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Study of Structural Representation of Perfect Difference Network

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Abstract. *Discretization is a process which finds useful mathematical pattern from a set. The research in structural study has given rise to an approach to store and manipulate their given set for find relations or further design issues. This paper presents discrete structure of interconnection network (PDN), which helps to evaluating the connectivity and complexity for parallel and distributed system. The purpose of this study is to keep the geometrical, topological, fault tolerance and any other basic properties of a PDN within permissible limits at the time of designing hybrid interconnection network. The study of connectivity of interconnection network is a interactive work that involved solving or reducing the complexity of perfect difference network (PDN).*
Keywords: *Perfect Difference Network, Perfect Difference Set, Interconnection Network, Discrete Structure, Data Structure.*

I. INTRODUCTION

Discrete mathematical structure includes sets, ordered set and other structure, (tree, graph, etc…) which is used to simplify the connectivity and complexity of interconnection network. In this paper we explore the two classes to organizing the study, first is data structure and another is operations that may be performed on data structure.

II. BACKGROUND DETAILS & RELATED WORK

Perfect difference sets were first discussed in 1938 by J. Singer. The formulation was in terms of points and lines in a finite projective plane, therefore it was not at all considered so much important until it was incorporated into perfect difference network [1]. The perfect difference sets were considered a really good prospect for being developed into a network mainly through the works of Dr. Behrooz Parhami and Dr. Mikhail A.Rakov. In their paper[2] they have discussed low diameter networks, beginning with D=2, the next best value to that of the complete network, and then proceeding to somewhat larger (constant) values leading to more economical networks. They have showed that perfect difference networks (PDNs), which are based on the mathematical notion of perfect difference sets, offer a diameter of 2 in an asymptotically optimal manner. In other words, PDNs allow O(d2) nodes when nodes are of degree d, or, equivalently, have a node degree that grows as the square-root of the network size. They also showed that symmetry and rich connectivity of PDNs lead to balanced communication traffic and good fault tolerance. And finally they proved that multidimensional PDNs offer a tradeoff between cost and performance in the sense that for any constant number q of dimensions, a q-dimensional PDN has diameter D = 2q and node degree that grows as the (2q)th root of n [3]. In their yet another paper [4], they have proposed an asymptotically optimal method for connecting a set of nodes into a perfect difference network (PDN) with diameter 2, so that any node is reachable from any other node in one or two hops. They have shown that PDN interconnection scheme is optimal in the sense that it can accommodate an asymptotically maximal number of nodes with smallest possible node degree under the constraint of the network diameter being 2. They have bisection width of a PDN. They concluded that PDNs and their derivatives constitute worthy additions to the repertoire of network designers and may offer additional design points that can be exploited by current and emerging technologies, including wireless and optical interconnects [4,5].In the companion paper to the above paper [3,4,5], they have compared PDNs and some of their derivatives to interconnection networks with similar cost/performance, including certain generalized hypercubes and their hierarchical variants. Additionally, they have also discussed point-to-point and collective communication algorithms and have derived a general emulation result that relates the performance of PDNs to that of complete networks as ideal benchmarks. They have shown that PDNs are quite robust, both with regard to node and link failures that can be tolerated and in terms of blandness (not having weak spots). In particular, they have proved that the fault diameter of PDNs is no greater than 4. Finally, they have studied the complexity and scalability aspects of these networks, concluding that PDNs and their derivatives allow the construction of very low diameter networks close to any arbitrary desired size and that, in many respects, PDNs offer optimal performance and fault tolerance relative to their complexity or

