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A HIGHLY SCALABLE STRUCTURE FOR WDM MULTIHOP LIGHTWAVE NETWORKS*

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Abstract: In this paper, the author proposes a new virtual topology, referred to as fully connected cubic network (FCCN), for the wavelength division multiplexing (WDM) multihop lightwave network. The FCCN is a multi-level, highly scalable and modular architecture. An m level FCCN is constructed by "fully connecting" 8 ($m-1$)-FCCNs. The FCCN satisfies very well all the design requirements for WDM lightwave networks. The nodal degree is no more than four, and independent of the network size. Both the diameter and the average hop distance are in the order of $\sqrt[3]{\textit{Number of nodes}}$. Owing to the highly scalable structure, the routing algorithm proposed in this paper is very simple to implement. Wavelengths reuse technique can be applied with high efficiency to FCCN.

Key words: multihop lightwave network, WDM, wavelength reuse, optical networks, FCCN
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INTRODUCTION

Lightwave networks based on optical fibers are playing more and more important role in telecommunications due to the broad bandwidth, small disturbance and little energy loss of optical transmission. But the potential of enormous bandwidth is held down by the opto-electric bottleneck, i.e., the mismatch between electronic processing rates and optical transmission bandwidth. Wavelength division multiplexing (WDM) over a passive broadcast medium is a well known scheme for realizing a high level of concurrency in a single optical fiber (Laude, 1993; Brackett, 1990).

WDM network architectures can be categorized into single-hop networks and multihop networks (Mukherjee, May 1992; Mukherjee, July 1992). In the former, the nodes must communicate with the others in one hop, thus requiring expensive wavelength-agile transceivers and pre-transmission coordination between transceivers. In the latter, a source node may hop through several intermediate nodes before reaching the destination. The intermediate nodes retransmit the packet using different wavelengths. Multihop networks can be realized by fixed tuned or slowly tunable transceivers, thus eliminating the need for pre-transmission communications and rapidly tunable devices as required for single-hop networks (Mukherjee, July 1992). Moreover, it is possible to configure an optimal logical topology for a multihop network to fit the network traffic patterns. The logical topology can be configured to simplify the routing algorithms and flow control in the networks, and improve the delay and throughout performance.

Logical topologies for WDM multihop lightwave networks are either regular or irregular. Regular topology offers several distinct advantages over the irregular ones (Li et al., 1992). We consider regular topologies only in this paper. Previously proposed regular topologies for WDM networks include tree (Gerla et al., 1988), star, mesh (Maxemchuk, 1985; Gerla et al., 1995), hypercube (Bhuyan et al., 1984; Saad, et al., 1988), shufflenet (Hluchyj et al., 1991), MSN(Chung et al., 1993; Banerjee et al., 1994; Park et al., 1995), de Bruijn (Sivarajan et al., 1991), and Kautz (Panchapakesan et al., 1995). Based on the diameter, average number of hops, and complexity of routing algorithm and congestion control, hypercube is considered as one of the best topologies. However, the major weakness of a hypercube is

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its nodal degree increasing logarithmically to the number of nodes in the network. This weakness severely limits the size of WDM networks based on hypercube topology since the nodal degree determines the number of transceivers needed for each node. Instead, the nodal degree should be small and independent of the network size.

In this paper, we propose a new regular multihop network topology, referred to as Fully Connected Cubic Network (FCCN). FCCN retains the merits of hypercube and, on the other hand, remedies the aforementioned major weakness. The nodal degree in FCCN is small and constant, and the topology can be scaled up hierarchically to any level. The number of nodes of FCCN can be arbitrary if we apply the idea of incomplete hypercube to FCCN. As we will show later, the overall design of FCCN excels other previously proposed architectures by meeting all six design principles for WDM lightwave networks outlined in (Banerjee et al., 1994): (1) small and constant nodal degrees, (2) small diameter and average number of hops, (3) small number of wavelengths required, (4) a simple routing algorithm, (5) high scalability and modularity, and (6) easy wavelength reuse.

