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A CONGESTION CONTROLLED LOGICAL TOPOLOGY FOR MULTIHOP OPTICAL NETWORKS

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Abstract : This paper considers the problem of designing the logical topology for any wavelength routed optical network, given the traffic matrix. A heuristic algorithm is proposed here for designing topologies based on De-Bruijn graph and compare our results with those obtained through deterministic approach. De-Bruijn graph is selected in this context as the logical topology because of some of its characteristic features like simple routing scheme, low diameter and small degree.

Keywords: Optical networks, traffic, congestion, hop distance.

1.INTRODUCTION

Optical networks use interconnection of high speed wide-band fibres [1] for transmitting information between any source destination pair of nodes. Wavelength division multiplexing (WDM), is the approach used in optical networks, for exploiting the huge bandwidth of the optical fibres where several communication channels [3] operate at different wavelengths on single fibres. The physical topology consists of the nodes and fibre links [4] in the network. On an all optical network physical topology, end-users in a fibre-based WDM network may communicate with one another via all-optical channels referred to as lightpaths. The set of light paths along with the nodes constitutes the logical topology [6] [7] which can be imposed over physical topology by carefully selected connectivity pattern providing dedicated connections between certain pair of nodes. Unlike physical topology, the logical topology can easily be configured to adapt to changing traffic. The logical topology may be represented by a [5] graph structure G=(V,E) where V is the set of nodes and E is the set of edges with each node of G representing a node of the network and each edge (denoted by u->v) representing a light path from node u to node v. In an N-node network ,if each node is equipped with N-1 transceivers and if there are enough wavelengths on all fibre links then every node pair would be connected by an all optical light path. But the cost of transceivers lead us to equip each node with only a few of them resulting to limit the number of WDM channels in a fibre to a small value. Thus only a limited number of light paths may be set up on the network, thus restricting the degree of each node in the network. The traffic destined to a node that is not directly receiving from the transmitting node must be routed through the intermediate nodes. The overlaid topology is referred to as multihop logical topology. De-Bruijn graph [2] , Ring-net, GEM-net, Shuffle-net etc are example of such logical topologies.

Congestion , the maximum load offered to any logical link , is a good metric for determining the efficiency in the network. The smaller the value of congestion, the better will be the network throughput. Given the traffic matrix and the physical topology, our objective is to design a logical topology so as to maximize the network throughput or minimize the congestion. The logical topology, implemented in this paper is a De-Bruijn graph, which has the characteristic features such as simple routing scheme, low diameter and small degree [8]. Thus the problem of logical topology design reduces to that of mapping of physical to logical nodes. In this paper we use a heuristic solution to map the physical nodes to the respective logical nodes of our regular topology-a De-Bruijn graph, depending on the traffic flowing between any source-destination pair for maximization of network throughput and compare the results obtained through this heuristic approach with that obtained through deterministic approach which involves a computation of the order of **n!**.

2.PROBLEM FORMULATION

Given a set of nodes X=(x1,x2,.......,xn) associated with a traffic matrix Tr where Tr(xi,xj) is the traffic flowing from node xi to xj and the set of positions in the De-Bruijn graph network expressed as Y=(1,2.......,n) where n is the number of nodes in the network. Consider the number of nodes (n) in the network to be expressed by the

mathematical relationship $n=\Delta^d$ where Δ is the degree and d is the diameter of the De-Bruijn graph.
We have to map n physical nodes of the network to the n vertices of the corresponding De-Bruijn graph such that total traffic congestion is minimal that is we have to minimize

$$\sum_{i,j} Tr(xi, Xj)*hop(xi, xj)$$

where hop(xi,xj)=minimum hopping distance between nodes xi and xj.
A deterministic solution involving exhaustive enumeration would necessitate O(n!) possibilities leading to exponential order of computation which makes the problem NP complete. The proposed heuristic solution gives near optimum result in polynomial time.

3.ALGORITHM

Step1: Sort the source-destination (s-d) pairs based on the corresponding value obtained from traffic matrix in descending order.
Step2 : Identify the chains that is their beginning and end positions in the sorted order of s-d pairs. Here a chain consists of a set of serially ordered s-d pairs where either the source or destination of each pair can be thought of as a parent or child of a member of the nodes which belong to the chain.
Step3 : Calculate the mean value of traffic flowing in the network and associate a parameter value for each chain where mean is defined as

$$\text{Mean}= (1/n^2)\ \Sigma\ \text{traffic\_value} \quad \text{For all s-d pairs}$$

And parameter value is calculated as

$$\text{Parameterval}= \sum_{\text{s-d pairs } \varepsilon \text{ a chain}} (\text{traffic\_value- mean})$$

Step4 : Sort the chains in descending order of their parameter values.