implementation cost [4,5,6].In the paper[5,6] some light has been thrown on the various properties of periodically regular rings and on those of swapped interconnection networks respectively, which is equally helpful in understanding the various properties of perfect difference networks and their applicability. Dr. Mahendra Gaikwad under the guidance of Dr. Rajendra Patrikar has implemented PDN in Network-on-Chip (NoC) and also purposed energy model in paper [7]. The proposed energy model is then validated against the simulation results obtained with Inter-tile link geometry and PDN circular geometry for NoC architecture. In paper [3,4] Dr. Rakesh Kumar Katare has implemented Study of Topological Property of Interconnection Networks and its Mapping to Sparse Matrix Model. In paper [3] A Comparative Study of Hypercube and Perfect Difference Network for Parallel and Distributed System and its Application to Sparse Linear System. In paper [7] Dr. Rajendra Patrikar has implemented PDN in Wireless Sensor Networks (WSN), where nodes are randomly deployed. Most of all protocols in WSN are designed for its random deployment. Projective Geometry can be used for the fixed-geometrical deployment of wireless sensor nodes. Which leads to reduces the cost and optimization of network can be achieved using Perfect Difference Set (PDS). PDN is an asymptotically optimal method for connecting a set of nodes into a Perfect Difference Network (PDN) with diameter 2, so that any node is reachable from any other node in one or two hops utmost. It is mainly based on the mathematical notion "the Perfect Difference Sets". PDNs have a diameter of 2 and a node degree of approximately 2, which place them close to complete networks in terms of routing performance and much lower with respect to implementation cost. The symmetry and rich connectivity of PDNs lead to balanced communication traffic and good fault tolerance for wired network. The rich connectivity and small diameters of PDNs and related networks make them good candidates for wireless/optical network technologies. The data delivered over a network can take different ways and passes through certain nodes in an interconnection network. This study becomes important since it affect performance, robustness, cost etc. of the network. PDN architecture has diameter = 2 based on PDS while as the diameter =3 in case of Hypercube. Therefore, the performance of PDN lies between hypercube and complete graph topologies[8,9].

III. PERFECT DIFFERENCE NETWORK

Perfect Difference Network [1][8][9] is the network architecture, in which the diameter is always 2, i.e., every node ith needs to visit only two links to communicate with other nodes $i \pm 1$ & $i \pm S_j$(mod n), for $2 \leq j \leq \delta$. In a Perfect Difference Network, the total number of nodes is $\delta^2 + \delta + 1$, i.e., if $\delta = 2$ then the total number of nodes in PDN is 7 and if $\delta = 3$, then number of nodes in PDN is 13. Also the degree of every node in a PDN is 2δ i.e., if $\delta = 2$ then degree of every node in a PDN is 4 and similarly for other prime or power of prime numbers. The design of Perfect difference network is done in such a way where each node is connected via directed links to every other node. The links in PDN architecture are bidirectional.
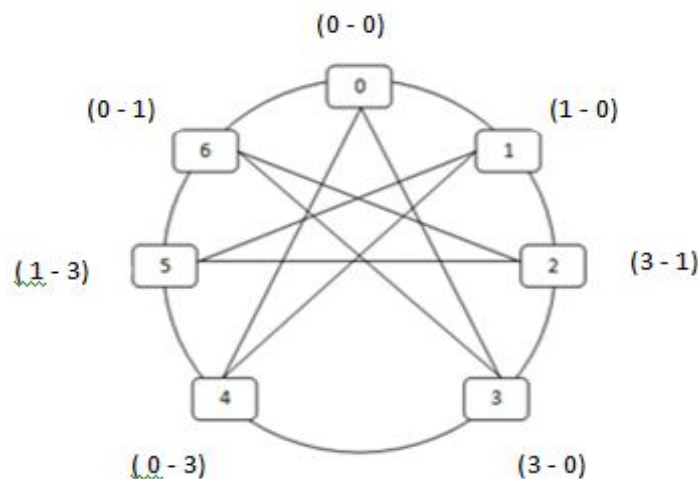

Figure 1: Geometric model of Perfect Difference Network with $\delta = 2$ and PDS = {0, 1, 3}.

