceil$	$n \lceil \frac{n+1}{2} \rceil$	2^{n-1}
FCC	$n+1$	$\lceil \frac{n}{2} \rceil$	**(n+1)** $\lceil \frac{n}{2} \rceil$	2^n

Table 2: Average node distance comparison

n	HC	CC	FCC
2	1	1	0.7
3	1.25	1.37	1.25
4	2	1.903	1.5
5	2.5	2.15	2.0625
6	3	2.75	2.406
7	3.5	3.25	2.906
8	4	3.75	3.269
9	4.5	4.125	3.76
10	5	4.625	4.146
11	5.5	5.125	4.64
12	6	5.5	5.03
13	6.5	6	5.53
15	7.5	6.875	3.78
20	10	7.75	5.35
30	15	13.75	13.26

Table 3: Message traffic density comparison

n	HC	CC	FCC
2	1	1	0.466667
3	1	0.91333333	0.625
4	1	0.9515	0.6
5	1	0.86	0.6875
6	1	0.91666667	0.687429
7	1	0.92857143	0.7265
8	1	0.9375	0.726444
9	1	0.91666667	0.752
10	1	0.925	0.753818
11	1	0.93181818	0.773333
12	1	0.91666667	0.773846
13	1	0.92307692	0.79

Table 4: Mean inter node distance rates of FCC

n	γ_a	γ_r
2	1.428571	0.3
3	1	0
4	1.333333	0.25
5	1.212121	0.175
6	1.246883	0.198
7	1.204405	0.16971429
8	1.223616	0.18275
9	1.196809	0.16444444
10	1.205982	0.1708
11	1.185345	0.15636364
12	1.192843	0.16166667
13	1.175407	0.14923077
15	1.984127	0.496
20	1.869159	0.465
30	1.131222	0.116

Table 5: Cost effectiveness factor of FCC(n)

n	$\rho = 0.1$	ρ =0.2	ρ =0.3	ρ =0.4
3	0.8333333	0.714285	0.625	0.555555
4	0.8	0.666666	0.571428	0.5
5	0.7692307	0.625	0.526315	0.454545
6	0.740740	0.588235	0.4878048	0.416666
7	0.7142875	0.55555	0.454545	0.3846153
8	0.689655	0.526315	0.425531	0.357142
9	0.66666	0.5	0.4	0.33333
10	0.645161	0.4761904	0.3773584	0.3125

TABLE 6: Time cost effectiveness factor of FCC(n) ,

$$\alpha = 1, \sigma = 1$$

n	$\rho = 0.1$	ρ =0.2	ρ =0.3	ρ =0.4
3	1.50943396	1.3114754	1.31147541	1.038961039
4	1.52380952	1.28	1.103448276	0.96969696
5	1.5023474	1.22605364	1.035598706	0.896358543
6	1.46453089	1.16575592	0.968229954	0.827943078
7	1.42064372	1.106309421	0.905874026	0.766926303
8	1.37560451	1.050471892	0.84965151	0.71329061
9	1.33159948	0.99902439	0.799375487	0.666232921
10	1.28951013	0.951938272	0.754438959	0.624809323

Table7: Comparison of Reliability analysis

N	HC	CC	FCC
3	0.029853	0.108906	0.824142
4	0.039605	0.117863	0.82591
5	0.049259	0.12673	0.82766
6	0.058816	0.135508	0.829392
7	0.068276	0.144198	0.831107
8	0.077642	0.1528	0.832805
9	0.086913	0.161316	0.834485
10	0.096091	0.169747	0.836149
11	0.105177	0.178092	0.837796
12	0.114172	0.186354	0.839427

Table 8: Reliability Comparison with time, n=10

T	HC	CC	FCC
1000	0.652323	0.729968	0.966914
2000	0.096091	0.169747	0.836149
3000	0.010032	0.03611	0.743418
4000	0.00101	0.009131	0.670653
5000	0.000101	0.00257	0.606571
6000	1.02E-05	0.000756	0.548816
7000	1.02E-06	0.000226	0.496586
8000	1.02E-07	6.78E-05	0.449329
9000	1.02E-08	2.04E-05	0.40657
10000	1.03E-09	6.15E-06	0.367879

