Extended Crossed cube: A New Fault Tolerant Interconnection Network

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Abstract: *This paper introduces a new fault tolerant interconnection topology called the Extended crossed cube (ECC). The proposed topology is hierarchical, expansive and recursive in nature. It has reduced diameter, average distance and constant degree of nodes. The paper illustrates various other properties of the proposed system, such as fault-tolerance, reliability, message traffic density, cost, cost effectiveness factor and time-cost-effectiveness factor. The various performance metrics show that the proposed topology is a better candidate for parallel processing than its predecessors. The optimal routing and broadcasting algorithms for the new network are also presented.*

Keywords: *Cost effectiveness, Fault tolerance, Interconnection topology, Message traffic density, Reliability,*

I. Introduction

In recent years, there has been considerable interest and increased efforts in developing massive parallel super computing systems. In parallel systems the interconnection topology plays an important role [1, 2]. Among all topologies Hypercube is one of the most versatile networks and has received much attention due to many of its attractive properties including regularity, symmetry, small diameter, strong connectivity, recursive construction, partition ability and relatively small link complexity [3]. Variations of this basic topology have been proposed in the literature to further enhance some of its features [4-6]. They include the Folded Hypercube [7], the Twisted cube [8], the Banyan Hypercube [2] and the Cube Connected Cycles [9].

The Crossed cube (CC) has smaller diameter than the hypercube [10,11]. Also, the mean distance between vertices is shorter than that of the hypercube. Another high performance –low cost architecture called the Incomplete crossed hypercube CI^{n}_{n-m} is constructed by combining two crossed hypercubes CQ_n and CQ_{n-m} for $1 \leq m \leq n$ [12]. It has shorter mean inter node distance for large n. It is more useful than other incomplete networks. Unfortunately it is not a symmetric network. The Folded crossed hypercube (FCCn) is a hybrid hypercube type structure constructed from a varietal cube, by only adding the new edges (u,v) with un-1…u1u0 = $v'_{n-1}..v'_1v'_0$ for $0 \leq u \leq (2^n - 1)$ [13]. Another variation of the Crossed cube called the Folded Crossed cube (FCC) is introduced [14].

The Extended hypercube (EH) is a hierarchical, expansive recursive structure which retains the positive features of the k-cube at different levels of hierarchy [15]. With the use of network controllers it has better routing properties. It has reduced diameter and average distance. In the Varietal hypercube the diameter is about two third of the diameter of the hypercube [16]. So, the cost of the network is reduced. Another variation of EVH is Extended varietal hypercube with crossed connections (EVHC) [17]. The link complexity of this network is quite high.

However, the analysis of reliability, fault tolerance, and other performance parameters such as cost, cost-effectiveness, time-cost-effectiveness are some of the important aspects which need to be addressed in the design of any interconnection architecture [18,19]. This demand motivates the current study to propose a new hierarchical fault-tolerant network called Extended crossed cube (ECC).

The proposed topology exploits most of the attractive features of EH and CC. The proposed topology exploits most of the attractive features of EH and CC. This paper is organized as follows. The Section 2 presents topological features of the ECC. In Section 3 the message routing and broadcasting issues are discussed. The various Performance parameters are evaluated in Section 4. Results are presented in section 5. The Section 6 concludes the paper.

II. Proposed Interconnection Network

2.1 Extended Crossed cube

The proposed interconnection topology is an undirected graph in which vertices correspond to the processing elements and edges correspond to the bidirectional links of the interconnection network. The new topology inherits some of the important properties of Crossed cube and Extended hypercube. The Fig.1 illustrates the CC topology.

2.1.1 Construction

The k-dimensional Extended crossed cube is a hierarchical structure having different labels. It can be defined as ECC (*k*, *l*) a labeled graph which can be constructed recursively with two special types of vertices called Network Controller (NC) and Processing Elements (PE) as shown in Fig. 2. The PEs perform computational task where as NCs are responsible for communication task.

