According to the properties of Small -world network, even only with the local information, we can find the shortest path. The advantages of Small-World should be considered to optimize the performance of network while designing a Small-World based topology. According to the nature of the Small-World networks, we propose a new method to design a NoC topology for a specific application. As the two basic principles of Small- World are clusters and shortcuts, we take both the cluster and long-rang links into consideration. We divide the nodes into clusters, and insert long-range links between remotely communicating clusters. We name this method as "Cluster Based Long-range Links Insertion Algorithm".

3. Cluster Based Long-Range Links Insertion Algorithm

A. Background

The basic topology is m = n 2Dmesh, as shown in Fig. 1(a). The nodes communicate with each other through the network. The process of designing a topology is shown in Fig.3. Firstly we get the communication graph. We compare the traffic volumes between the nodes, making the nodes whose traffic volumes distinctly larger a cluster. Then we insert the long links between two distant clusters.

Figure 3: Flow chart of insertion algorithm

A cluster can be composed of several cluster units. Usually we define 4 nodes or 9 nodes as a unit cluster, just as Fig. 2 shows. We define the 2*2 unit cluster as even unit cluster and 3*3 unit cluster as odd unit cluster. The diagonal links are inserted to optimize the performance within a cluster. A network is composed of several clusters. For a large scale of networks, we can regard a small cluster as a node. In other words, a network can be made up of several clusters which are also composed of several low level clusters. The relationship between clusters in different levels is the iterative relationship.

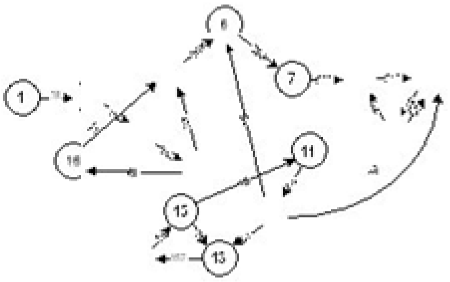
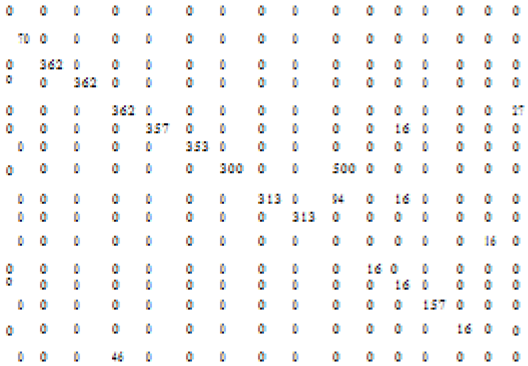


Figure 4: VOPD

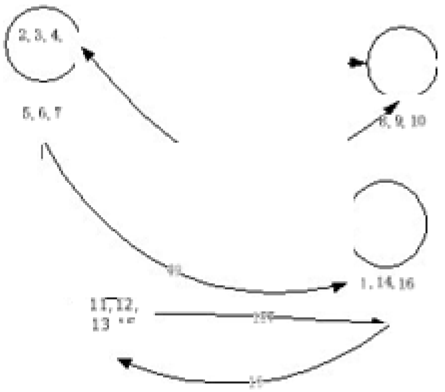


0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	362	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	362	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	362	0	0	0	0	0	0	0	0	0	0	0	27
0	0	0	0	357	0	0	0	0	0	0	16	0	0	0	0
0	0	0	0	0	353	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	300	0	0	500	0	0	0	0	0	0
0	0	0	0	0	0	0	313	0	94	0	16	0	0	0	0
0	0	0	0	0	0	0	0	313	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	157	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	0

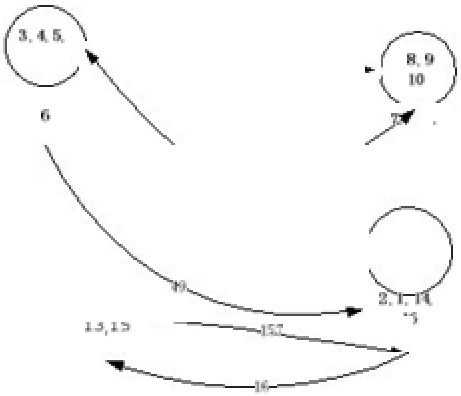
Figure 5: Traffic matrix

Table 1: The Nodes Division

>350	2→3→4→5→6→7,10→8
300-350	7→8→9→10
100-200	13→14
0-100	1→2,4→16→5,12→6,10→9,12→9, 11→12→13→15,14→15→11



(a) The Primary Partition



(b) The Final Result

Figure 6: The Partition of Nodes

B. The Partition of Clusters

For a specific application, we divide the nodes into 4 global clusters according to the traffic volumes and physical distance. For example, Fig. 4 is a communicating core graph of VOPD. To divide the nodes into four global clusters, first we get the traffic matrix as shown in Fig.5, then we draw a communication distribution according to the matrix, as shown in TABLE I. We make the first and second group as two clusters. Then we continue to divide the remaining nodes into clusters. For the VOPD application, the primary result is shown in Fig. 6 (a). Finally we adjust the results to make the partition as simple and regular as possible. The final result is shown in Fig.6 (b). To avoid congestion, we should also take the communication relationship into consideration. The mapping result is shown in Fig. 7. For an application, as long as we divide the nodes according to the traffic volumes, the result is reliable. Fig. 8 is a probable mapping result of 25 nodes; two odd clusters have a common node. Since appropriate partition and mapping can help to avoid link congestion and reduce latency and power consumption, the partition of clusters and mapping is very important

C. Long-Range Links Insertion Algorithm

After mapping, we insert the long-range links between the remotely communicating clusters. To minimize the number of the long-range links inserted into the topology, firstly, we have to confirm which nodes to insert the long-range links. When choosing the nodes to insert the long-range links, we should take the acceptable length of long links into consideration. At the same time, if possible, the long-range links should be inserted into different nodes. Furthermore, we choose the nodes which have large traffic volumes with the remote clusters. Usually there is a need to insert long-range links between the diagonal clusters. Fig. 9 shows several results of long-range links insertion. The diameter of the network and the hops of the packets traveling from one cluster to the remote cluster have been reduced. As a result, the latency and power consumption also have been greatly reduced.

