On New Architectures for Lightwave Networks

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Abstract

In this paper we propose two different architectures, the *Multi-Mesh* and the *Incomplete Multimesh*, for use in wavelength division multiplexed optical networks. These architectures can be deployed as a physical topology for single hop or a logical topology for multihop networks. In terms of simplicity of interconnection and routing, these architectures are comparable to the regular mesh and the torus networks. However, the new architectures exhibit significantly superior topological properties than the mesh and the torus. For example, whereas a two dimensional torus with N nodes has a diameter of $\Theta(N^{0.5})$, a Multi-Mesh network with the same number of nodes and links has a diameter of $\Theta(N^{0.25})$. The Incomplete Multi-Mesh can be constructed for any number of nodes and is incrementaly expandable. We provide results of our simulation studies for the call blocking probabilities for the Multi-Mesh network. The advantage of the Incomplete Multi-Mesh over the de Bruijn network lies in the fact that unlike the de Bruijn network, this network can be constructed for any number of nodes and is incrementally expandable.

Keywords: Optical networks, mesh, torus, de Bruijn graph, Multi-Mesh, multihop networks.

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1 Introduction

Optical networks use interconnection of high-speed broadband fibers to transmit information. Typically, in such a network, the stations (also referred to as the end-nodes) are interconnected by optical fibers and routers. Wavelength Division Multiplexing (WDM) enables multiple communication at different wavelengths over a single fiber. Each wavelength on a given fiber is called a *channel*. These networks support *lightpaths* which are end-to-end communication paths passing through one or more fibers, using one WDM channel per fiber. Optical networks can be divided into two classes - *single hop* and *multihop* networks. An important objective in a single hop network design is to minimize the total number of carrier wavelengths needed for communication among various end stations. An important requirement for high throughput in a multihop optical network is to ensure that the average delay due to buffering at the intermediate nodes is small. Simple interconnection topologies, such as the *ring* and the *mesh*, and more complex ones, such as the *shufflenet* and the *de Bruijn graph* have been proposed for single and multihop networks [1, 6, 10, 12]. Ideally, a topology should be incrementally scalable, should have a simple routing strategy and should be able to communicate even in presence of node (router) and link failures. In addition, the requirement for carrier wavelengths (channels) should be low in a single hop network and the average delay should be low in a multihop network. None of the proposed topologies satisfy all these orthogonal, if not conflicting, requirements [8, 10].

In a single hop network, a *lightpath* is a path from a source S to a destination D that uses the same wavelength for communication over the entire path. It may be noted that this path may pass through several routers on its journey from the source to the destination. If a lightpath from S to D passes through k intermediate routers on its journey from the source to the destination, then it has to reserve $k+1$ channels, one for each segment (fiber) in the path from S to D. Since two different lightpaths cannot be assigned the same WDM channel if they share the same fiber [8], the demand for the number of channels per fiber will be higher if many lightpaths have to share the same fiber. As the length of the source-destination path is bounded by the *diameter* (distance between two nodes of the network that are furthest from each other), one might think that the demand for the number of channels per fiber will be low, if the network topology has a small diameter . However, this is not necessarily true. The reason for this is, even though the topology may have a small diameter, because of the interconnection pattern, a large number of lightpaths may be forced to travel through a small number of fibers, thereby increasing the demand for the number of channels in those fibers.

In a multihop network, the communication delay may be proportional to the number of intermediate routers the packets have to pass through on their journey from the source to the destination. As a consequence, in such an environment a topology with a small diameter is quite attractive.

In this paper we have proposed the use of two new architectures, *Multi-Mesh, (MM)* and *Incomplete Multi-Mesh, (IMM)*, for lightwave application. The *Multi-Mesh (MM)* architecture was originally proposed for parallel processing systems [2, 3, 4, 5]. The MM structure is defined for n^4 nodes for any integer n. Since in a LAN/MAN/WAN environment, it is difficult to satisfy such a stringent requirement on the number of nodes, we have generalized this architecture so that it can be defined for any number of nodes N, $1 \leq N \leq n^4$ for some integer n. The new architecture, IMM, is also incrementally expandable, i.e., an N node network can be extended to an $N+1$ node network without major changes to the existing structure. It may be noted that although the authors in [13] refer to the network discussed in their paper as the *Multi-Mesh* network, in the research community this network is known as the *Manhattan Street Network* [7]. The *Multi-Mesh* network in our paper refers to the network proposed in [2, 3, 4, 5].