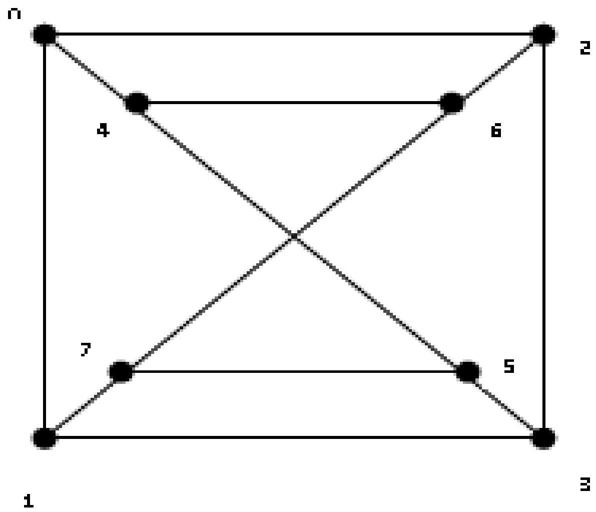

Fig 1: Crossed cube of dimension 3 CC3

The NC is placed at the top, which is at the highest level and PEs at the 0th level. The basic module ECC (k,1) consist of k-dimensional CC with one NC, has some level of hierarchy. The NC at the first level and the k-CC at the 0th level is shown in Fig 2. In addition, there is k-CC of 2^k NCs at the (l-1)th level. Again it can be seen that 2k NCs form a k crossed cube at the (l-1)th level. Any ECC(k,l) can be recursively built from the basic module ECC(k,1).

As for example, the NCs of each ECC(k,2) can be built from ECC(k,1) and this procedure can be repeated hierarchically to build the required size of ECC. The Fig. 3 shows ECC(3,2) built from eight numbers of ECC(3,1)s. The inner side node addresses are not shown for clarity. The NC's at the (l-1)th level of ECC(k,1) are addressed by 0.The k-CC at the lth level consisting of 2k NCs have address as 00,01….0M,where M=2k-1,The address of the NC precedes the node address of PEs. Thus the PEs connected to the NC's 0i(0 ≤i ≤m) have addresses 0i0,0i1,…0iM as shown in the Fig. 3.

In an ECC, the NCs are used as the communication processor for transferring messages globally between different levels and also for local communication between two different basic modules. However, the NCs are not used for the communication between two nodes of the same basic module. There are (k+1) parallel paths between any two nodes of the ECC(k,l) , k-path contributed by the k-edges of CC and one path due to the NC.

2.2 Topological Properties

2.2.1 Degree

In an ECC (k,l) each PE is directly connected to K neighboring PEs of the same k-CC and to a NC at the next higher level. But for a NC, where NC is connected to 2k NCs at its just lower level , k- NCs at its next higher level. Therefore, the degree of a NC other than the top most NC is (2k+k+1).

2.2.2 Diameter

The diameter is the maximum distance between the nodes of the network. Also it gives an indication about the maximum separation between two nodes under the fault free condition.
For an efficient and cost effective communication, a lower value of diameter is preferable.

Theorem 1.

The diameter of ECC (k,l) denoted by D(G) is $\left\lceil\frac{k+1}{2}\right\rceil + 2(l-1)$.

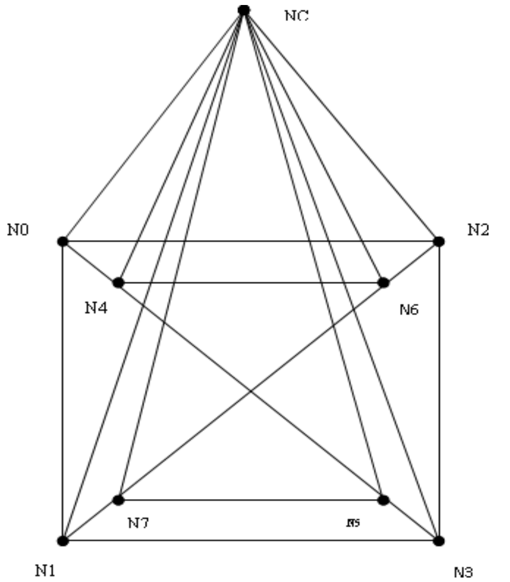

Fig 2: Extended Crossed cube ECC(3,1)