FCCN ARCHITECTURE

We first explain the motivation for the FCCN architecture by considering a cubic network of eight nodes in Fig. 1, and an 8-node clique in Fig. 2. The nodes in both cases are labeled with octal numbers such that the labels of any two adjacent nodes differ in exactly one bit in their binary representations. We also add one more unused link to each node in both cases to emphasize the possibility of expanding the topologies by providing an extra degree to each node. A comparison of these two cases illustrates the trade-off between nodal degree and diameter. In Fig. 1, the nodal degree is 3 and the diameter is 3. Whereas in Fig. 2, by increasing the nodal degree to 7, only one hop is required to reach any node; thus the diameter is 1.

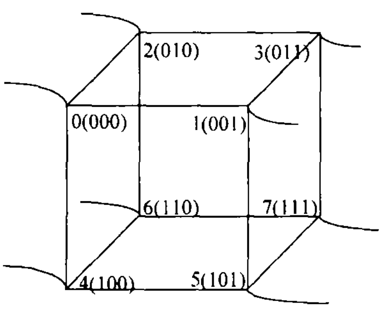

Fig. 1 A cubic network of 8 nodes

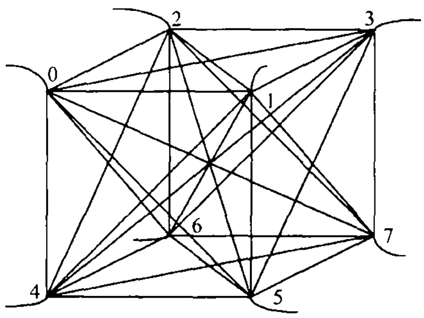

Fig. 2 A clique network of 8 nodes

The strategy of designing the logical topology here is to take the advantage of the smallest diameter of the 8-node clique while keeping a small and constant nodal degree. To achieve this goal, we substitute each node of the clique by another cubic network of 8 nodes. As a result, a 2-level FCCN (or just 2 – FCCN) is constructed by "fully connecting" 8 cubic networks in the manner of an 8-node clique, as shown in Fig. 3. We refer to these 8 1-FCCNs as 2nd level supernodes or 2-supernodes in a 2-FCCN. In general, an m-FCCN, $m > 1$, is constructed by fully connecting 8 ($m - 1$)-FCCNs in the manner of an 8-node clique. The 8 supernodes on each level are labeled according to the labels of the nodes in an 8-node clique. A 1-FCCN is simply the cubic network in Fig. 1. Therefore the nodal degree of an m-FCCN is no more than 4. In the rest of this section, we will describe the addressing scheme of the nodes, the exact node connectivity among the eight supernodes, and give a formal definition of the FCCN architecture.

Node addressing scheme

Each node in an m-FCCN can be uniquely identified by specifying the k-supernode, $k = 2, \cdots, m$, in which this node belongs to at each level except the first one, and the nodal position

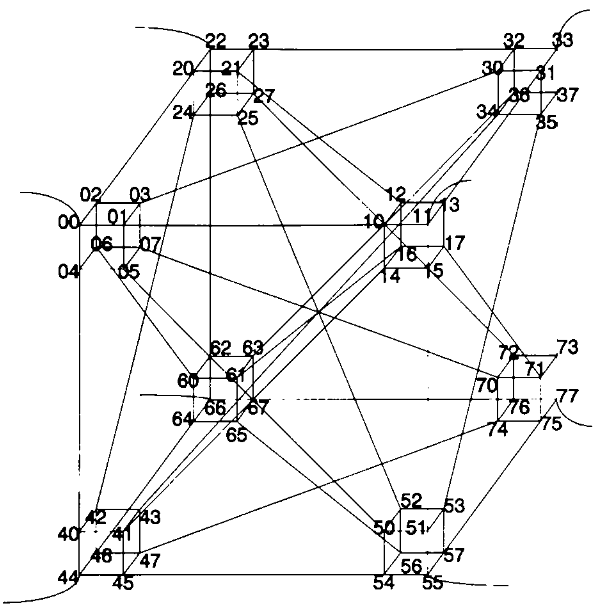

Fig.3 A - 2-FCCN

on the first level. Therefore, a node's address is given by a string of m octal numbers (b_m, b_{m-1}, $\cdots b_1$), where b_k, $i = 1, \cdots, m$, is an octal number specifying the k-supernode. For $m = 1$, the nodes are addressed according to Fig. 1. For example, consider a node labeled by (1 2 3). This node belongs to the 1st 3-supernode, 2nd 2-supernode, and is finally identified as the 3rd node on level 1. In the following we present an inductive definition of the addressing scheme.