The architecture proposed in this paper can be used both as a physical as well as a logical topology for optical networks. In terms of simplicity of interconnection and routing, the architecture is comparable to the regular mesh and the torus. However, the it exhibits significantly superior topological properties than the mesh and the torus. For example, whereas a two dimensional torus with N nodes has a diameter of $\Theta(N^{0.5})$, a MM network with the same number of nodes and links has a diameter of $\Theta(N^{0.25})$.

The advantage of a Incomplete Multi-Mesh over a de Bruijn network lies in the fact that unlike the de Bruijn network, this network can be constructed for any number of nodes and is incrementally expandable.

The paper is organized as follows: section 2 describes the Multimesh and Incomplete Multimesh architectures, sections 3 and 4 establish the connectivity and diameter of the architectures respectively, section 5 describes the simulation environment and simulation result and section 6 concludes the paper.

2 The Multi-Mesh and Incomplete Multi-Mesh Architectures

The Multi-Mesh (MM) interconnection network was originally proposed for parallel processing in [2]. Since then researchers have developed techniques for efficiently carrying out several different computational tasks on this network [3, 4]. The interconnection pattern in this topology is an extension of the simple mesh connection. In an $n \times n$ mesh, the processors are arranged in n rows and n columns. The MM uses this as a building block for the construction of the network. The idea is to use n^2 such blocks arranged again in n rows and n columns. Thus a MM network has exactly n^4 nodes. Each of these n^4 nodes are identified with a four tuple label (α, β, x, y). The first two, (α, β), identifies the block and the last two, (x, y), identifies the node within a block. Each of these co-ordinates can take a value between 1 and n (both inclusive).

The $n \times n$ nodes within each block are connected as a regular two dimensional mesh. The interblock connections are made using the following rules:

1.) $\forall \beta, 1 \leq \beta \leq n$, the node $(\alpha, \beta, 1, y)$ is connected to the node (y, β, n, α) where $1 \leq y, \alpha \leq n$,

2.) $\forall \alpha, 1 \leq \alpha \leq n$, the node $(\alpha, \beta, x, 1)$ is connected to the node (α, x, β, n) where $1 \leq x, \beta \leq n$,

It may be observed that the interconnection rules given above generates a regular topology where each node is connected to exactly four edges. A partially completed MM network with eightyone nodes is shown in figure 1.

The number of nodes in an N node MM network is always n^4, for some integer n. This restriction may be acceptable in a parallel processing environment where the number of nodes do not change very often, but may not be acceptable in its use in a local, metropolitan or wide area network environment where the number of nodes change quite frequently. We propose a new variation of the MM interconnection topology where we relax the MM topology requirement that the number of nodes always be n^4. This variation of MM, called *Incomplete Multi-Mesh* (IMM) can be constructed for any number of nodes. The construction mechanism is simple. One needs to specify the total number of nodes N and the block size n. Then the IMM will have $m = \lceil N/n^2 \rceil$ blocks. The

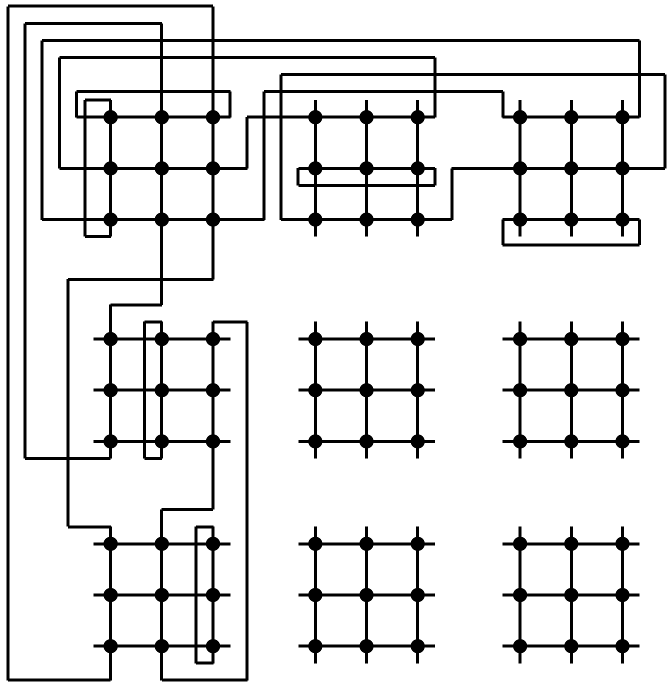

Figure 1: Multi-Mesh Network with 81 nodes (Not all interblock links are shown for clarity)