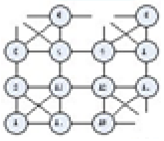


Figure7: Mapping result of 4 x 4 2D mesh

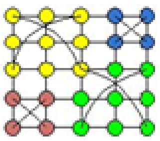
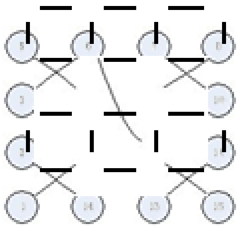
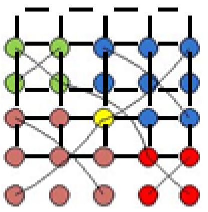


Figure 8: Mapping result of the 5x5 2D mesh



(a) 4 x 4 2D mesh



(b) 5 x 5 2D mesh

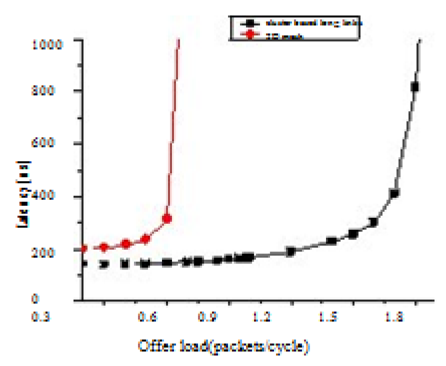
Figure 9: Topologies with Long-Range Links

4. Routing Algorithm with Long-Range Links

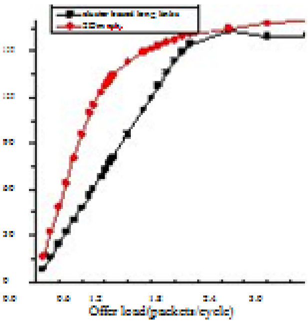
The topologies with long-range links usually adopt deadlock free routing algorithm. We can also enumerate all the possible paths [3]. In this paper, to avoid deadlock [8], we utilize the deadlock detection and recovery mechanism. The routing strategy proposed in this paper is based on the XY dimension -order routing algorithm. First we define the 4 clusters as 4 quadrants and name them with numbers (1 to 4). Within a cluster, the lower level clusters are also named as numbers according to the interior quadrants. As a result, the bottom quadrants of the unit clusters (level n) are named by n-dimension numbers. So the address of the nodes can be expressed as q_1, q_2,, q_n, x, y, x, y is the coordinate in bottom cluster which represents the address of the node in bottom cluster, q_1, q_2,..., q_n is the address of the bottom cluster, n is the depth of the cluster. When the packet arrives, we get the local and destination address. The comparison begins from the global quadrant number, that means, first we compare the two q_1. If local q_1 and destination q_1 are same which means the local node and destination node are in the same global cluster, we continue to compare q_2, and this work continues until local q_i and destination q_i are different. If q_1, q_2,, q_n are all same, local node and destination node hop between nodes while in this topology, to see from level i which means q_i is different, packets hop between clusters in level i. We regard the clusters in level i as nodes. Through default routing algorithm (the XY dimension-order routing algorithm extended with long- rang links), we get the path in level i. To arrive the expected nodes along the path in level i, we have to consider from level i − 1. In lower levels, we the current destination is q_i we have found the path in level i, and it is a progress of iteration. When q_1, q_2,, q_n are all the same, we utilize the default routing algorithm to lead the packet to the destination. The last, we have to apply the dead lock detection and recovery mechanism to avoid dead lock.

5. Performance Analysis and Simulation

We evaluate the topology by simulating in the OPNET simulation platform. We observe the delay, throughput and energy consumption of the network. The energy consumption of the network is defined as formula (3), E_s is the energy consumption of routers, E_l is the energy consumption of links. As shown in formula (4), $E_{bit}^{i,\,j}$ is the energy consumption of transmitting one bit from router r_i to router r_j, E_t is the total energy consumption of the network, $C_{i,\,j}$ is the communication volume from router r_i to router r_j, N_r is the number of routers along the path. We compare the topology proposed in this paper with the traditional 2Dmesh with XY dimension-order routing algorithm. We simulate the application of VOPD as shown in Fig. 4 on the topology shown in Fig. 9(a). The simulation results in Fig. 10(a) show the performance of the network was optimized. The delay has been reduced while the throughput has not been changed much. For the reduction of network diameter, the hops that link. The energy consumption is also reduced.



(a) Delay



(b) Throughput

Figure 10: The Simulation Results

6. Conclusion

In this paper, we proposed new Cartesian networks based topology. This topology combines mapping and long-range links insertion, which can greatly optimize the performance of the network. So there is a high speed network transmission and efficiency is higher compared to other algorithm. Power consumption, delay and storage capacity is low, which leads to minimum chip size.

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