Definition 1 (Node addressing scheme for an m-FCCN)

Each node in an m-FCCN is uniquely identified by a string of m octal numbers (b_m, b_{m-1}, $\cdots$, b_1).

1. For $m = 1$, the eight nodes are addressed according to Fig. 1.

2. For $m > 1$, given the nodes' addresses for an $(m-1)$-FCCN, i.e., ($b_{m-1}, \cdots, b_1$), the address of a node in an m-FCCN is given by (b_m, b_{m-1}, $\cdots$, b_1) if the node belongs to the b_mth m-supernode.

Node connectivity

Given the node addressing scheme in the last subsection, here we are concerned with the exact node connectivity of the 8 supernodes on every level other than the first one. The supernodes are fully interconnected through gateway nodes as defined in the following.

Definition 2 (gateway nodes)

For an m-FCCN, we define a kth level connected gateway node (denoted as k-CGN, $1 < k \leq m$) to be a node in ith k-supernode and it connects to another node in jth k-supernode, where $i \neq j$. We also define an unconnected gateway node (denoted as UGN) to be one that has an unused link for constructing a higher level FCCN. There are 8 UGNs for any m and they are always on mth level (the level number is therefore omitted).

1. For $m = 1$, all the nodes are UGNs and there are no 1-CGNs.

2. For $m > 1$, according to addressing scheme, nodes with $b_m = b_{m-1} = \cdots = b_1$, are UGNs.

3. Based on (1) and (2) and the fact that a UGN in an m-FCCN will become either a UGN or an $(m+1)$-CGN in an $(m+1)$-FCCN, a node with $b_k \neq b_{k-1} = b_{k-2} = \cdots = b_1$ in an m-FCCN for $1 < k \leq m$ is a k-CGN.

According to the above definition, each node in an m-FCCN, $m \geq 1$, is either a UGN or a k-CGN, $1 < k \leq m$. After some computation, it can be shown that the number of $(m-k)$-CGNs is 56×8^k, for $k = 0, 1, \cdots, m-2$.

For easy reference, we expand our notations for the gateway nodes further. We denote the 8 UGNs as UGN(i), $i = 0, 1, \cdots, 7$, according to the label of the supernode where this UGN resides. For example, the node (0 0 0 0) in a 4-FCCN is denoted as UGN(0). For a k-CGN, we decompose this address into three parts: (b_m, $\cdots b_{k+1}$), (b_k), and (b_{k-1}, $\cdots$, b_1). The first part specifies the node's address from mth level to $(m-k)$th level, conveniently denoted as α_{m-k} and α_0 implies that k is the highest level. The second part specifies the label of the k-supernode whete the k-CGN resides and let $b_k = i$. According to Def. 2, the elements inside the third part must be the same and let $b_{k-1} = \cdots = b_1 = j$. Therefore we denote such k-CGN, as a connected gateway node from the ith k-supernode to the jth k-supernode, as k-CGN (α_{m-k}, i, j). For example, the node (0 1 2 3 4 4 4 4) in an 8-FCCN and is denoted as 5-CGN (α_3, 3, 4), where $\alpha_3 = (0\ 1\ 2)$. And the node (0 1 2 3 4 5 6 7) is denoted as 2-CGN(α_6, 6, 7), where $\alpha_6 = (0\ 1\ 2\ 3\ 4\ 5)$.

The remaining part of defining an m-FCCN is to specify the interconnection of the 8 supernodes on each level. Def. 3 in the following provides this specification.

Definition 3 (Node connectivity for an m-FCCN on kth level)

1. For $k = 1$, the eight nodes are connected according to Fig. 1.

2. For $1 < k \leq m$, given the node connectivity for $(k-1)$th level, the node connectivity on kth level is given by: There exists a link between two kth level connected gateway nodes k-CGN(α_{m-k}, i, j) and k-CGN(α_{m-k}, j, i) for $i, j = 0, 1, \cdots, 7$.