blocks will be arranged in rows and columns as in MM. There will be $\lceil m/n \rceil$ rows, with each row having at most n blocks. The last row of blocks may be partially complete with $mod(m,n)$ blocks. A complete block will have $n \times n = n^2$ nodes. A partially complete block with q nodes will have $\lfloor q/n \rfloor$ complete rows with each row having exactly n nodes. The last row within a block may be partially complete with $mod(q,n)$ nodes. An IMM with forty nodes is shown in figure 2. The main advantages of the IMM is that not only does it allow the construction of such a network for any number of nodes, it is also *incrementally expandable* in the sense that an N node network can easily be augmented to an $N+1$ node network. This incremental expansion possibility of IMM makes it very attractive for use in a LAN/MAN/WAN environment where the number of nodes undergo frequent changes.

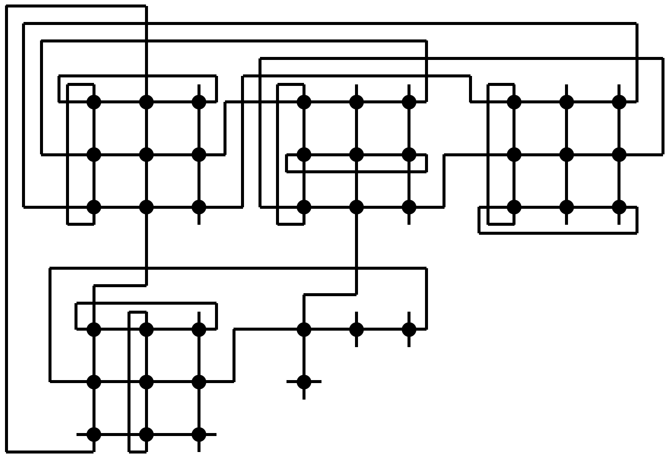

Figure 2: Incomplete Multi-Mesh Network with 40 nodes

3 The Connectivity of Multi-Mesh and Incomplete Multi-Mesh Architectures

A MM network is regular graph with node degree four. The *node connectivity* between a pair of nodes in a graph is the number of *node disjoint* paths between these nodes. The *node connectivity* of a graph is the minimum of the node connectivity over all pairs of nodes. Since the degree of each node in a MM is four, it is clear that the upper bound of connectivity of MM is four. In this section, we show that in a MM network this upper bound is indeed realized, i.e., the connectivity of MM is four.

Theorem 1 *The connectivity of Multi-Mesh network is four.*

Proof: We show that there exists four node disjoint paths between the nodes $(\alpha_1, \beta_1, x_1, y_1)$ and $(\alpha_2, \beta_2, x_2, y_2)$ for any value of $(\alpha_1, \beta_1, x_1, y_1)$ and $(\alpha_2, \beta_2, x_2, y_2)$. We consider four cases:

Case 1: $\alpha_1 \neq \alpha_2$ and $\beta_1 \neq \beta_2$

Case 2: $\alpha_1 = \alpha_2$ and $\beta_1 \neq \beta_2$

Case 3: $\alpha_1 \neq \alpha_2$ and $\beta_1 = \beta_2$

Case 4: $\alpha_1 = \alpha_2$ and $\beta_1 = \beta_2$

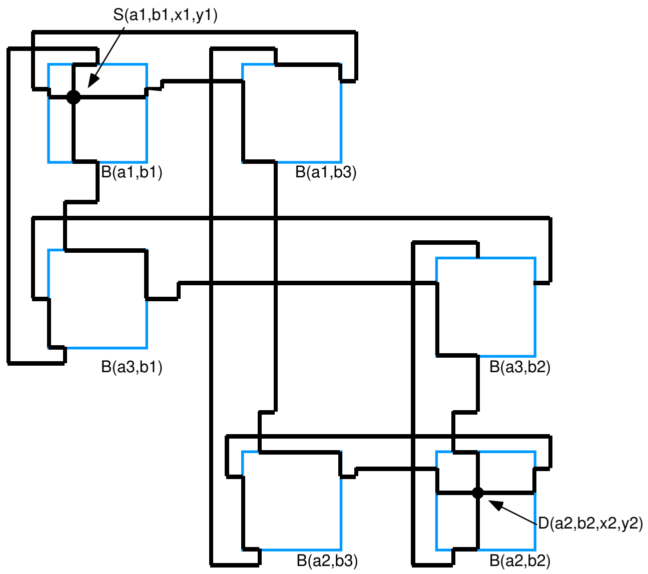

Figure 3: Disjoint paths between the nodes $(\alpha_1, \beta_1, x_1, y_1)$ and $(\alpha_2, \beta_2, x_2, y_2)$