Proof:
In ECC (k,l) ,the most distant nodes require two (l-1) loops between source destination PEs and NC and the diameter of CCk is $\left\lceil\frac{k+1}{2}\right\rceil$. So, the diameter of ECC (k,l) is

D(G)= $\left\lceil\frac{k+1}{2}\right\rceil + 2(l-1)$ □

2.2.3 Cost

Theorem 2.
The cost of the ECC network is given by

Proof:
The cost of a Cube based network is given by the product of the node degree and the diameter. In an ECC network the degree of PEs and the NCs are different. The average degree of a node is

Davg = $\frac{(k+1)*2^{kl}+(2^k+k+1)\left(\frac{2^{kl}-1}{2^k-1}\right)}{2^{kl}+(2^k+k+1)(2^{kl}-1)}$

and the diameter is

D(G)= $\left\lceil k+\frac{1}{2}\right\rceil + 2(l-1)$

Hence the cost is given by

C= $\frac{\left\lceil k+\frac{1}{2}\right\rceil+2(l-1)(k+1)*2^{kl}+(2^k+k+1)\left(\frac{2^{kl}-1}{2^k-1}\right)}{2^{kl}+(2^k+k+1)(2^{kl}-1)}$

2.2.4 Average distance

The average distance conveys the actual performance of the network. The summation of distances of all nodes from a given node over the total number of nodes gives the average distance of the network. In ECC there exist two types of communication namely local and global. Therefore, there are two average distances : local average distance and global average distance.

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2.2.4.1 Local average distance

Theorem 3.

The local average distance of the ECC(k,l) is given by $\bar{d}_k = \frac{11x+4y}{8}$, where k=3x+y, y<3 and x, y are integer values.

Proof:

In the ECC(k,l) network the lower level is a Crossed cube. So, the average distance in the basic module is same as that of the Crossed cube and it is $\bar{d}_k = \frac{11x+4y}{8}$, where k=3x+y, y<3 and x, y are integer values [11].

2.2.4.2 Global Average distance

The global average distance of the ECC network is given by

$$C= \frac{\left(\left\lceil\frac{k+1}{2}\right\rceil * 2(l-1)\right) * (k+1) * 2^{kl} + (2^k+k+1)\left(\frac{2^{kl}-1}{2^k-1}\right)}{2^{kl}+(2^k+k+1)(2^{kl}-1)}$$

$d' = \frac{\sum d\, N_d}{N+M}$, where N= 2^{kl} and M= $\frac{2^{kl}-1}{2^k-1}$

and Nd is the number of processors at a distance d from the source node. N is the total number of PEs and M is the total number of NCs. The global average distance is dependent on the degree of ECC and increases with it.

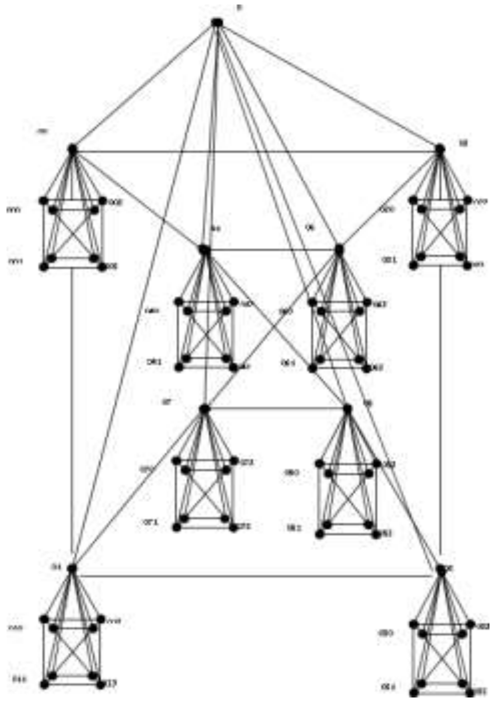

Fig 3: Extended crossed cube, ECC(3,2)

2.2.5 Nodes

The total number of nodes in ECC (k,l) denoted by p is given by $2^{kl} + \frac{2^{kl}-1}{2^k-1}$.