For example, there is a link between the nodes (0 1 2 3 4 4 4 4) and (0 1 2 4 3 3 3 3) on 5th level in an 8-FCCN. By combining Defs. 1 and 3, we have an inductive definition for the FCCN architecture in Def. 4.

Definition 4 (m-FCCN)

An m-FCCN is a graph $G_m = (V_m, E_m)$ such that

1. For $m = 1$, it is equivalent to a cubic network of 8 nodes, as shown in Fig. 1.

2. For $m > 1$, given an $(m-1)$-FCCN, an m-FCCN is constructed by interconnecting eight $(m-1)$-FCCNs. The nodes in the m-FCCN are addressed according to Def. 1 and the interconnection of the 8 $(m-1)$-FCCNs is performed according to Def. 3.

In Fig. 4, we show a 3-FCCN, in which we purposely omit the links except those connecting from the Oth 3-supernode to the other seven 3-supernodes, and those connecting from the Oth 2-supernode to the other seven 2-supernodes inside the Oth 3-supernode.

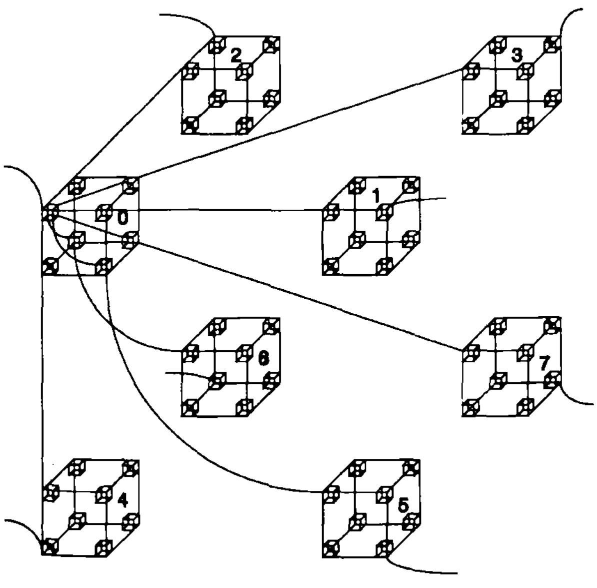

Fig. 4 A 3-FCCN (with partial links)

PROPERTIES OF FCCN

The total number of nodes in an m-FCCN, $|V_m|$, is given by 8^m since a higher level FCCN is always constructed from eight lower level FCCNs and the 1-FCCN consists of 8 nodes. The nodal degree is no more than 4, regardless of the network size. In this section we will derive other important properties of FCCN in Property 1-3. The number of edges (Property 1) determines the number of wavelengths required if wavelength reuse is excluded. Diameter (Property 2) is defined as the maximum of the minimum distances between any pair of nodes in the network in terms of hop distance. It therefore affects the average number of hops and as a result the network utilization. Superset (Property 3) determines the architecture's scalability, which is the architecture's ability to build a higher level architecture based on the lower level ones.

Property 1 (Nodal degree): The nodal degree is no more than 4, regardless of the network size.

Proof: It is obvious from the construction of the FCCN.

Property 2 (Number of links): $|E_m| = 2 \times 8^m - 4, \forall m$.

Proof: By induction

1. $|E_1| = 12$.

2. Given that $|E_{m-1}| = 2 \times 8^{m-1} - 4$ for $m > 1$

$|E_m|$ = number of edges for the 8 m-supernodes + number of edges interconnecting the 8 m-supernodes

$= 8 \times |E_{m-1}| + (8 \times 7)/2 = 2 \times 8^m - 4.$

Property 3 (Diameter): $D_m = 2\sqrt[3]{|V_m|} - 1, \forall m$.

Proof:

By observation, the diameter is given by two nodes, say n_1 and n_2, which must belong to different m-supernodes, say ith and jth respectively. By considering only mth level and $(m-1)$th level, D_m is given by the sum of a maximum distance from n_1 to the m-CGN(α_0, i, j) and 1 hop and a maximum distance from the m-CGN (α_0, j, i) to n_2. The second component refers to the one hop between the two connected gateway nodes in different m-supernodes. By the definition of diameter, the sum of the 1st and 3rd components is given by $2D_{m-1}$. Thus we have the following recurrence equation

$$D_m = 2D_{m-1} + 1 \text{ for } m > 1 \quad (1)$$

Now we prove the property using Eq. (1) and induction:

1. $D_1 = 2\sqrt[3]{8} - 1 = 3$.