Case 1: $(\alpha_1 \neq \alpha_2$ and $\beta_1 \neq \beta_2)$

The four disjoint paths between the nodes $(\alpha_1, \beta_1, x_1, y_1)$ and $(\alpha_2, \beta_2, x_2, y_2)$ is shown in figure 4 ($\forall i$, $\alpha_i = a_i$ and $\beta_i = b_i$ in the figure). The four node disjoint paths are as follows:

Path 1: $(\alpha_1, \beta_1, x_1, y_1) \rightarrow (\alpha_1, \beta_1, x_1, n) \rightarrow (\alpha_1, \beta_1, \beta_3, n) \rightarrow (\alpha_1, \beta_3, \beta_1, 1) \rightarrow (\alpha_1, \beta_3, n, 1) \rightarrow (\alpha_1, \beta_3, n, \alpha_2) \rightarrow (\alpha_2, \beta_3, 1, \alpha_1) \rightarrow (\alpha_2, \beta_3, 1, n) \rightarrow (\alpha_2, \beta_3, \beta_2, n) \rightarrow (\alpha_2, \beta_2, \beta_3, 1) \rightarrow (\alpha_2, \beta_2, x_2, 1) \rightarrow (\alpha_2, \beta_2, x_2, y_2)$.

Path 2: $(\alpha_1, \beta_1, x_1, y_1) \rightarrow (\alpha_1, \beta_1, x_1, 1) \rightarrow (\alpha_1, \beta_1, \beta_3, 1) \rightarrow (\alpha_1, \beta_3, \beta_1, n) \rightarrow (\alpha_1, \beta_3, 1, n) \rightarrow (\alpha_1, \beta_3, 1, \alpha_2) \rightarrow (\alpha_2, \beta_3, n, \alpha_1) \rightarrow (\alpha_2, \beta_3, n, 1) \rightarrow (\alpha_2, \beta_3, \beta_2, 1) \rightarrow (\alpha_2, \beta_2, \beta_3, n) \rightarrow (\alpha_2, \beta_2, x_2, n) \rightarrow (\alpha_2, \beta_2, x_2, y_2)$.

Path 3: $(\alpha_1, \beta_1, x_1, y_1) \rightarrow (\alpha_1, \beta_1, n, y_1) \rightarrow (\alpha_1, \beta_1, n, \alpha_3) \rightarrow (\alpha_3, \beta_1, 1, \alpha_1) \rightarrow (\alpha_3, \beta_1, 1, n) \rightarrow (\alpha_3, \beta_1, \beta_2, n) \rightarrow (\alpha_3, \beta_2, \beta_1, 1) \rightarrow (\alpha_3, \beta_2, n, 1) \rightarrow (\alpha_3, \beta_2, n, \alpha_2) \rightarrow (\alpha_2, \beta_2, 1, \alpha_3) \rightarrow (\alpha_2, \beta_2, 1, y_2) \rightarrow (\alpha_2, \beta_2, x_2, y_2)$.

Path 4: $(\alpha_1, \beta_1, x_1, y_1) \rightarrow (\alpha_1, \beta_1, 1, y_1) \rightarrow (\alpha_1, \beta_1, 1, \alpha_3) \rightarrow (\alpha_3, \beta_1, n, \alpha_1) \rightarrow (\alpha_3, \beta_1, n, 1) \rightarrow (\alpha_3, \beta_1, \beta_2, 1) \rightarrow (\alpha_3, \beta_2, \beta_1, n) \rightarrow (\alpha_3, \beta_2, 1, n) \rightarrow (\alpha_3, \beta_2, 1, \alpha_2) \rightarrow (\alpha_2, \beta_2, n, \alpha_3) \rightarrow (\alpha_2, \beta_2, n, y_2) \rightarrow (\alpha_2, \beta_2, x_2, y_2)$.

It can be seen from figure 4 that these paths are node disjoint.

Case 2: ($\alpha_1 = \alpha_2$ and $\beta_1 \neq \beta_2$)

This case is very similar to case 1. The two paths originating from the node (x_1, y_1) in the block (α_1, β_1) first reach their left and right boundary of the block. Since $\alpha_1 = \alpha_2$, the two blocks have a cycle between them. The two paths leave the left and right boundary of the (α_1, β_1) block, through the links that form the cycle, to enter the right and left boundary of the block (α_2, β_2) respectively. From this boundary nodes, they reach the destination node (x_2, y_2).

