JUXTAPOSITION OF TWO STANDARD NETWORK TOPOLOGIES FOR A GENUS PROGENY

Sounak Sadhukhan
M.E Student
Department of Information Technology
Jadavpur University
Kolkata

Samar Sen Sarma
Professor
Department of Computer Science and Engineering
University of Calcutta
Kolkata

ABSTRACT

In network topology design and routing, different graph models are used; such as mesh, ring, star, Pascal graph, and hypercube graph and so on. Each of these different models has several advantages and disadvantages. simple-(q,n)-Graph, is a combination of hypercube graph and Pascal graph, gives standard measurement than other available graph models when all the parameters like degree, diameter, connectivity, reliability, expansion-contraction capability and fault tolerance has considered. But, simple-(q,n)-Graph has a major drawback in case of expansion, 2^{q+1} number of nodes would be reconfigured, if the dimension is changed from q to q+1. We propose a new graph model, is a combination of mesh and Pascal graph. Like simple-(q,n)-Graph, it gives standard measurement in case of all the parameters, but it also overcomes the drawback of simple-(q,n)-Graph and gives better result in terms of number of edges in the graph model and maximum number of edges incident in a node.

Keywords

Pascal graph, Mesh, Mesh-Pascal(a,b,n)-Graph, Uniform Pascal Graph Network (UPGN), Non-uniform Pascal Graph Network (NUPGN), Pascal Graph Network (PGN), Mesh Network (MN).

1. INTRODUCTION

In choosing a topology the goals can be divided roughly into two categories, performance and cost. On the performance side we look for an optimal combination of some parameter values; like (i) small diameter: the diameter should be small, so that the processors are likely to be able to communicate more quickly, (ii) expandability: it should be easily expandable and can produce an arbitrary large version of the network, (iii) short communication channel: if the network can be efficiently embedded in two or three dimensional space, such that all the communication channels are relatively very short, information can propagate quickly among the processing elements, (iv) redundant path: there should be exist more than one path between each pair of vertex; so, a partially defective network may continue to function.

On the cost side we look for the following; (i) minimum number of communication channel: each physical connection costs money. Thus the number of communication channels should be small, so the cost is likely to be small, (ii) fixed degree: if each processing elements are connected to a fixed number of other processing elements, then one processing element design can serve for all sizes of network. Complete graph K_n satisfies all of these properties, but it ruled out because of the expense [1]. But it is quite difficult to get such a graph model which provides best result in all of these areas.

In this paper we introduce Pascal graph and shows its properties. We have studied mesh or grid graph. We are mainly concentrating on network properties of these graphs. We propose a new graph model Mesh-Pascal(a,b,n)-Graph, is a combination of mesh and Pascal graph which gives better network phenomena compared to others. In Mesh-Pascal (a,b,n)-Graph, (a X b) is the order of mesh and n = order of Pascal graph. The properties of this proposed graph model have mixed effect from both of these graphs and it also overcomes the individual drawbacks of mesh and Pascal graph, as well as simple-(q,n)-Graph [2]. This paper is organized as: section 2 gives the knowledge of the Pascal graph and some of its properties, section 3 gives a brief description about mesh graph ICN, section 4 gives the algorithms for generating the proposed graph model and discusses about the technical aspect, section 5 gives the details of representation and addressing of nodes in this new graph model, section 6 with result and discussion, section 7 concludes the paper.

2. PASCAL GRAPH AND ITS SOME PROPERTIES

Pascal Matrix: A (n X n) symmetric binary matrix is called the Pascal matrix PM(n) of order n if its main diagonal elements are all 0's and its lower triangle (and therefore the upper also) consist of the first (n-1) rows of Pascal's triangle modulo 2 [1].

Pascal Graph: An undirected graph with n vertices corresponding to PM(n) as its adjacency matrix is called the Pascal graph PG(n) of order n [1].

Some helpful properties of Pascal graph with respect to Mesh-Pascal(a,b,n)-Graph:

a) In Pascal graph vertex V_0 is adjacent to all other vertices. Vertex V_i is adjacent to V_{i+1} in the Pascal graph for $i \geq 0$ [2].

b) Two odd numbered vertices are never been connected [2].

c) PG(n) is a sub-graph of PG(n+1) for all $n \geq 1$ [1].

d) All Pascal graph of order ≥ 3 are 2 connected [1].

e) Number of edges in the Pascal graph of order n is always $\leq (\lfloor (n-1)^{\log_2 3} \rfloor)$ [1].

f) More than one node except V_0 in Pascal graph has the special property like V_0 [3].