2.2.6 Links

The total number of links in an ECC network is given by

$$E = 2^k\left(\frac{k}{2}+1\right) \times 2^{k(l-1)}\left(\frac{1-2^{-kl}}{1-2^{-k}}\right)$$

2.2.7 Message Traffic Density

The message traffic density of ECC is given by

$$\rho = \frac{\bar{d} N_t}{E},$$

where *E* is the total number of links. Assuming that each node is sending one message to a node at distance $\bar{d}$ on the average and considering the availability of n links to accommodate such a traffic, ρ can be a good measure to estimate the message traffic in the network. N_t is the total number of nodes consisting of the PEs and the NCs.

2.2.8 Extensibility

The ECC is hierarchical in nature and can be built by extension of the number of levels without affecting the basic structure. The most important advantage of this property is that degree of a node remains the same independent of the total number of nodes and hence allows for further expansion. Thus, the ECC architecture is well suited for hierarchical expansion of multicomputer system.

III. Routing and Broadcasting

In multicomputer systems, for message communication, processors exchange message efficiently and reliably. For communication, two important concepts are popular: routing and broadcasting. An optimal routing algorithm finds the shortest path between two communicating nodes.

3.1. Routing

The use of NC categorizes the inter-processor communication into two sub modules namely the local communication and the global communication [15]. Communication among the PEs belonging to the same k-CC is classified as local communication. Communications between the PEs of different basic modules via the network controller is called the global communication.

For local communication, the message is routed within the same CC without going to the NC and this can be done by the routing algorithm for a k-CC following the approach [11]. This approach is better than the look up table approach [10]. The algorithm always finds a shortest path between source and destination nodes in O(n) time. Where as in the global communication the NCs are involved. The topmost NC transmits the message from source to destination PEs via the network of NCs. The message passing operation in the global communication involves i) the source PE, ii) up to 2(l-1) NCs and iii) the destination PE.

The transfer of message between two nodes at different levels of hierarchy is referred to as the vertical shift [10]. The routing in ECC involves two vertical shifts for level to level communication and a cube shift for movement in the crossed cube. The algorithm first checks whether it is a local communication or a global one. The message routing for different source and destination pairs has been given for illustration in Table 1.

The following procedure describes the routing procedure. Let u be the source node with node address $D_l^s D_{l-1}^s D_{l-2}^s \dots D_0^s$, and v be the destination node with node address $D_l^d D_{l-1}^d D_{l-2}^d \dots D_0^d$.

TABLE 1. MESSAGE ROUTING SEQUENCE

Distance	Destination	Routing Sequence From 043
1	041	043-041
2	040	043-041-040
3	060	043-04-06-060
4	021	043-04-0-02-021

The procedure for routing a message from the host system to a PE involves a vertical shift from D_l^s to $D_l^d D_{l-1}^d D_{l-2}^d \dots D_0^d$ via $D_l^d D_{l-1}^d$, $D_l^d D_{l-1}^d D_{l-2}^d$, $D_l^d D_{l-1}^d \dots D_1^d$, where $D_l^s = D_l^d$ (as illustrated in Table 1).

An algorithm is proposed below for message routing.