Two other paths from the source node (x_1, y_1) in the block (α_1, β_1) first reach their top and bottom boundary of the block. The block (α_1, β_1) forms a vertical cycle with the block (α_3, β_1), $(\alpha_1 \neq \alpha_3)$. The two paths leave the top and bottom boundary of the (α_1, β_1) block, through the links that form the cycle, to enter the bottom and top boundary of the block (α_3, β_1) respectively. The block (α_3, β_1) forms a horizontal cycle with the block (α_3, β_2). The two paths leave the left and right boundary of the (α_3, β_1) block, through the links that form the cycle, to enter the right and left boundary of the block (α_3, β_2) respectively. The block (α_3, β_2) forms a vertical cycle with the block (α_2, β_2). The two paths leave the top and bottom boundary of the (α_3, β_2) block, through the links that form the cycle, to enter the bottom and top boundary of the block (α_2, β_2) respectively. From this entry points in the block (α_2, β_2) they reach the destination node (x_2, y_2). The four paths established this way between the nodes $(\alpha_1, \beta_1, x_1, y_1)$ to $(\alpha_2, \beta_2, x_2, y_2)$, $(\alpha_1 = \alpha_2)$ are disjoint.

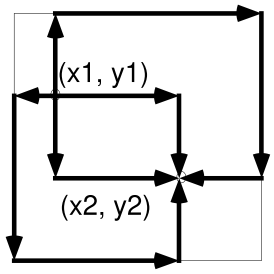

Figure 4: Disjoint paths between the nodes $(\alpha_i, \beta_i, x_1, y_1)$ and $(\alpha_i, \beta_i, x_2, y_2)$

Case 3: $(\alpha_1 \neq \alpha_2$ and $\beta_1 = \beta_2)$

Since the Multimesh network is symmetric with respect to horizontal and vertical direction, this case is identical to case 2 with a ninety degree rotation of the network. Same arguents as in case 2 apply in this case.

Case 4: $(\alpha_1 = \alpha_2$ and $\beta_1 = \beta_2)$

In this case, we need to establish four disjoint paths between the nodes $(\alpha_i, \beta_i, x_1, y_1)$ and $(\alpha_i, \beta_i, x_2, y_2)$ for $1 \leq i \leq n$. Since both the source and the destination nodes belong to the same block, we will omit identifying the block. The four disjoint paths are as follows:

Path 1: $(x_1, y_1) \rightarrow (x_1, y_2) \rightarrow (x_2, y_2)$

Path 2: $(x_1, y_1) \rightarrow (x_2, y_1) \rightarrow (x_2, y_2)$

Path 3: $(x_1, y_1) \rightarrow (x_1, 1) \rightarrow (n, 1) \rightarrow (n, y_2) \rightarrow (x_2, y_2)$

Path 4: $(x_1, y_1) \rightarrow (1, y_1) \rightarrow (1, n) \rightarrow (x_2, n) \rightarrow (x_2, y_2)$

In all the cases there exists four disjoint paths between every pair of nodes. This proves the theorem.

The connectivity of an Incomplete Multimesh (IMM) can be as low as one. In the forty node IMM network shown in figure 2, it can be seen that the node (2, 2, 2, 1) is attached to only one node (2, 2, 1, 1). Since the degree of this node is one, the connectivity of this graph cannot be any more than one.

4 The Diameter of Multi-Mesh and Incomplete Multi-Mesh Architectures

The diameter of a complete MM network with N nodes, where $N = n^4$ nodes was shown to be $2n = 2N^{1/4}$ in [2]. This property is very attractive because, a comaparable network - a two dimensional torus, with exactly same number of nodes and edges will have a diameter $N^{1/2}$. In the following we show that when the MM is incomplete, the diameter increases by at most $2n - 1$. In other words, the diameter of an IMM network with N nodes ($1 \leq N \leq n^4$) and blocks of size $n \times n$ is at most $4n$.

At the risk of being repetitive, we state once again that, if the total number of nodes in an IMM is N and the block size is $n = \lceil N^{0.25} \rceil$, then structure will have $m = \lceil N/n^2 \rceil$ blocks. The blocks will be arranged in a two dimensional array of blocks as shown in figure 5. There will be $p = \lceil m/n \rceil$ rows, with each row having at most n blocks. The last row of blocks may be partially complete with $q = mod(m, n)$ blocks. A complete block will have $n \times n = n^2$ nodes. A partially complete block with r nodes will have $\lfloor r/n \rfloor$ complete rows with each row having exactly n nodes. The last row within a block may be partially complete with $mod(r, n)$ nodes. The nodes within a block are connected as a regular two dimensional mesh.