3. MESH GRAPH ICN

If number of chain of nodes are stacked one on top of another, so that the nodes are connected both vertically and horizontally. Then the resulting topology is called a 'grid' or a 'mesh'. Let us assume that there are N number of nodes in an ICN [4] where $N = a$ X b. Let N nodes n_0, n_1, ..., n_N are available. A Mesh or Grid is obtained by stacked '*a*' number of chains, each of which contains '*b*' number of nodes in such a way that each of nodes at the corner is connected with two nodes and the nodes at the edge are connected with three other nodes whereas each internal node is connected with four nodes.

4. THE PROPOSED GRAPH MODEL

Definition: A Mesh-Pascal(a,b,n)-Graph is a special undirected graph that contains '*a*' number of nodes along X-axis and '*b*' number of nodes along Y-axis (total *ab* number of nodes) and forms a 2D array (called Mesh Network) and $\leq 2ab$ ($2ab$ for Uniform Pascal Graph Network and $\leq 2ab$ for Non-Uniform Pascal Graph Network) number of Pascal graphs (called Pascal Graph Network) of order *n*, one along positive Z-axis and another along negative Z-axis in an effective and flexible manner.

4.1 Interconnection topology of the Mesh-Pascal(a,b,n)-Graph:

This graph model uses both Pascal graph and mesh. This graph model can be represented into two modes; one is Uniform Pascal Graph Network (UPGN) mode another is Non-uniform Pascal Graph Network (NUPGN) mode [2]. UPGN mode is special case of NPGN mode.

a) Algorithm for Uniform Pascal Graph Network mode:

Given the order of the Mesh Network (MN) and the order of the Pascal Graph Network (PGN), this algorithm computes the interconnections between these two types of graphs and generates Mesh-Pascal(a,b,n)-Graph in Uniform Pascal graph Network mode.

Algorithm_UPGN(*a*,*b*,*n*)

/* Given order of Mesh Network is (*a* X *b)* and order of Pascal Graph Network is *n*. */

Step 1: '*a*' number of chains, each of which contains '*b*' number of nodes, are stacked in such a way that each node on a chain is connected with the nodes at the same position on other chains, which are nearest neighbours of it.

Step 2: Create 2*ab* numbers of PGN of order '*n'* using Algorithm_Pascal_Generation(*n*).

Step 3: Compute special nodes (nodes which are connected to all other nodes in Pascal graph like V_0) among '*n*' nodes in PGN using Algorithm_Special_Node().

Step 4: Each node that belongs to MN is connected with the first node of two PGN in such a way that one PGN is along the positive Z-axis, another one is along the negative Z-axis and also each PGN is not connected with more than one node at MN.

Step 5: Every node that belongs to the Mesh Network is connected with one of the special node of each of those two PGN.

Step 6: Along with it each node of the MN is connected with the first node of PGN that is connected with its adjacent node at the MN in both sides.

Step 7: Stop.

b) Algorithm to construct Pascal Graph Network (PGN):

Algorithm_Pascal_Generation(*n*)

/* '*n*' is the order of the Pascal Graph Network. First we generate the adjacency matrix of Pascal graph of order n and then we generate the PGN from the adjacency matrix. */

Step 1: Consider a matrix PM[*n*,*n*]. Initialize the diagonal element with 0 and PM[*n*,1] is 1 for all $n = 2, 3, ..., n$.

Step 2: i. Repeat this step for $i = 3$ to n.

ii. Repeat this step for $j = 2$ to i-1.

PM[*i*,*j*] = PM[*i*-1,*j*-1] + PM[*i*-1,*j*];

PM[*i*,*j*] = PM[*i*,*j*] (mod 2).

Step 3: i. Repeat this step for $i = 2$ to n.

ii. Repeat this step for $j = 1$ to i-1.

PM[*j*,*i*] = PM[*i*,*j*].

After this step we can create a Pascal Matrix of order *n* contains only 0 or 1 as its element. This is the adjacency matrix for the Pascal Graph of order *n*.

Step 4: i. Repeat this step for $i = 1$ to n.

ii. Repeat this step for $j = 1$ to n.

If PM[*i*,*j*] is 1, then there exists an edge between node *i* and node *j*.