Algorithm: msgrouting(u,v)
begin
if $[D_l^s \dots D_0^s] = [D_l^d \dots D_0^d]$
then destination is source; terminate.
else set j=0;
while j=0
do for i=1 to l
begin
if $D_{l-i}^s = D_{l-i}^d$ then j=I;
end
begin

vertical shift from $D_l^s D_{l-1}^s D_{l-2}^s \dots D_0^s$ to $D_l^d D_{l-1}^d D_{l-2}^d .. D_j^d$;

cube shift from $D_l^s D_{l-1}^s .. D_j^s$ to $D_l^d D_{l-1}^d D_{l-2}^d \dots D_j^d$;

vertical shift from $D_l^d D_{l-1}^d \dots D_j^d$ to $D_l^d \dots D_0^d$;

end

end

3.2. Broadcasting

There can be two broadcasting options in ECC networks namely up and down broadcasting. Up broadcast is concerned with the message transfer in the upward direction starting at the lowest level containing the PEs. As the process proceeds after two upward shifts, down broadcast becomes effective and distributes the message in downward direction. However for message transfer within the same module at which the message originates, the algorithm of [11] is followed.

IV. Performance Evaluation

4.1 Fault Tolerance

In parallel computing environment fault tolerance of a network is an important metric. 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 [20], 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 any symmetric interconnection networks, the connectivity is equal to the node degree. For the ECC network which is a hierarchical network of k- crossed cubes with all processing elements at the lowest level and all communication processors at the highest level the node degree is (*k+1*). So ECC can tolerate up to *k* faults.

4.2 Fault Diameter

The Fault diameter impacts the diameter when fault occurs, due to removal of nodes from the network [21]. 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 4.

For, the ECC(k,l) network the fault diameter is df = $\left\lceil \frac{k+1}{2} \right\rceil + 2l - 1$

Proof:

The diameter of ECC (k, l) is. $\left\lceil \frac{k+1}{2} \right\rceil + 2(l-1)$. When a message travels from the source PE to the NC at next higher level, then a faulty link among PEs does not affect it. But if it travels through the faulty links, then the message is routed through another PE to reach the NC. Thus, the diameter increases by unity. So the fault diameter becomes

df = $\left\lceil \frac{k+1}{2} \right\rceil + 2(l-1) + 1$ = $\left\lceil \frac{k+1}{2} \right\rceil + 2l - 1$

4.3 Reliability

Reliability is an important performance parameter of any network. Two reliability measures are of particular interest: i) Terminal Reliability and ii) Broadcast Reliability [22]. The current paper concentrates on the approximate terminal reliability evaluation only. Terminal Reliability (TR) is generally used as a measure of the robustness of communication network. It is the probability of the existence of at least one fault free path between a designated pair of input and output terminals. In ECC being a directed graph, the vertices and edges are weighted with reliabilities of the components they represent. This graph can be used to formulate TR expression between the source and destination pairs. Since ECC involves two different kinds of communications namely local and global, its reliability analysis must take into consideration these two issues.

4.3.1 Reliability Analysis in Local Communication

Two nodes A and B are considered with n number of node disjoint paths lying between them. Let ri be the number of links involved in path i, where $1 \lneq \lneq n$. Thus, there are ri-1 number of nodes in path i. Let P(Ei) be the probability of successful route through the ith path. Then
Rl be the link reliability, which is calculated from link failure rate and
Rn be the node reliability, which is calculated from processor failure rate
Theorem 5.

For an ECC the two terminal reliability in local communication 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(Ei)= $R_l^{r_i} R_n^{r_i-1}$

So, TR= P($E_1 \cup E_1 \cup E_1 \cup E_1 \cup E_1$

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

□

5.3.2 Reliability Analysis in Global Communication

Theorem 6.

For an ECC network, the two terminal reliability in global communication is given by TR= $R_l^s R_n^t$

Proof:

Since the NC in an ECC network is the only means for level to level communication, there exists only one node-disjoint path with s number of links and 't' number of nodes for global communication. Thus, the path between any two PEs has the lowest reliability and it can be given by

$TR= 1-(1-R_l^s R_l^t) = R_l^s R_l^t.$

4.4 Cost Effectiveness Factor

The success of any parallel algorithm design relies on two measures namely: cost effectiveness and time-cost effectiveness [23]. The cost effectiveness of a parallel algorithm considers not only the cost of the processors but also the cost of communication links. It takes into account the cost of the entire multiprocessor as well as the processor utilization by the parallel algorithm.