Theorem 2 *The diameter of an Incompte Multimesh network at most* $4n - 1$.

Proof: Consider any source node $S = (a1, b1, x1, y1)$ and any destination node $D = (a2, b2, x2, y2)$. Without loss of generality, we assume $a1 \leq a2$. The IMM topology is constructed in such that only the last row can have less than n blocks and the last block

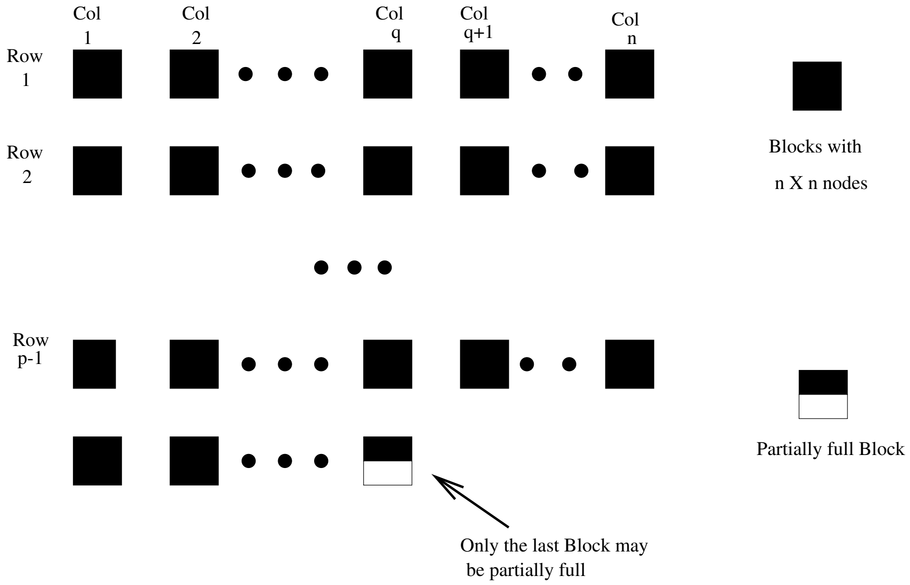

Figure 5: Blocks in a generalized Multi-Mesh network

in the last row can have less than n^2 nodes. We will refer to the block in which the source (destination) node is present as the source (destination) block.

We consider the following two cases:

Case 1: Both the source and the destination block is complete

The diameter of any complete block is n. The routing from the block $(a1, b1)$ to the block $(a2, b2)$ can be done in the following way: $(a1, b1) \rightarrow (a1, b2) \rightarrow (a2, b2)$. Since the $(a1, b2)$ block can be reached from the $(a1, b1)$ block in one hop and the the $(a2, b2)$ block can be reached from the $(a1, b2)$ block in one hop, the length of a path from any node the block $(a1, b1)$ to the block $(a2, b2)$ is at most $n + 1 + n + 1 + n = 3n + 2$.

Case 2: The destination block is incomplete

If both the source and the destination is in the incomplete block, maximum distance between them can be at most $2n-3$. This can happen only when both the horizontal and the vertical loop present in a complete block is missing. If the source and the destination nodes are in different blocks, the routing from the source block $(a1, b1)$ to the destination block $(a2, b2)$ can be done in the folowing way: $(a1, b1) \rightarrow (a1, b2) \rightarrow (a2, b2)$. Since the

$(a1, b2)$ block can be reached from the $(a1, b1)$ block in one hop and the $(a2, b2)$ block can be reached from the $(a1, b2)$ block in one hop, the length of a path from any node the block $(a1, b1)$ to the block $(a2, b2)$ is at most $n + 1 + n + 1 + 2n - 3 = 4n - 1$.

Note: In our extensive experimentation to determining the diameter of an incomplete multimesh network, we never found the diameter to exceed $3.5n$. We *conjecture* that the diameter of an incomplete multimesh is indeed $3.5n$.

In the following table we present a comparison between various parameters of torus, Multi-Mesh and de Bruijn networks.