Step 5: Stop.

c) Algorithm for finding the special nodes in the Pascal Graph Network:

Algorithm_Special_Node()

Step 1: if $n = 2^{(\log_2 n)}$, then Special node $j = 2^{(\log_2 n) - 1} + 1$ where $j > 1$ [3].Return the value of *j*.

Step 2: if $n < 2^{(\lceil \log_2 n \rceil)}$, then Special node $j = 2^{(\lfloor \log_2 n \rfloor)} + 1$ where $j > 1$ [3].Return the value of *j*.

Step 3: if $n = 2^{(\lfloor \log_2 n \rfloor)} + 1$, then Special node $j_1 = 2^{(\lfloor \log_2 n \rfloor - 1)} + 1$ and $j_2 = 2^{(\lfloor \log_2 n \rfloor)} + 1$ where j_1 and $j_2 > 1$ [3]. Randomly select any value between j_1 and j_2 and return.

Step 4: Stop.

d) Algorithm for Non-Uniform Pascal Graph Network mode:

Given the order of the Mesh Network (MN) and the order of the each Pascal Graph Network (PGN), this algorithm computes interconnections between these two types of graph and generate Mesh-Pascal(a,b,n)-Graph in Non-Uniform Pascal graph Network mode.

Algorithm_NUPGN(a,b,n_1 ,n_2, ..., n_{2ab})

/* Given order of Mesh Network is (*a* X *b)* and order of Pascal Graph Networks are n_1, n_2 ..., n_{2ab}. Where $n_i = 0, 1, \ldots$ for all $i = 1,2....,2ab$.*/

Step 1: 'a' number of chains, each of which contains 'b' number of nodes, are stacked in such a way that each node on a chain is connected with the nodes at the same position on the other chains, which are nearest neighbours of it.

Step 2: Call Algorithm_Pascal_Generation(n_i) for each all i = 1, 2, ..., 2ab.

Step 3: Compute special nodes (nodes which are connected to all other nodes like V_0) for each of the PGN using Algorithm_Special_Node().

Step 4: Each node that belongs to MN is connected with the first node of two PGN (some nodes of MN may be connected with the PGN that contained 0 or 1 number of nodes), in such a way that one PGN is along the positive Z-axis, another one is along negative Z-axis and also each PGN is not connected with more than one node on MN.

Step 5: Every node that belongs to the Mesh Network is connected with one of the special node of each of those two PGN (only possible if $n_i > 1$).

Step 6: Along with it each node of the MN is connected with the first node of PGN that is connected with its adjacent node at the MN in both sides.

Step 7: Stop.

From the property of Pascal graph, we know that in a Pascal graph of order n, vertex V_0 is adjacent to all other vertices and vertex V_i is adjacent to V_{i+1} for $i \geq 0$ and we also know that more than one node except V_0 in Pascal graph have the special property like V_0 [3]. This proposed graph model is designed in such a way that, all of the properties that a good network should have, it has almost all. The proposed graph model has been suggested keeping ICN in mind. Each node of the MN connected with two PGN. Every node of the MN is not only adjacent with first node but also one of the special nodes of each of these two PGN. So, if the first node of any PGN is damaged, though that PGN would not disconnect from the main MN. This makes the model very much reliable and fault tolerant than the other graphs.

4.1 Technical aspect of the proposed graph model

a) The Uniform Pascal Graph Network (UPGN) mode:
The proposed graph model has the following properties when implemented in UPGN mode.

- The graph model has total number of nodes: $(2n + 1)ab$, where ab = number of nodes in MN and n = order of the Pascal graph.

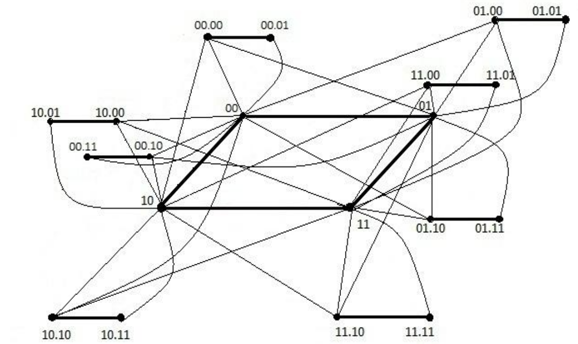


Fig 1—Mesh-Pascal(a,b,n)-Graph in UPGN mode, where a = 2, b = 2 and n = 2.