2. For $m > 1$, given that $D_{m-1} = 2\sqrt[3]{|V_{m-1}|} - 1 = 2\sqrt[3]{8^{m-1}} - 1$.

Using (1), $D_m = 2 \times (2\sqrt[3]{8^{m-1}} - 1) + 1 = 2^{m+1} - 1 = 2\sqrt[3]{|V_m|} - 1$.

Property 4 (Superset):

An m-FCCN represented by $G_m = (V_m, E_m)$ has the property of $V_m \supset E_n$ and $E_m \supset E_n$, for $m > n$.

Proof: It is clear from the construction of a higher level FCCN.

Almost all the aforementioned regular topologies, such as hypercube, also possess the property of $V_m \supset V_n$ for $m > n$. However a regular topology, such as shufflenet, may not possess the property of $E_m \supset E_n$ for $m > n$. This property makes FCCN easy to be increased without requiring any reconfiguration of the previous topology.

ROUTING ALGORITHM AND HOP DISTANCE

Routing in an m-FCCN involves inter-supernode routing and routing in a cubic network of 8 nodes (termed as cubic routing for convenience). The latter is easily known by comparing the binary representation to determine the next route. The basic idea of routing in an m-FCCN is to route a packet to the correct "destination supernodes" in which the destination node resides on every level except the first level, i.e., inter-supernode routing. When the packet is finally delivered to the 1st level, the packet is delivered to the destination node using the cubic routing.

The kth level inter-supernode routing is performed by the connected gateway nodes on that level. For example, if the highest level that the source and destination differ in their supernodes' labels is k, say the source is in ith k-supernode and the destination is in jth k-supernode. The packet will be first routed from the source to the k-CGN that bridges ith k-supernode and jth k-supernode. After the packet is delivered to the jth k-supernode, the procedure repeats again to forward the packet to the correct destination supernode on a lower level. Cubic routing is also used when a packet is forwarded from a node inside a k-supernode to the supernode's gateway for the destination supernode.

In the following we present a routing algorithm for an m-FCCN based on the idea just described. The algorithm is a "self-routing algorithm". When a node receives a packet, it only uses its own address and the destination address to forward the packet. The algorithm guarantees that the packet will be delivered to the destination and in most cases the resulting path is a shortest path in terms of hops. In some cases, however, it can be shown that the resulting path is not a shortest path. Nevertheless, as we will show later, the average hop distance for this algorithm is reasonably low and is in the order of $\sqrt[3]{|V_m|}$.

Algorithm 1: (Routing algorithm for an m-FCCN)

Denote a destination node as d: $(d_m, d_{m-1}, \cdots, d_1)$ and the address of the node that receives a packet as s: $(s_m, s_{m-1}, \cdots, s_1)$. s is the source node when the packet was first sent out. Upon receiving a packet, a comparison of s and d is made. The routing decision is made according to the following:

```
  if {s = d}
    the packet received by d.                (arrives at the destination)
  or else {
    let s_i ≠ d_i, i = 1,…,m, and            (i is the highest level that s and d disagree)
    s_j = d_j for j > i
```

```
if { i = 1 }                                              (s and d belong to the same 2-supernode)
(1) route the packet from s to d using cubic routing.
    else {
        compare s_1 with d_i, if (s_1 = d_i)              (s is a CGN to the d_i th supernode at least
                                                           on the 2nd level)
(2) route the packet to the other supernode via
    this node (inter-supernode routing).
    else {
(3) route the packet to the node with address            (route the packet to an to the d_i th super-
                                                           node at least on CGN the 2nd level)
    (s_m, s_{m-1}, ..., s_2 d_i) using cubic routing.
        }
    }
}
```

Decision (2) involves inter-supernode routing whereas decisions (1) and (3) involve cubic routing. The following two examples illustrate the working of the algorithm. The horizontal arrows refer to the cubic routing and the vertical ones refer to the inter-supernode routing. The numbers above the horizontal arrows and next to the vertical arrows correspond to the routing decisions indicated in the algorithm. It is interesting to observe the routing pattern that involves alternating between routing to a connected gateway node and an inter-supernode routing. This pattern repeats until the packet reaches 1st level and is delivered to the destination by invoking decision (1).