Table 1: Comaprison Table of Various Network Attributes

Network Type	Node Degree	Connectivity	Diameter
Torus	4	4	$\Theta(N^{0.5})$
Multi-Mesh	4	4	$\Theta(N^{0.25})$
De Bruijn	$\Delta, \Delta - 1$	$\Delta - 2$	$\Theta(log\ N)$

5 Simulation Environment and Results

We have studied the route and wavelength assignment (RWA) problem in a wavelength routed single hop network with a physical topology based on the Multimesh architecture. The RWA problem is a complex and intractable problem and as is done by other researchers [10] we have used an extensive set of simulation experiments to study the RWA problem.

5.1 Simulation Objectives

Given that each node of the network has a specified number of optical transmitters and receivers, m, the objective of the simulation is to find the number of wavelengths necessary to ensure that the call blocking probability p will be below an acceptable threshold value. We use Monte-Carlo simulation to determine the number of wavelengths necessary to ensure a small call blocking probability. In this simulation we have used a fixed route to give us an upper bound on the number of wavelengths needed for RWA.

5.2 Assumptions in Simulation Experiments

The following assumptions are made in our study:

a) The traffic between all source-destination pairs are equally likely.

b) Each source node has the capability of tuning its transmitter to any one of the N wavelengths used in the network.

c) The statistical traffic model given in [10] is applicable to our network.

d) The wavelength continuity constraint is satisfied, so that a light path traversing a number of fibers always uses the same wavelength on every fiber in the path.

5.3 Performance Metric

In our experiment we are determining the number of wavelengths necessary to ensure that the call blocking probability p will be below an acceptable threshold value. Our performance metric is the number of wavelengths we would need in a network of a give size. This is reasonable because a network with a given number of nodes that require fewer wavelengths is less expensive compared to a network requiring more wavelengths which, in general, require more fibers and hence more optical hardware(e.g., amplifiers and routers).

5.4 Simulation Algorithm

The following steps were taken to observe the variation of the call blocking probability p with the number of wavelengths used in the network N, when each node of the network has exactly m transmitters and receivers.

Step 1: The simulation is initialized by setting the number of blocked calls to 0 and the total number of attempted connections to 0.

Step 2: The steps 3-8 were repeated one hundred times.

Step 3: The network is initialized by ensuring that no edge is carrying any lightpath and all m transmitters and receivers of each node in the network are available for use.

Step 4: While at least one node S has a transmitter free and one node D has a receiver free ($S \neq D$), repeat steps 5 - 8.

Step 5: Select at random, a pair (S, D) of nodes such that

a) the node S has at least one of its m transmitters free and

b) the node D has at least one of its m receivers free and

c) S is distinct from D and

d) either the node pair (S, D) was never selected earlier or the last attempt for a connection from S to D was successful.

Step 6: Examine the shortest path P from S to D (or one of the shortest paths if there were more than one) to find out if there exists a wavelength $\lambda_i, 0 \leq i < N$ such that none of the edges in the path P currently has a lightpath with a wavelength λ_i.

Step 7: If no such wavelength is available, we conclude that the call is blocked. In this case we

a) increase the number of blocked calls by 1,

b) insert the pair (S, D) in a list of source and destination pairs of nodes that were blocked in previous attempts and

c) return to step 4.

Step 8: If a wavelength λ_i is found, we

a) allocate the wavelength λ_i on each fiber of the path P for the communication from S to D,

b) reduce the number of transmitters of the source node S and the number of receivers of the destination node D by 1 and

c) return to step 4.

5.5 Simulation Experiments, Results and Discussion

We carried out the experiment for three different values of m, 5, 10 and 15, (m is the number of transmitters and receivers in each node). In our Monte-Carlo simulation of the multimesh network we varied the number of wavelengths N used in the network to observe the variation of the call blocking probability p. At the completion of the simulation, we calculate the relative frequencies of the blocked connections to obtain an estimate of the blocking probability when the network has N available wavelengths for connection establishment. This simulation had to be repeated many times with increasing values of N so that the call blocking probability p falls below an acceptable threshold value.

In figures 6, 7, 8 we plotted the blocking probability versus the number of wavelengths using a logarithmic scale. In the graphs, the squares, diamonds and crosses represent the cases with $m = 5$, 10 and 15 respectively. These graphs may be used by a network designer to determine an appropriate value of N for a network with a specified value of m and acceptable limit of the call blocking probability p.