- The graph model has maximum degree:

  i. When $a = 2$, $b = 2$ and $n = 1$, then degree is 8 and if $n > 1$ then degree is MAX (10, n+2).
  ii. When $a = 2$ or $b = 2$ then degree is MAX (13, n+3).
  iii. When $a > 2$ and $b > 2$ and $n = 1$ then degree is 14 and if $n > 1$ then degree is MAX (16, n+4).

- Diameter of the graph: When $n = 0$ or $n = 1$, then diameter = (a+b–2), otherwise diameter is (a+b).

- Total number of edges:

  i. When, $a = 2$, $b > 1$and $n = 1$ then, total no. of edges = 19b-10**.**
  ii. When, $a > 1$, $b = 2$ and $n = 1$, then, total no. of edges = 19a-10.
  iii. When, $a = 2$, $b > 1$and $n > 1$ then, total no. of edges $\leq 23b-10+4b(\lfloor (n-1)^{\log_2 3} \rfloor)$**.**
  iv. When, $a > 1$, $b = 2$ and $n > 1$, then, total no. of edges $\leq 23a-10+4a(\lfloor (n-1)^{\log_2 3} \rfloor)$**.**
  v. When, a > 2, b > 2 and n > 1, no. of edges $\leq 14ab-5a-5b+2ab(\lfloor (n-1)^{\log_2 3} \rfloor)$**.**

b) Calculation of degree, diameter and no. of edges for Fig 1:

- The total number of nodes: (2n + 1)ab = (2 X 2 + 1) **X** (2 X 2) = 20.
- Maximum degree of the graph: Here, $a = 2$, $b = 2$ and $n > 1$, so, maximum degree of a node is, MAX (10, n+2) = MAX(10, 2+2) = MAX(10, 4) = 10.
- Diameter of the graph: Here $n > 1$. So, diameter of the graph is a+b = (2 + 2) = 4.
- Total number of edges ≤ 23 X 2 - 10 + 2 X 4 X 1= 44.

c) The Non-Uniform Pascal Graph Network (NUPGN) mode:
The proposed graph model has the following properties when implemented in NUPGN mode.

- The graph model has total number of nodes: ab + ($n_1 + n_1' + n_2 + n_2' + \ldots + n_{ab} + n_{ab}'$), where ab = number of nodes in MN and n_i = order of the i^{th} Pascal graph ($1 \leq i \leq ab$) along positive Z-axis and n_i' = order of the i^{th} Pascal graph ($1 \leq i \leq ab$) along negative Z-axis.

- The graph model has maximum degree:

  i. When $a = 2$ and $b = 2$ then degree is MAX(10, MAX($n_1, n_1', n_2, n_2', \ldots, n_{ab}, n_{ab}'$) + 2).
  ii. When $a = 2$ or $b = 2$ then degree is MAX(13, MAX($n_1, n_1', n_2, n_2', \ldots, n_{ab}, n_{ab}'$) + 3).
  iii. When $a > 2$ and $b > 2$ then degree is MAX(16, MAX($n_1, n_1', n_2, n_2', \ldots, n_{ab}, n_{ab}'$) + 4).

- Diameter of the graph: $a + b$ (when $n_j > 0$ and $n_j' > 0$ for all j).

- Total number of edges:

i. When, $a = 2$, $b > 1$, $n_j > 1$ and $n_j^{/} > 1$ for all j then, total no. of edges $\leq 23b\text{-}10+\sum_{j=1 \text{ to } 2b} \lfloor (n_j - 1)^{\log_2 3} \rfloor + \sum_{j=1 \text{ to } 2b} \lfloor (n_j^{/} - 1)^{\log_2 3} \rfloor$.

ii. When, $a > 1$, $b = 2$, $n_j > 1$ and $n_j^{/} > 1$ for all j then, total no. of edges $\leq 23a\text{-}10+\sum_{j=1 \text{ to } 2a} \lfloor (n_j - 1)^{\log_2 3} \rfloor + \sum_{j=1 \text{ to } 2a} \lfloor (n_j^{/} - 1)^{\log_2 3} \rfloor$.

iii. When, $a > 2$, $b > 2$, $n_j > 1$ and $n_j^{/} > 1$ for all j then, total no. of edges$\leq 14ab\text{-}5a\text{-}5b+\sum_{j=1 \text{ to } ab} \lfloor (n_j\text{-}1)^{\log_2 3} \rfloor + \sum_{j=1 \text{ to } ab} \lfloor (n_j^{/} - 1)^{\log_2 3} \rfloor$.