In Property 5, we compute the average hop distance for an m-FCCN using routing Algorithm 1, denoted as H_m. Here we assume that each node in the network is equally likely to be the source and destination nodes.

Property 5 (Average hop distance):

The average hop distance for an m-FCCN using Algorithm 1 is given by:

$$H_1 = 1.5$$

$$H_m = \frac{105}{64} \times 2^{m-1} + \frac{14}{64}m - \frac{23}{64} \in O\sqrt[3]{|V_m|}) \quad \text{for } m > 1 \qquad (2)$$

Proof:

Proof for $m = 1$ is simple. Since the cubic network is symmetric, we can consider any node as the source node. Since the 8 nodes, including the source node, are equally likely to be the source node, H_1 is given by $\frac{1}{8} \times (3 \times 1 + 3 \times 2 + 1 \times 3)$.

For $m > 1$, we first consider the cases of $m = 2$, 3 and then derive a general expression for the average hop distance.

$m = 2$

1. s is a UGN (with probability 1/8)

(1) d is in the same 2-supernode as s (with probability 1/8): H_1

(2) d is in another 2-supernode (with probability 7/8): $H_1 + 1 + H_1$

2. s is a CGN (with probability 7/8)

(1) 1 d is in the same 2-supernode as s (with probability 1/8): H_1

(2) d is in another 2-supernode (with probability 7/8): $5/7\ H_1 + 1 + H_1$

$m = 3$

1. s is in the 2-supernodes associated with the UGNs. We label this set of nodes as S_o (with probability 1/8)

(1) d is in the same 2-supernode as s (with probability 1/8): H_2

(2) d is in another 2-supernode (with probability 7/8)

1) s is the UGN (with probability 1/8): $(H_1 + 1 + H_1) + 1 + H_2$

2) s is not the UGN (with probability 7/8): $(5/7\ H_1 + 1 + H_1) + 1 + H_2$

2. s is not in S_o (with probability 7/8)

(1) d is within the same 2-supernode as s (with probability 1/8): H_2

(2) d is in another 2-supernode (with probability 7/8):

1) s is a CGN to S_o (with probability 1/8): $\{H_1 + 5/7(1 + H_1)\} + 1 + H_2$

2) s is not a CGN to S_0 (with probability 7/8): $\{5/7\ H_1 + 5/7(1 + H_1)\} + 1 + H_2$

Other cases of m can be derived similarly. In general, we have

$$H_m = H_{m-1} + \frac{7}{8} + \frac{42}{64}H_1 + \frac{42}{64} \times \{(2^{m-2} - 1)H_1 + 2^{m-2} - (m-1)\} + \frac{42}{64}(m-2), \quad \text{for } m > 1 \tag{3}$$

By repeated substitution, Eq. (3) can be expressed as

$$H_m = H_1 + \frac{14}{64}(m-1) + \frac{42}{64} \times \{(2^{m-1} - 1)H_1 + 2^{m-1} - 1\} \tag{4}$$

By substituting $H_1 = 3/2$ into Eq. (4), we obtain Eq. (2).

The average number of hops is an important parameter to evaluate the network performance, because it is inversely proportional to the network channel efficiency. In property 6 the network channel efficiency and some related performance, such as network throughout and per user throughout, are studied.

Property 6 (Some network performances related to the number of hops)

1. The channel efficiency(η):

$$\eta = \frac{1}{H_m} \tag{5}$$

2. The network throughout(C):

$$C = \eta(2 \times 8^m - 4) \approx 2 \times 2^{2^m} \propto O(N^{\frac{2}{3}}) \tag{6}$$

3. The per user throughout(c):

$$c = 4\eta \propto O(\frac{1}{\sqrt[3]{N}}) \tag{7}$$

Proof: The proof can be found in the literature (Hluchyj et al., 1991).

WAVELENGTH REUSE AND SCALABILITY

Wavelength reuse

Wavelength (spatial) reuse technique allows a particular wavelength to be used in more than one place in a lightwave network. Although there is an enormously used bandwidth in a single optical fiber, it can be proved to be insufficient for accommodation of enough wavelengths if the number of the nodes is too large. The channel spacing required is not small enough to provide a large number of channels, due to the limitation of the optical technique, e.g., the insufficient selectivity, laser chirp, or component instabilities. Wavelength reuse technique is thus essential in solving the problem of insufficient number of wavelengths.

