A New Logical Topology Based on Barrel Shifter Network over an All Optical Network

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Abstract

This paper presents a new logical topology SBS-net, a Scalable Barrel Shifter network to be used as a logical topology over an all-optical network using WDM. The major emphasis of the present work is to improve upon the scalability issue. This SBS-net connects any arbitrary numbers of nodes as opposed to the Barrel Shifter, de Bruijn graph and Shufflenet. The average hopping distance between two nodes using this topology is smaller compared to that in de Bruijn Graph, Shufflenet & GEM net.

1. Introduction

This paper considers the problem of enhancing the scalability of an optical network [4], [5], [6], [3], by overlaying a new logical topology over a wavelength routed all optical network physical topology. Scalability, indeed, is one of the primary concerns in designing an optical topology due to high prices of components. On an all-optical network physical topology, light paths can be set between any pair of nodes. By carefully selecting lightpaths, a logical topology can be overlaid upon the physical topology of the network. Node pairs that are not directly connected via lightpaths must use a sequence of lightpaths through some intermediate nodes for communication between them. De Bruijn graphs [1], GEM-nets [2] are examples of such multi-hop [7] logical topologies. The present paper compares the features of all different existing logical topologies with a new topology SBS-net.

2. SBS-net Topology

This topology assumes exactly same structure as that of a re-circulating single-stage *Barrel-shifter* when number of nodes, $N=2^n$, with an undirected link from node c_j to c_k, called *neighbor* of c_j, iff $c_k \in \{c_j \pm 2^i \bmod N\}$, where i=0,1, …, n-1. Each node has exactly 2n-1 links attached to it. Diameter of the graph is $\log_2 N/2$.

When $2^{n-1}<N<2^n$, a node $c_{j'}$ has neighbors, $c_{j'} \pm 2^i \bmod 2^n$, i=0,1,…..,n-1. All neighbors may not be present. So number of links used by a node may be less than 2n-1. We also proposed an improvised utilization strategy for unused links. With this improvised strategy the regular interconnection pattern of a node with its neighbors is violated and node $c_{j'}$ can have neighbors other than the nodes $c_{j'} \pm 2^i \bmod 2^n$, which are called *temporary neighbors*. Their addresses are $c_{j'} \pm 2^q + 2^{q-1}$, $q \in \{0,1, \ldots\ldots, n-1\}$.

3. Routing Strategy for $N=2^n$

A region refers to a set of nodes between two neighbors.

Whole region: If a region with respect to a node has both its boundary nodes present, it is said to be a whole region.

Broken region: When $2^{n-1}<N<2^n$, a node may not have all its neighbors. In this case a region may not have both its boundary nodes, it is said to be a broken region.

Property 1: In a region AB, if P is any arbitrary node then if P is closer to B(A), P can be reached from B(A) in fewer number of hops when leaps are to be taken in 2's power.

Property 2: The path to P thru B(A) is the shortest path; P cannot be reached via any other neighbor with fewer number of hops.

Routing, here, is very straightforward. Each node keeps a data structure containing information about their neighbors. When a *source* wants to send data to a *destination*, it checks to see which region the destination belongs and sends data to the nearer boundary. If boundary node itself is the intended node, i.e., source has a direct link to destination, the job is done. Otherwise we try to find out next region with respect to the node we just reached, which encloses destination. In effect the enclosing region gradually narrows down and eventually destination coincides with a boundary. Maximum possible hopping in this routing is $\lceil \log_2 N/2 \rceil$ or $\lceil n/2 \rceil$.

3.1. Problem When $2^{n-1}<N<2^n$

When $2^{n-1}<N<2^n$, all neighbors of a node may not be present. Therefore, a few of the regions may be either not present or broken. Absence of an entire region has no effect over routing. But when there is a broken region, routing via the only existing boundary instead of the nearer one may increase required hopping.

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4. Revised Routing Strategy for $2^{n-1}<N<2^n$

Here, when a source s wants to send data to any destination d, d could belong to a whole region as before; in this case the routing is same as described in the previous section. Otherwise d belongs to a broken region. In this case s looks for all neighbors of d ($d\pm2^i$, i=0,1, …, n-1). It then checks to see which of them (one or more) lie in one of its whole regions. This check ensures both the existence of that neighbor, as well as a viable alternative, called *target* to send data to. At the most $\lceil \log_2 2^n/2 \rceil$ or $\lceil n/2 \rceil$ hops are required to do so. So maximum number of hops required is $\lceil n/2 \rceil+1$.

Property 3: When $2^{n-1}<N<2^n$, for a node A in a broken region of another node B, at least one of A's neighbors fall in a whole region of B.

4.1. Problem of Porous Regions

A porous region with respect to a node R is a region such that both of the end nodes of it exists while some of the intermediate nodes are not there. To send data at some existing node in this type of regions, if source chooses the nearer boundary and transfer data, for that boundary or some other subsequent nodes along the path the destination may fall in a broken region.

This problem does not exist when $N<2^{n-1}+2^{n-2}$, as no node can have a region spanning more than 2^{n-2} nodes. For all such porous regions, one of its terminals would be in 1st & 4th quadrant each. When the destination is $c=11a_{n-3}\dots a_0$, i.e., c is in 4th quadrant, routing entails some additional considerations, such as,

I. If the destination is in a whole region, i.e., its terminals are $t_1=11a_{n-3}\dots a_0$ & $t_2=11a_{n-3}\dots a_0$, routing is as usual.

II. Otherwise, c is either in porous or broken region; we choose its farthest neighbor ($c\pm2^{n-1}$), the target, in 2nd quadrant and send data to it. All imaginable enclosing regions (since longest region contains 2^{n-2} nodes) of target must be full. Again maximum number of hops required is $\lceil n/2 \rceil+1$.

5. Unused Links Utilization Policy

Consider a node R. We bifurcate R's broken region(s) as soon as it(they) is(are) at least half full and attach its unused link with its(their) middle node. This effectively creates the longest possible whole region with length 2^i, i=0,1, …, n-2 out of that broken one. Routing to this newly formed region is thus simplified.

A node may have half/more than half full region(s), so its unused link(s) is(are) required to connect to its(their) middle node(s).Whereas the node itself may be one such middle node of other node(s). We start from node 0 and move anticlockwise to utilize unused links at each node, if there is any. Both the origin node and terminal node are considered.

5.1. Impact on Neighbor Set of a Node

When a node grants link request from elsewhere, it implies that this node is the middle node of a broken region of another node. Its own neighbor set and consequently its regions are changed. A region of 2^l nodes is formed by links 2^l & 2^{l+1}. Whenever a link is set up with the middle node of such a region, it gets a new neighbor 2^l+2^{l-1} nodes apart. Therefore this will always bifurcate its own 2^l-nodes region, be it broken or whole.

The maximum possible hopping for routing in these newly formed regions is $\lfloor n/2 \rfloor$.

6. Performance

For a single-stage barrel shifter the minimum number of re-circulations B is upper bounded by $B \le \lceil \log_2 N/2 \rceil$. When $2^{n-1}<N<2^n$, maximum number of re-circulations required is shown to be $\lceil \log_2 2^n/2 \rceil+1$ or $\lceil n/2 \rceil+1$, just one hop greater than the regular one.

7. Conclusion

SBS-net introduces a higher degree of scalability in multihop WDM optical network, compared to the existing topologies such as de Bruijn Graph and Shufflenet etc. by extending the routing strategy of Barrel Shifter network to connect any number of nodes. A method to utilize unused links when total number of nodes in the modified network is not power 2 is also presented in this paper.

8. References

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