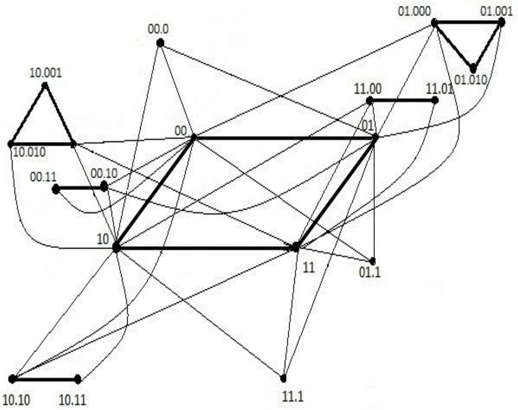


Fig 2—Mesh-Pascal(a,b,n)-Graph in NUPGN mode, where $a = 2$, $b = 2$, $n_1 = 1$, $n_1^{/} = 2$, $n_2 = 3$, $n_2^{/} = 1$, $n_3 = 3$, $n_3^{/} = 2$, $n_4 = 2$ and $n_4^{/} = 1$.

d) Calculation of degree, diameter and no. of edges for Fig 2:

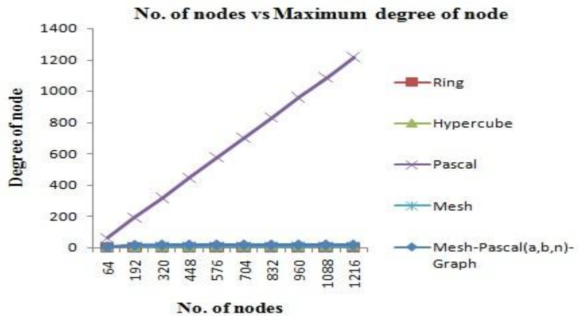
- The total number of nodes: $ab + (n_1 + n_1^{/} + n_2 + n_2^{/} + \ldots + n_{ab} + n_{ab}^{/}) = (2 \text{ X } 2) + (3 + 2 + 2 + 1 + 3 + 1 + 1 + 2) = 19$.
- Maximum degree of the graph: Here $a = 2$, $b = 2$. So, maximum degree of a node is MAX(10, MAX(n_1, $n_1^{/}$, n_2, $n_2^{/}$, … , n_{ab}, $n_{ab}^{/}$) + 2) = MAX(10, MAX(3, 2, 2, 1, 3, 1, 1, 2) + 2) = MAX(10, 5) = 10.
- Diameter of the graph: $a + b = 2 + 2 = 4$.
- Total number of edges: 2X2+5X4+3X3+(0+3+1+3) + (1+0+0+1) = 42.