IV. EXPERIMENTAL SETUP AND RESULTS

After designing the geometric model of perfect difference network we apply following algorithm[8,9]:

- $i \pm 1$
- $i \pm s_j$(mod n), for $2 \leq j \leq \delta$

on node i to split perfect difference network into another data structure(tree).

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Let Design the PDN with diameter/degree is one/direct link. By the definition of PDN it is proved that if $\delta=2$ then the total number of node are 7. A PDN with direct link has shown below:
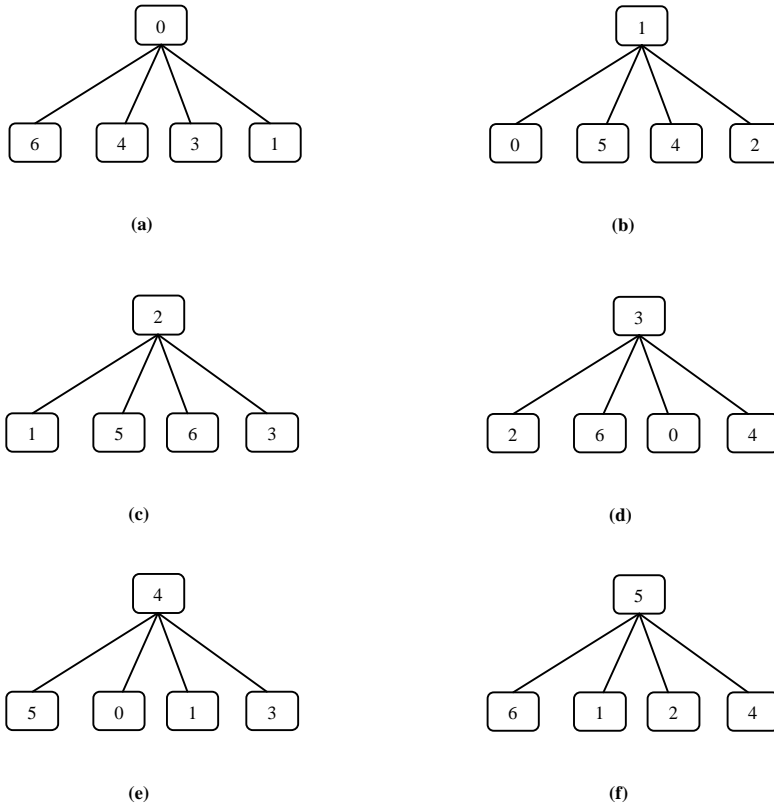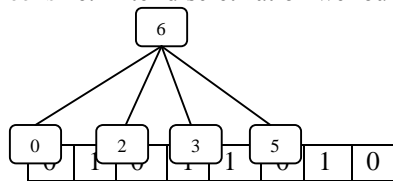Node 0

(a) **(b)**

(c) **(d)**

(e) **(f)**

Figure 2 shows the discrete structure of perfect difference network based on the direct connection (connectivity with diameter 1) and degree is 2δ. After discretization we found few subset from set $\{0,1,\ldots,\delta^2+\delta\}$.
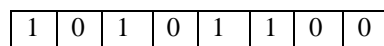
Node 0:
$n_0 =$

$P(x)=x^6+x^4+x^3+x^1$

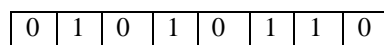**(g)**

Figure 2: Discrete Geometrical Model of PDN

Node 1:
$n_1 =$

1	0	1	0	1	1	0	0

$P(x)=x^5+x^4+x^2+x^0$

Node 2:
$n_2 =$

0	1	0	1	0	1	1	0

$P(x)=x^6+x^5+x^3+x^1$

Node 3:
$n_3 =$
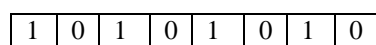
1	0	1	0	1	0	1	0

$P(x)=x^6+x^4+x^2+x^0$

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Node 4:

$n_4 =$

1	1	0	1	0	1	0	0

$P(x)=x^5+x^3+x^1+x^0$

Node 5:

$n_5 =$

0	1	1	0	1	0	1	0

$P(x)=x^6+x^4+x^2+x^1$

Node 6:

$n_6 =$

1	0	1	1	0	1	0	0

$P(x)=x^5+x^3+x^2+x^0$

The most significant way of representing a perfect difference network or set the memory is to store their elements/nodes one after the other[4]. Let us consider the problem of determining the alternate path between two nodes. Intuitively, the basic operation required for checking and verifying the connection of nodes is the comparisons of there elements. The requirement implies that each individual element of set must at some time be selected for comparison.

PDS=$\{0,1,3\}$, $\delta=2$

$N = \{0,1, \dots , \delta^2 + \delta)$

If n_k contains the ith element of N , then the ith bit of the representative bit (subset n_k) sequence will be 1; otherwise it will be a 0. Now, we can perform the set operations to find the alternate node for communication. The intersection of the sets $n_0 \wedge n_1$: 01011010 $\wedge$ 10101100 giving the bit sequence 00001000 representing $\{4\}$. Node 4 is alternate node for node 0 and node1.

Similaily, $n_0 \wedge n_2$: 01011010 $\wedge$ 01010110 = $\{1,3,6\}$

$n_0 \wedge n_3$: 01011010 $\wedge$ 10101010 = $\{4,6\}$

$n_0 \wedge n_4$: 01011010 $\wedge$ 11010100 = $\{1,3\}$

$n_0 \wedge n_5$: 01011010 $\wedge$ 01101010 = $\{1,4,6\}$

$n_0 \wedge n_6$: 01011010 $\wedge$ 10110100   = $\{3\}$

Now, the alternate node/hope of node 0 is found; that is used by communication algorithm to determine the optimal path to a destination. To aid the process of path/ node selection communication algorithm initializes and maintain route table, which contain information, mainly adjacent node, next hope, etc….

Lemma 1: All the diagonal edges continuously connected with each other in a PDN.

Proof: The connection of diagonal edge starts initially from node zero and also completes a cycle. Let us see,

In the reference of figure 1:

Node 0 is connected to node 3,

Node 3 is connected to node 6,

Node 6 is connected to node 2,

Node 2 is connected to node 5,

Node 5 is connected to node 1,

Node 1 is connected to node 4,

and node 4 is connected to node 1.

It shows that there is no disconnection between diagonal edges, due to transitive property of the diagonal edges it behave like star.

Lemma 2: The communication between nodes in a PDN is Transitive.

Proof: R is transitive if for all *x, y, z* □A, (*x, y*) □ R and

(*y, z*) □ R implies (*x, z*) □□R.

(Equivalently, for all *x, y, z* □□A, *x* R *y* and *y* R *z* implies *x* R *z*.)

Apply this property in the PDN we have, With the use of this property in the PDN has to be proved that the relation between nodes in a PDN is Transitive. In the reference of figure1 we have,

5 R 1 (Node 5 is related to Node 1) and 1 R 4 (Node 1 is related to Node 4)

=>   5 R 4 (Node 5 is related to Node 4)

5 R 2 (Node 5 is related to Node 2) and 2 R 6 (Node 2 is related to Node 6)

=>   5 R 6 (Node 5 is related to Node 6)

0 R 3 (Node 0 is related to Node 3) and 3 R 6 (Node 3 is related to Node 6)

=>   0 R 6 (Node 0 is related to Node 6)

Transitive property shows that the connection between two point occur via third point. As such the relation between nodes in a PDN is Transitive.

V. CONCLUSIONS

From the results it is clear that Perfect Difference Network is a robust, high performance interconnection network. The research in structural study has given rise to an approach to store and manipulate their given set for find relations or further design issues. This paper presents discrete structure of interconnection network (PDN), which helps to evaluating the connectivity and complexity for parallel and distributed system. In future communication algorithm and some others relation can be developed.

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