Theorem 7.

The cost effectiveness of ECC(k,l) is derived as $CEF(p)=\frac{1}{1+\rho\left(1-\frac{1}{p}\right)\left(\frac{k}{2}+1\right)}$.

Proof:

In general the number of links is a function of the number of nodes that is E= f(p).

The total number of processors is given by

$$p = 2^{kl} + \frac{2^{kl}-1}{2^k-1}$$

And the total number of links in ECC is

$$E= 2^k * \left(\frac{k}{2}+1\right) * 2^{k(l-1)} \left(\frac{1-2^{-kl}}{1-2^{-k}}\right)$$

$$= (p-1)\left(\frac{k}{2}+1\right)$$

So,

$$g(p)= f(p)/p= \left(1-\frac{1}{p}\right)\left(\frac{k}{2}+1\right)$$

Where g(p) is the ratio of number of links to the number of processors and ρ is the ratio of link cost to the processor cost.

$$CEF(p) =\frac{1}{1+\rho g(p)} = \frac{1}{1+\rho\left(1-\frac{1}{p}\right)\left(\frac{k}{2}+1\right)}$$

4.5 Time Cost Effectiveness Factor □

This measure takes into account the time for solution of a problem as a parameter. The TCEF considers that a delayed solution is not at all beneficial. Rather a faster solution is more rewarding. For ECC the TCEF is formulated as follows:

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

Where T1 is the time required to solve the problem by a single processor using a fastest sequential algorithm. Tp 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. For tabulation α and σ are taken as 1.

V. Results and Discussions

The diameter of ECC is compared with that of HC, EH and EVH [18]. The result is shown in Fig. 4. The ECC is found to have least diameter.

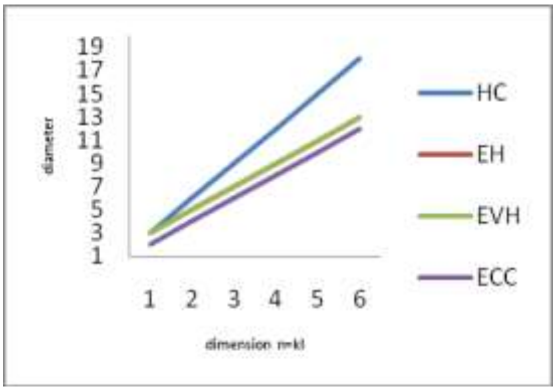

Fig 4: Comparison of Diameter

Fig. 5 shows the comparison of cost of the ECC network with that of the EH and the EVH network. It is observed that the cost of ECC is the least.

Various parameters of ECC(k=3,l) are evaluated for different values of l and listed in Table 2. The parameters include number of PEs, NCs, links, cost, average distance and message traffic density and global reliability.

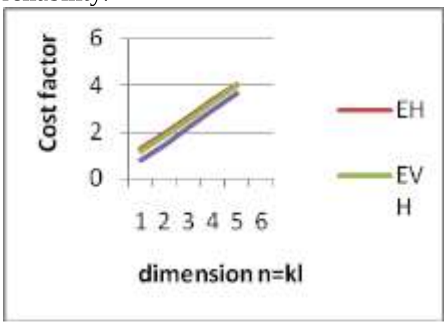

Fig 5: Comparison of Cost

Level (*l*)	1	2	3	4	5
Number of PEs	8	64	512	4096	32768
Dimension	3	6	9	12	15
No. of NCs	1	9	73	585	4681
No. of Links	20	180	1460	11700	93620
Cost	0.7826	1.4632	2.78	2.9	3.626
Average Distance	1.5	3.2	4.23	5.25	6.26
Diameter	2	4	6	8	10
Fault Diameter	3	5	7	9	11
Msg. Traffic Density	0.675	1.297	1.694	2.1004	2.504
Reliability(G)	0.36059	0.1970	0.006338	0.00084	0.000111

TABLE 2. PARAMETERS OF ECC**(**k=3,l**)**

In Table 3 and 4 the computed values of CEF and TCEF of ECC*(k=3,l)* are shown. Fig. 6 shows the variation of cost effectiveness with respect to network dimension. It is monotonically decreasing function of *p* that is the total number of nodes like the Hypercube. Thus, when the size of the network grows it becomes less and less cost effective.