In a lightwave network, wavelength reuse is associated with the physical topology. Here we choose the simple broadcast passive stars as our physical topology. That means there is not any wavelength conversation and wavelength routing cross connector in the physical topology. Owing to the highly incremental structure, FCCN lends itself naturally to wavelength reuse by just adding a few wavelengths to the previous wavelength assignment. Examples of 2-FCCN configuration using passive star couplers are shown in Fig.5. In the figure the previously assigned wavelengths are not labeled, and " + " means adding some new wavelengths to the previous wavelength assignment to configure a higher level FCCN. The number of wavelengths required after applying wavelength reuse can be computed from the number of links in the FCCN. In 1-FCCN, 12 wavelengths are needed, which are the same as the number of edges in the network. In 2-FCCN, an additional 28 wavelengths are needed, which is the number of links required for interconnecting the eight 2-supernodes.

Property 7 bellow involves the number of wavelengths required in an m-FCCN after applying wavelength reuse, denoted as W_m, and the wavelength reuse efficiency (η_m), which is defined as $\frac{|E_m|}{W_m}$.

Property 7 (Wavelength reuse in an m-FCCN):

The number of wavelengths required in an m-FCCN after applying wavelength reuse and the wavelength reuse efficiency are given respectively by

$$W_m = 12 + 28 \times (m - 1) \tag{8}$$

$$\eta_m = \frac{2 \times 8^m - 4}{12 + 28 \times (m - 1)} \tag{9}$$

Proof: $W_1 = 12$ (number of edges in 1-FCCN) and each additional level will need another 28 wavelengths (number of links connecting 8 supernodes). For η_m, it is derived directly from