Step5 : Start with the sorted chains from top to bottom where both the source and destination are not assigned. First a source is randomly assigned to a vertex which is unallocated. Then, find an unallocated freechild of the source from the graph assign it to the destination. While scanning other s-d pairs of the chain if source is only assigned then for assigning destination use the same technique of finding freechild. If only destination is assigned then use find unallocated freeparent. If both source and destination is assigned nothing is done.
This terminates as soon as all the nodes have been allocated or mapped.

4.EXAMPLE

Consider a De-Bruijn graph having delta value 3 and diameter value 2 that is with 9 nodes.The traffic matrix associated with the graph is given below.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	00	03	02	09	12	34	19	08	05
2	12	00	02	13	10	03	06	07	09
3	06	08	00	14	04	03	17	19	03
4	15	12	10	00	08	07	12	09	05
5	07	04	10	01	00	09	04	03	01
6	18	04	19	06	06	00	33	03	09
7	09	10	11	12	05	06	00	07	08
8	11	02	03	04	05	10	12	00	09
9	09	06	13	05	20	13	07	11	00

Step1: Sorting the s-d pairs we get the following order 0)1-6, 1)6-7, 2)9-5, 3)6-3, 4)1-7, 5)3-8, 6)6-1, 7)3-7, 8)4-1, 9)3-4, 10)2-4, 11)9-6, ………..

Step2:The chains are a)1-6,6-7 b)9-5 c)6-3 d)1-7 e)3-8 f)6-1 g)3-7 h)4-1,3-4,2-4 I)9-6,9-3 j)……

Step3:The mean value of traffic is 8.037.

The parameter values associated with each chain is (a)50.93, (b) 11.96, (c)10.96, (d)10.96, (e)10.96, (f)9.96, (g)8.96, (h)17.89, (I)11.93, (j)-142.52.

Step4:The chains sorted according to parameter value in descending order to get the order (a), (h), (b), (I), (c), (d), (e), (f), (g), (j).

Step5: First s-d pairs of chain (a) are allocated. Now for s-d pair 1-6 randomly allocate node 1 to node 01. So node 6 is allocated to a freechild of node 01 which is 10 in this case. Now for next s-d pair 6-7 in chain(a) node 6 is already allocated. So to allocate node 7 find freechild of node 6 i.e. freechild of 10 which is 00 in this case. If in the start of a new chain both source and destination are not allocated then source is chosen randomly from the set of free nodes as has been done for chain b) with s-d pair 9-5.

In this fashion the mapping of logical to physical nodes is given below

01→1
10→6
00→7
20→4
02→3
12→2

21→9
11→5
22→8

5.TIME COMPLEXITY

The proposed heuristic has a time complexity of O(n^2*logn).

6. EXPERIMENTAL RESULTS

In this section the results of simulation is summarized. Deterministic approach shows slightly better value of the congestion metric when compared with the heuristic approach. As the network size increases the deterministic approach fails to converge but this heuristic gives the near optimal results in reasonable time.

TABLE 1

Degree of De-Bruijn graph (Δ)	Diameter of the graph (d)	No of nodes in the graph (Δ^d)	No of obs	Optimal congestion value	Congestion value from heuristic	Variation in results
2	3	8	1	558	566	1.83%
			2	645	678	5.12%
			3	2002	2113	5.54%
3	2	9	1	989	996	0.71%
			2	1026	1049	2.24%
			3	3343	3381	1.14%

7.CONCLUSION

This paper aims at designing a logical topology as a function of traffic matrix over a wavelength routed physical topology so as to reduce the congestion of the network. Exhaustive solution for a De-Bruijn graph is not feasible when the number of nodes exceeds 9 as it would take years to compute. However the heuristic has O(n^2 *log n) time complexity which makes it feasible even for large networks where the number of nodes is very high. From the Experimental results given above we find that the heuristic gives near to optimum solution and never degrades to worst case value of congestion.

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