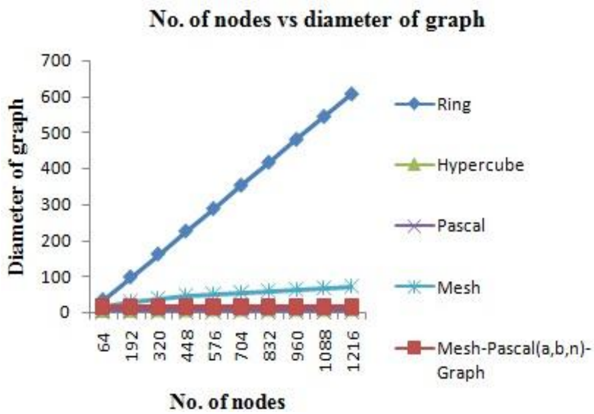
5. REPRESENTATION AND ADDRESSING OF A NODE IN THE PROPOSED GRAPH MODEL

Representation and addressing of a node is very important feature in a network. Here, binary number system has been used for representing each node [2]. Any node belonging to the MN is represented by ($\lceil \log_2 ab \rceil$) bits, where ab = total number of nodes belongs to MN. Here, we use row-major addressing for MN. The nodes which do not belong to the MN are represented as ($\lceil \log_2 ab \rceil . \ i \ \lceil \log_2 n \rceil$). The '$i$' bit is required to identify the Pascal graph, i.e., if $i = 0$, the Pascal graph is along the positive Z-axis and if $i = 1$, the Pascal graph is along the negative Z-axis. In the Fig 1, $a = 2$, $b = 2$ and $n = 2$, for a Mesh-Pascal(a,b,n)-Graph in UPGN mode, the number of bits required to represent MN is 2 and number of bits required to represent the PGN is ($\lceil \log_2 4 \rceil .(1 + \lceil \log_2 2 \rceil)$) = 2.(1 + 1) = 2.2 bits i.e., 4 bits. The representation in NUPGN is similar. The only difference is that any non-MN node in the NUPGN mode is represented as ($\lceil \log_2 ab \rceil . \ i \ \lceil \log_2 n_j \rceil$, $1 \leq j \leq ab$) (nodes of Pascal graphs along positive Z-axis) or ($\lceil \log_2 ab \rceil . \ i \ \lceil \log_2 n_j^{/} \rceil$, $1 \leq j \leq ab$) (nodes of Pascal graphs along negative Z-axis).

6. RESULT AND DISCUSSION

In this proposed graph model, expansion can be possible in three ways, by adding nodes to the PGN, or by adding nodes at the MN or by both. From the Fig 3, we can conclude that this proposed model is better than ring, mesh and Pascal graph. Pascal graph is best among them in terms of diameter but it is worse in terms of maximum degree of a node and total number of edges. On the other hand, ring and mesh perform well in terms of maximum degree of a node and total number of edges, but they both perform poorly in terms of diameter of graph. The proposed graph gives a standard measurement in terms of degree, diameter and total number of edges. The only graph which comes close to it is hypercube graph. But the hypercube graph fails measurably compared to the proposed graph model when we consider total number of edges, reliability of the network and expansion-contraction of the network. If we expand the hypercube from the dimension q to q+1, it would reconfigure 2^q number of nodes (which increases exponentially). But this proposed model can be expanded either by adding nodes at MN, reconfiguring only 3a (expansion along Y-axis) or 3b (expansion along X-axis) number of nodes (which grows linearly), or by adding nodes to PGN; so we have to reconfigure a few numbers of nodes only and we do not have to change the hardware of all nodes. In Mesh-Pascal(a,b,n)-Graph, multiple paths exist between any two nodes, so the network is reliable and fault-tolerant. The multiplicity of paths decouples the processors and allows the topology to simultaneously support many messages. Routing algorithm can take advantage of the multiple paths to avoid particularly busy routes. So, when reliability, diameter, degree, total number of edges, expansion, fault tolerance all are considered together, the proposed graph model is good enough in comparison with other models. It gives minimal degree and diameter but maximal reliability and expansion.





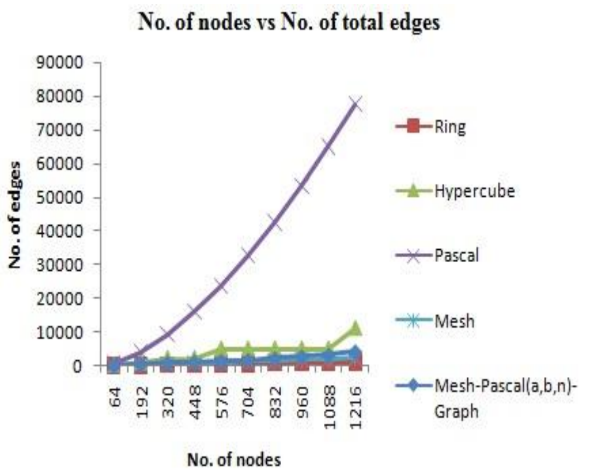
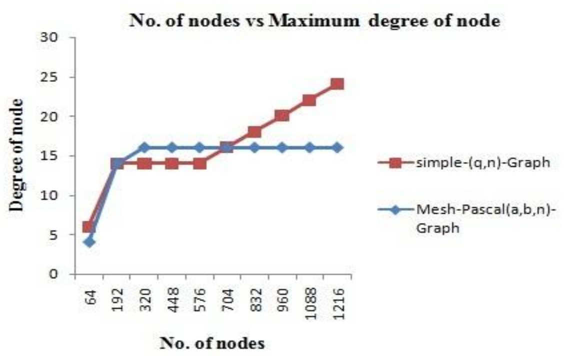