The graphs show a steep decline in the values of p as N is increased. This implies

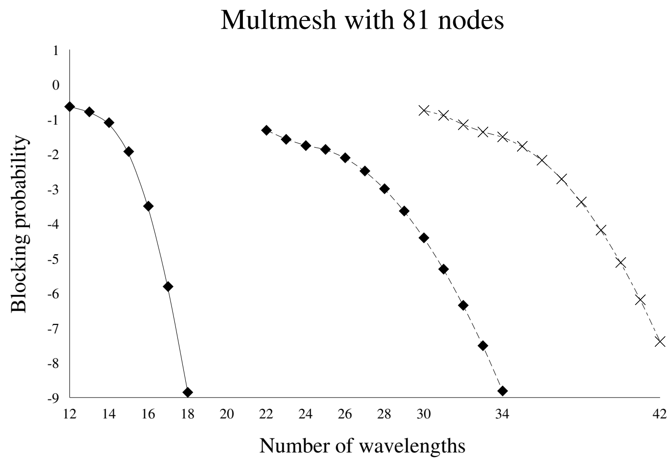

Figure 6: Call blocking probability versus number of wavelengths in 81 node Multimesh

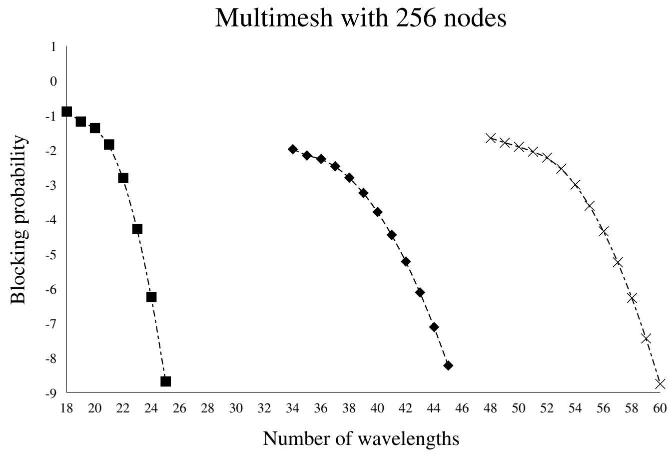

Figure 7: Call blocking probability versus number of wavelengths in 256 node Multimesh

that it is possible reduce the call blocking probability to an arbitrarily small value by a modest increase in the number of wavelengths. It is also interesting to see that the number of wavelengths needed is comparable to that used in more complex topologies such as the de Bruijn or the Kautz graph. These graphs have been studied for optical networks and are well known for their low diameter and simple routing schemes. The results related to the analytic and simulation studies of these networks can be found in [12, 9]. The call blocking probability is the *metric* that is used by the researchers in this area to evaluate the efficacy of any particular topology [12, 9]. For this reason we also use the same metric to evaluate the effectiveness of the Multimesh topology.

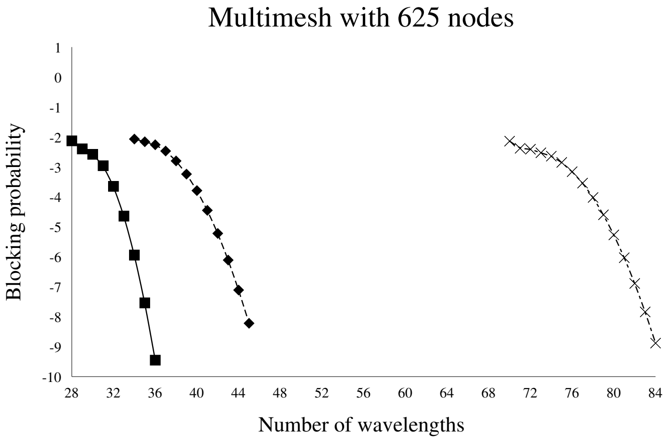

Figure 8: Call blocking probability versus number of wavelengths in 625 node Multimesh

6 Conclusion

In this paper we have proposed two new architectures for wavelength division multiplexed optical networks. We provide analytical results related to the topological properties of the network. We prove that the Multimemsh network is optimally *fault-tolerant*, in the sense that its connectivity is equal its node degree, which is four. We also prove that the diameter of an Incomplete Multimesh network is $4n - 1$. The diameter of a Multimesh network with n^4 nodes was shown to be $2n$ in [2]. Thus, in case of an Incomplete Multimesh diameter increases at most by $2n - 1$. In our extensive experimentation we never found an instance where the diameter was greater than $3.5n$. In addition to the analytical results, we provide the results of our simulation studies. Simulation results indicate that these new topologies very comparable to the Torus, de Bruijn and Kautz graphs proposed for WDM lightwave networks [12, 9] and can be used as an alternative to these networks. In this paper we have studied the situation when no wavelength conversion is allowed. The efficacy of this architecture when wavelength conversion is allowed, is currently under study.

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