Table 3. Cost effectiveness factor of ecc(k=3,l)

ρ / *l*	0.1	0.2	0.3	0.4
1	0.81818	0.6923	0.6	0.52941
2	0.66819	0.5017	0.4016	0.3348
3	0.5715	0.40136	0.3078	0.25106
4	0.50001	0.333345	0.25001	0.2
5	0.44444	0.285715	0.21052	0.16667
6	0.4	0.25	0.181	0.1428
7	0.362	0.21	0.15	0.12
8	0.33	0.2	0.143	0.11
9	0.3	0.18	0.12	0.1
10	0.2856	0.16	0.11	0.09

TABLE 4. TIME COST-EFFECTIVE FACTOR OF ECC(K=3,L)

ρ / *l*	0.1	0.2	0.3	0.4
1	1.7647	1.73077	1.69811	1.66666
2	1.32426	0.99658	0.798905	0.666666

3	1.5983606	1.33257	1.14257	1
4	1.599	1.3323	1.14282	1
5	1.5997	1.3333	1.14285	1
6	1.5999	1.3333	1.14286	1

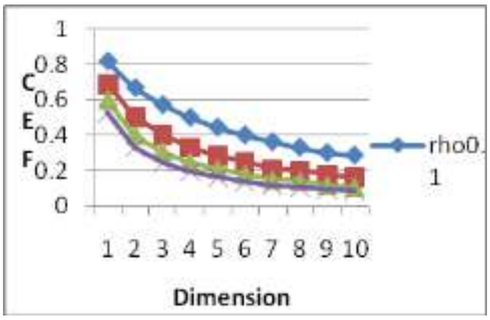

Fig 6: Comparison of CEF

The Fig.7 below shows the comparison of TCEF for the *ECC(k,l)* network. The graph shows that the

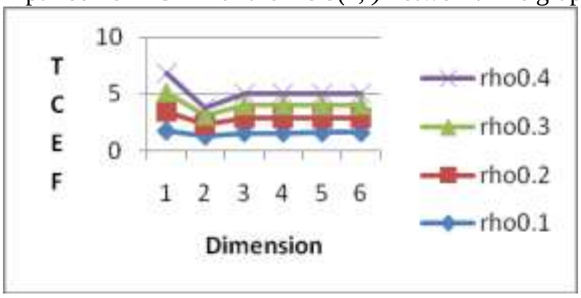

Fig 7: Comparison of TCEF

VI. Conclusions

A new fault-tolerant interconnection network topology called the Extended crossed cube has been proposed in the current work. It is a recursive, hierarchical structure with well defined basic modules that is a crossed cube. The proposed network is observed to perform well in terms of fault tolerance, reliability, cost, cost-effectiveness and time-cost- effectiveness factors. The various topological properties of the proposed network are analyzed and evaluated. The detail study reveals that the new proposed network is quite cost effective, reliable and fault tolerant.