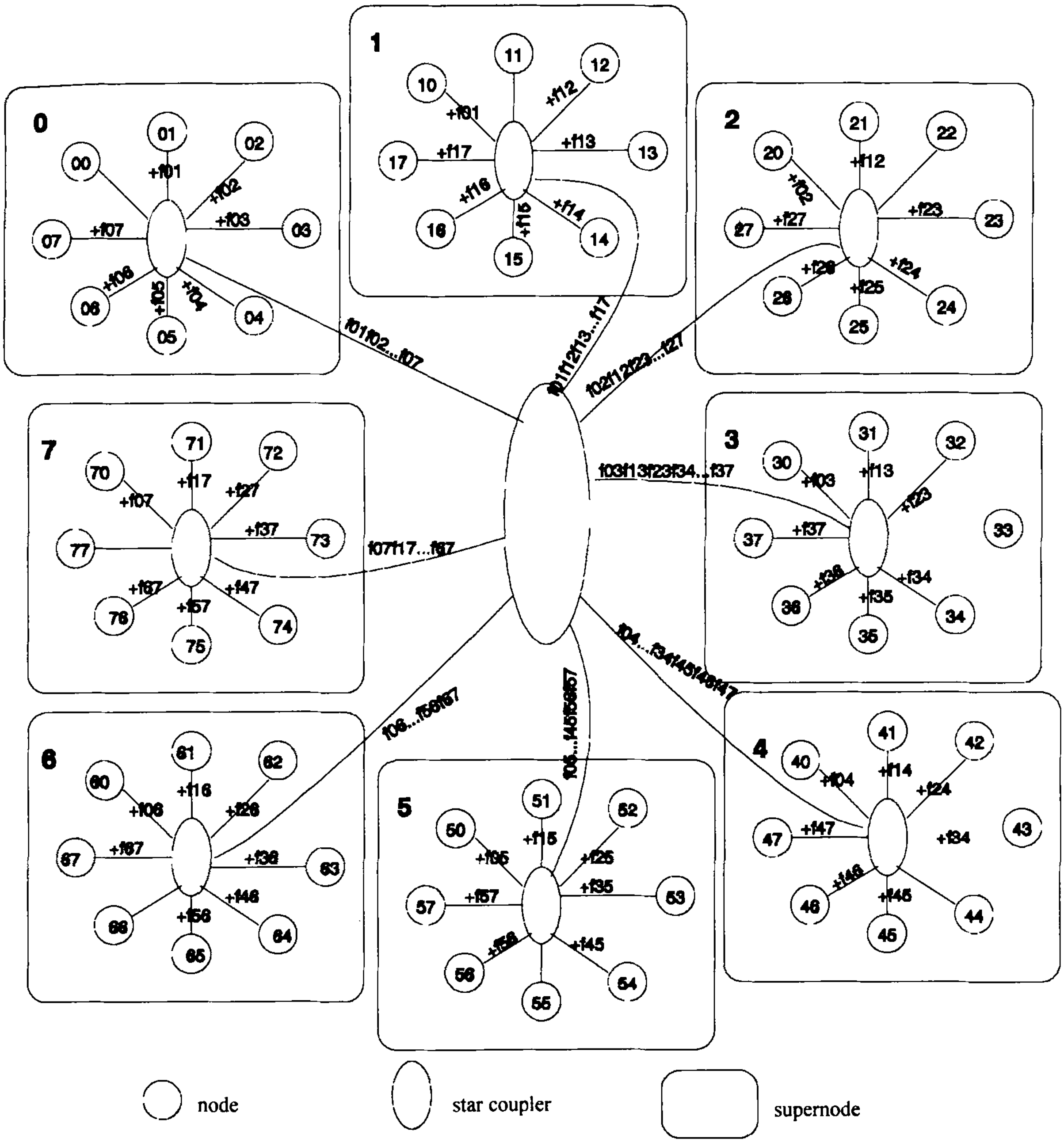

Fig. 5 2-FCCN configuration using passive star couplers

(8) and Property 2.

We have also derived η_m for hypercube with N nodes ($N = 2^m$) and Mesh torus with N nodes:

$$\text{Hypercube: } \eta_m = \frac{\frac{mN}{2}}{12 + \frac{(m-3)N}{2}}$$

for $N \leq 64$ (10a)

$$\eta_m = \frac{\frac{mN}{2}}{12 + 96 + \frac{(m-6)N}{2}}$$

for $64 < N \leq 512$ (10b)

$$\text{MSN}: \eta_m = \frac{2N}{10 + \frac{12 \times \frac{N}{8}}{2}}$$

$$\text{for } N \leq 64 \qquad (11a)$$

$$\eta_m = \frac{2N}{10 + 48 + \frac{32 \times \frac{N}{64}}{2}}$$

$$\text{for } 64 < N \leq 512 \qquad (11b)$$

We compare η_m for m-FCCN, hypercube and MSN for the cases of 64 nodes and 512 nodes and the result is summarized in the following. The results in Table 1 indicate that FCCN is very efficient in exploiting the wavelength reuse technique due to its highly scalable structure, when compared with the other two topologies. The efficiency will also increase as the network size increases.

Table 1 Wavelenght reuse efficiency comparison of m-FCCN, hypercube and MSN.

N	η_m for m-FCCN	η_m for hypercube	η_m for MSN
64	3	1.8 ($m=6$)	2.2
512	15	2.6 ($m=9$)	5.5

Scalability

Scalablity (one additional user can always be added) is a basic requirement in lightwave network design. Scalabilty is defined to be the property that one more node may always be added to a network, thereby permitting service to be offered to an arbitrarily large population of users spread over some arbitrary service domain. This definition of scalablity implies that any scalable architecture will be required to have the property that the number of wavelengths is independent of the number of nodes in the network. But if this requirement is satisfied, the average number of hops will increase rapidly with the number of nodes. So there exists no really scalable network.

Property 8 (Scalabity):

FCCN is a scalable network, because the number of wavelengths required is the cubic root of the number of nodes, i.e., $W \in \sqrt[3]{N}$, here W and N is the number of wavelengths and nodes, respectively.

Proof: It can be obtained from Equation (8).

CONCLUSION

A highly scalable network is proposed in this paper. The architecture, named as FCCN, has small and constant nodal degree. It has good scalability, routing complexity and efficiency of wavelength reuse. Also, the FCCN gives a much smaller diameter and average hop distance. Compared with other topologies (e.g., Hypercube and MSN), the network has highest wavelength reuse efficiency.

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