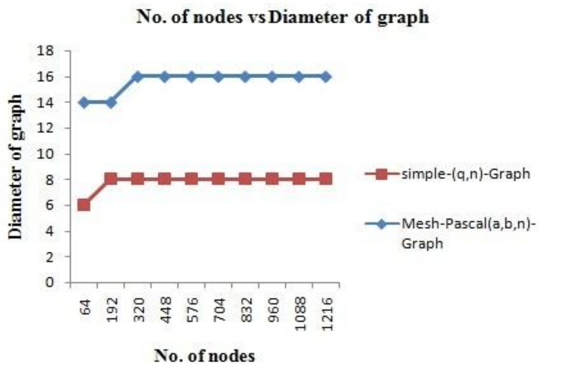
Fig 3—Comparison of maximum degree of nodes, diameter of the graph and no. of edges of Mesh-Pascal(a,b,n)-Graph with ring, hypercube graph, Pascal graph and mesh. The comparison has been made by taking a = 8, b = 8 and n as required in UPGN mode.

6.1 Comparison between simple-(q,n)-Graph and Mesh-Pascal(a,b,n)-Graph:

simple-(q,n)-Graph and Mesh-Pascal(a,b,n)-Graph both perform well in terms of degree, diameter, reliability and expansion. But, from the Fig 4 given below, we can conclude that Mesh-Pascal(a,b,n)-Graph performs better than simple-(q,n) -Graph in terms of number of edges in the graph model and maximum number of edges incident on a node. Maximum number of edges incident on a node increases with the dimension of hypercube subnet (HS) [2] in simple-(q,n)-Graph; so hardware cost will increase whereas in Mesh-Pascal(a,b,n)-Graph, maximum number of edges incident on a node is always constant for MN with the order of MN. These are two advantages of Mesh-Pascal(a,b,n)-Graph over simple-(q,n)-Graph; but simple-(q,n)-Graph performs always better in terms of diameter, though they both have diameter in linear order for any representation.

But the main advantage of Mesh-Pascal(a,b,n)-Graph over simple-(q,n)-Graph is, while we want to expand simple-(q,n)-Graph from dimensions q to q+1 we have to reconfigure 2^{q+1} number of nodes (which increases exponentially), Whereas in Mesh-Pascal(a,b,n)-Graph we would reconfigure only 3a (expansion along Y-axis) or 3b (expansion along X-axis) number of nodes while expanding MN (which grows in linear order). So, for this proposed graph model hardware cost to expand the network is very less than simple-(q,n)-Graph. It is a huge advantage of Mesh-Pascal(a,b,n)-Graph over simple-(q,n)-Graph.





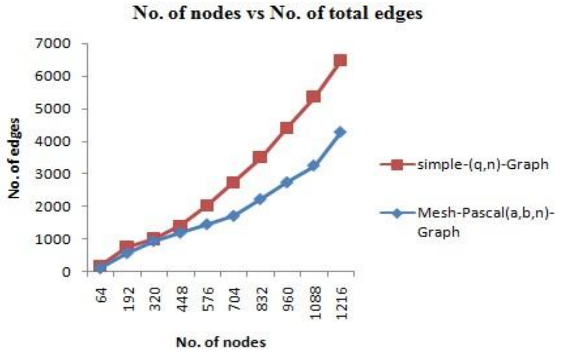


Fig 4—Comparison of maximum degree of nodes, diameter of the graph and no. of edges of simple-(q,n)-Graph with Mesh-Pascal(a,b,n)-Graph model. The comparison has been made by taking q = 6, a = 8, b = 8 and n as required in UPGN mode.

7. CONCLUSION

Selecting various graph models to represent computer network topologies had always been an active research area for computer scientist [2][5]. This is a novel approach which merges two ICN model and develop a newer one that is so versatile that we can use it in several applications, such as client-server model, mobile computing, distributed computing etc. The mode of implementation can be chosen from the particular application point of view. It gives better measurement for all the parameter than the other available ICN such as ring, mesh, Pascal graph, hypercube graph. Like simple-(q,n)-Graph, it gives standard measurement in case of all the parameters, but it also overcomes the drawbacks of simple-(q,n)-Graph. Mesh-Pascal(a,b,n)-Graph is an amalgamation between two different and popular ICN models, mesh and Pascal graph. The amalgamation is so effective and flexible but the idea requires more research and study. A lot of studies on this matter will definitely reveal new direction for moving ahead.

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