References

[1]. Bhuyan L N and Agrawal D P. "Performance of Multiprocessor Interconnection Network"; IEEE Computers, 1989.
[2]. Feng T., "A survey Of Interconnection Networks"; IEEE Computers, 1981,1(4): 12-27.
[3]. Saad Y and Schultz M H., "Topological Properties of Hypercube"; IEEE Transactions on Computers, 1988, vol. 37 no. 7: 867-872.
[4]. Tripathy C R. "Star-cube: A New Fault Tolerant Interconnection Topology For Massively Parallel Systems"; IE(I) Journal, ETE Div., Jan 2004,vol.84, no 2: 83- 92.
[5]. Adhikari N and Tripathy C R., "Folded Dualcube: A New Interconnection for Parallel Systems"; Proceedings of 11th IEEE Int. Conf. on Information Technology, 17-18Dec 2008, pp.75-78.
[6]. Peter K. K. Loh, Wen Jing Hsu, and Yi Pan, "The Exchanged Hyper Cube", IEEE Transactions on Parallel and Distributed Systems, Sept. 2005, 16(9): 866-874.
[7]. Ahmed EI-Amawy and Shahram Latifi. "Properties and Performance of Folded Hypercubes", IEEE Transactions on Parallel and Distributed Systems, Jan-1991, 2(1): 31-42.
[8]. Efe Kemal. "Programming the Twisted Cube Architectures"; Proc. of 9th IEEE Int. Conf. DCS June 1989, pp. 254-262.
[9]. Preparta F P and Vullemin J., "The Cube Connected Cycles: A Versatile Network for Parallel Computation"; Communication ACM, May-1981, 24(5):300-309.
[10]. Efe Kemal, "The Crossed Cube Architecture For Parallel Computation"; IEEE Tran. On Parallel and Distributed Systems, Sept 1992, 3(5): 513-524.
[11]. Chang C P, Sung T Y and Hsu L H. Edge "Congestion and Topological Properties of Crossed Cube", IEEE Trans. on Parallel and Distributed Processing, Jan-2000, 11(1):64-80.
[12]. Zhang Yan-Qing and Pan Yi., "Incomplete Crossed Hypercubes", Journal of Supercomputing, Springer Science, 2009, 49(9): 318-333.
[13]. Zhang Y Q., "Folded-crossed hypercube: A Complete Interconnection Network"; Journal of System Architecture, 2002, 47: 917-922.

[14]. Adhikari N and Tripathy C R., “The Folded crossed cube: A New Interconnection Network for Parallel Systems”; International Journal of Computer Applications, July 2010,4(3): 43-50.

[15]. Kumar J M and Pattnaik L M., “Extended Hypercube: A Hierarchical Interconnection Network of Hypercubes”. IEEE Transactions on Parallel and Disrtibuted Systems, Jan-1992, 3(1): 44-57.

[16]. Cheng Shou-Yi and Chuang Jen-Hui. , “Varietal Hypercube- A New Interconnection Network Topology for Large Scale Parallel Computer”, Proc. of Inc. Conf. on Parallel and Distributed System, IEEE Comp. Soc. Press, Dec 19-21, 1994, pp.703-708.

[17]. Mohanty S P, Ray B N B, Patro S N ,and Tripathy A R. “Topological Properties of A New Fault Tolerant Interconnection Network for Parallel Computers”; Proceedings of IEEE Int. Conf. on Information Technology, ICIT Dec 2008, pp.36-40.

[18]. Tripathy C R and Dash R K., “A New Fault-tolerant Interconnection Topology For Parallel Systems” ; IE(I) Journal CP, 2008,89: 8-13.

[19]. Tripathy C R and Dash R K. , “Extended Varietal Hypercube – A Fault Tolerant Interconnection Topology For Parallel Systems”; Proceeding of Eight Int. Conf. on Information Technology, Dec 20-23, 2005, pp. 214-219.

[20]. Avizienis A.; “Fault Tolerant System”; IEEE Transactions on Computers, 1976, 25(12):1304-1312.

[21]. Latifi S. , “On The Fault Diameter of Star Graphs”; Information Processing Letters, 1993, 46:143-150.

[22]. Varma Arjun and Raghavendra C S., “Reliability Analysis of Redundant- Path Interconnection Networks”; IEEE Transactions on Reliability, April 1989, 38(1):130-138.

[23]. Sarkar D. , “Cost and Time Cost Effectiveness of Multiprocessing”; IEEE Transaction on Parallel and Distributed Systems, June 1993, 5(4): 704-712.