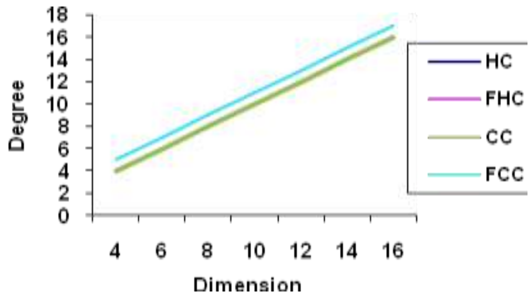


Figure 4 : Comparison of Degree

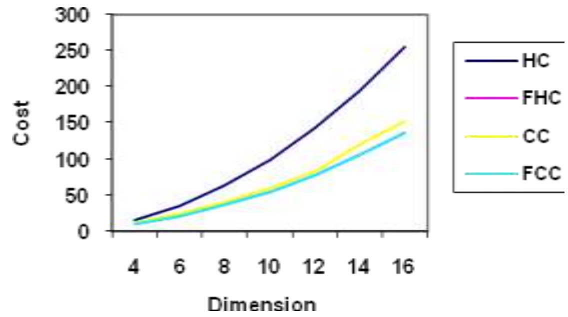


Figure 6 : Comparison of Cost

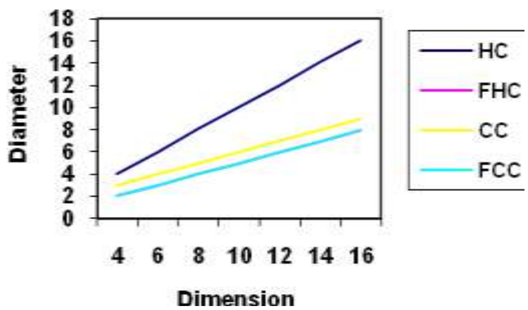


Figure 5 : Comparison of Diameter

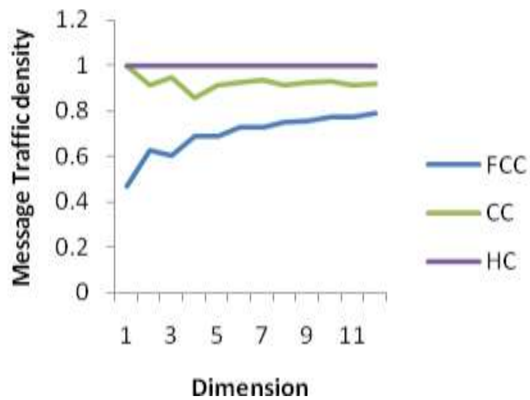


Figure 7: Message Traffic Density Comparison

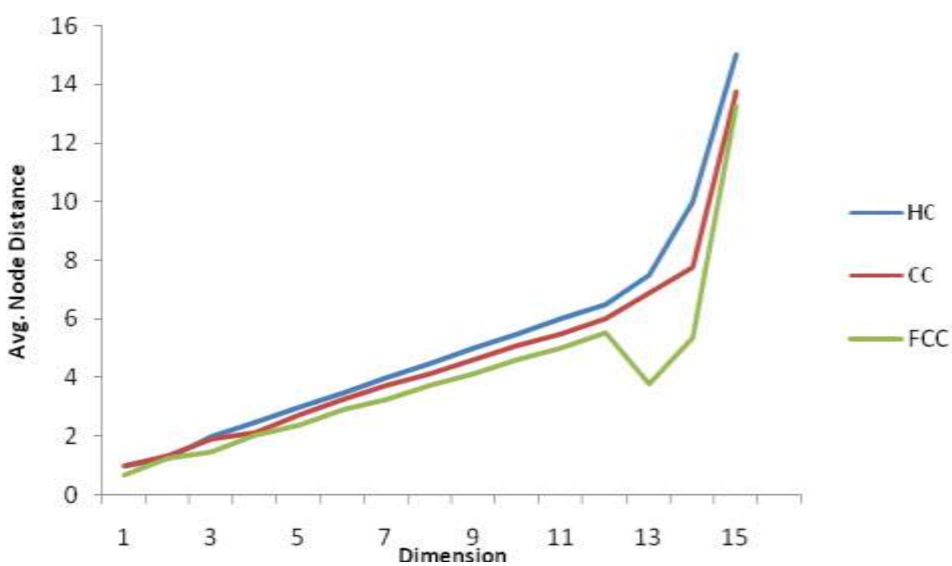


Figure 8 : Comparison of Avg. Node Distance

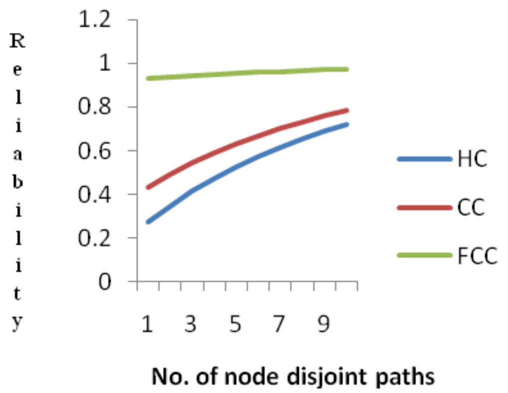


Figure 9: Comparison of two terminal reliability

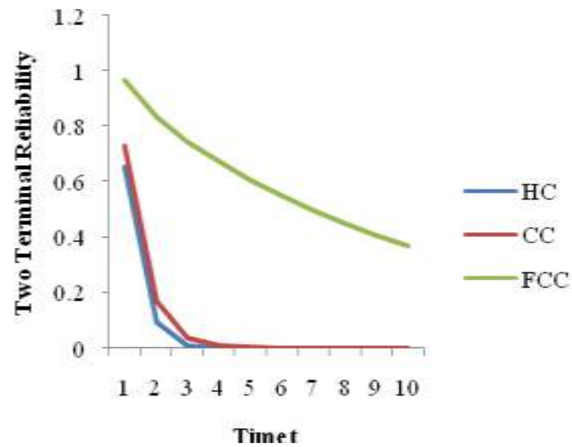


Figure 10: Variation of Reliability with Time

7. CONCLUSION

A new hybrid type, fault tolerant interconnection network for parallel systems called Folded Crossed cube has been proposed in this paper. The various topological properties of the proposed topology have been analyzed and evaluated. When the degree is n, the crossed cube is a very good architecture. But when the degree is (n+1), the Folded Crossed cube has been shown to be superior over the hypercube and crossed cube. With reduced diameter, better average distance, lesser message traffic density, lower cost makes the proposed network more suitable for parallel systems. In performance evaluation also the FCC network possesses better fault tolerance, high reliability with reduced cost.

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