Traffic Grooming based on Light-trail in Wavelength Routed Optical Network

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***Abstract*—**In wavelength routed optical networks, the number of wavelength channels is limited due to technological limitation and each wavelength channel as well as each lightpath support traffic in the Gbps range. In reality, we observe that the majority of individual connection request require a bandwidth in the Mbps range. Therefore, to utilize the network resources like bandwidth, transceivers effectively, we need to be efficiently groomed or multiplexed several low speed traffic requests into a high speed/capacity lightpath. The entire wavelength channel of this lightpath is used exclusively by the source-destination node pair. Data cannot be transmitted or received by the intermediate nodes along the lightpath. Therefore, the wavelength capacity again may be underutilized. To overcome this drawback a novel technique known as light-trail came into existence. The light-trail is a generalized version of the lightpath to avoid the inability of intermediate nodes to use a wavelength connection. In this work, we have investigated the static traffic grooming problem for wavelength routed optical networks. The work proposed a traffic grooming algorithm to maximize the network throughput for wavelength routed mesh optical networks using static light-trail. The effectiveness of the proposed approach has been established through extensive extensive simulation on different sets of traffic demands with different bandwidth granularities for different network topologies and compared the approach with existing algorithms.

***Index Terms*—**lightpath, light-trail, traffic grooming, wavelength channel, transceiver, wavelength division multiplexing(WDM).

I. Introduction

The rapid increase of the Internet traffic demands large volume of bandwidth. The Wavelength Division Multiplexing (WDM) is an emerging technology that leads to support tremendous bandwidth of the optical fiber to meet this need by allowing simultaneous transmission of traffic on many nonoverlapping wavelength channels. In WDM network, a lightpath may be established to carry traffic from source node to a destination node, i.e. to support unicast communication. A lightpath is an all optical communication channel that passes through intermediate nodes between a source and single destination without optical-electronic-optical conversion. A lightpath is implemented by selecting a path of physical links between the source and destination nodes, and reserving a particular wavelength on each of these links for the path. A lightpath must use the same wavelength on its entire links of the route if there is no wavelength converter at intermediate nodes, and this is known as wavelength continuity constraint [1]-[2]. Each of these wavelength channel/lightpath has tremendous data transfer rate (in the order of gigabytes per second) or bandwidth (in the order of several gigabytes), but in reality we observe that the most of the applications or individual connection requests have bandwidth requirement far less compared to the capacity of single wavelength channel/lightpath. Hence, in order to utilize the lightpath or wavelength channel capacity efficiently multiple low bandwidth traffic requests are multiplexed or groomed into a single lightpath is known as traffic grooming.

In a lightpath intermediate nodes do not have the grooming facility, this lead to underutilization of optical fiber bandwidth. We can overcome this drawback by allowing the intermediate nodes of a lightpath for adding and dropping of traffic, i.e. replacing lightpath with a light-trail. Similar to a lightpath, a light-trail is an all optical connection. The light-trail concept in optical networks was first proposed in [14]-[15]. A light-trail can be considered as a generalization of a lightpath leading to multiple users being able to access an optical path resulting in excellent provisioning and resource utilization. Since, a light-trail allows the nodes (other than the source and the destination) on the optical connection to access the optical path by either inserting or receiving data through the light-trail, which makes possible finer bandwidth granularity control and more efficient utilization of the optical bandwidth. An example [17] of a light-trail with four nodes is shown in Fig.1, where node S is called the convener node and node D is called the end node, nodes A and B are called the intermediate node of a light-trail. Here, node S, A and B can add traffic, and similarly node A, node B, and node D can drop traffic. Light-trail can be viewed as an optical bus between the convener and end nodes, with the characteristic that intermediate nodes can also access this bus, in contrast to a conventional lightpath.

The traffic grooming is a process of multiplexing or grouping of several low bandwidth traffic into a high capacity lightpath or light-trail. In order to nature of traffic pattern, the traffic grooming problem is classified into static traffic grooming and dynamic traffic grooming. The information about each traffic stream i.e., source, destination, and bandwidth requirement is known in advance. In case of dynamic traffic grooming, client traffic is dynamic in nature i.e., traffic (source, destination, and bandwidth requirement, call duration) arrive to the network and depart from the network following some manner.

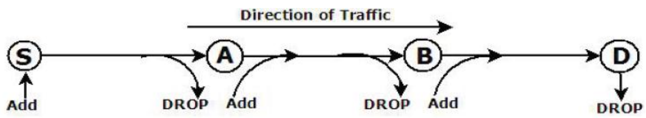

Fig. 1 An example of a light-trail

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The work proposed in this paper is based on light-trail concept for the static traffic grooming problem in wavelength routed WDM mesh networks with a limited number of wavelengths per fiber link and transceivers per node. The proposed approach Longest Light-trail Maximum Load (LLTML) tries to tightly pack the traffic on light-trails and allows single-hop grooming. The objective of this work is to maximize the network throughput in terms of total successfully routed traffic. The results show that the proposed approach gives significantly better performance with respect to the existing traffic grooming algorithms, Maximizing Single-Hop Traffic (MST)[3] and Shortest-path First Traffic Grooming (SFT) [4].

The rest of the paper is organized as follows: Section II focuses on some of the previous work related to this field. Problem formulation is presented in Section III. Our proposed approach is described in Section IV, where we explained our proposed algorithm with the corresponding pseudocode and analysis the complexity of the algorithm. In Section V, we compared our algorithm with an existing traffic grooming algorithm. A conclusion is drawn in Section VI.

II. Previous Work

The traffic grooming is one of the important and practical problem to design wavelength routed optical network and it is receive significant research attention in today. The work in [3]-[7] investigated the static traffic grooming problem using lightpath concept with the objective of maximizing the network throughput in terms of total successfully routed low-speed traffic. The dynamic traffic grooming problem is considered using lightpath [8]-[13] and using light-trail approach [14]-[17] for wavelength routed WDM networks.

Zhu and Mukherjee in [3] investigated the node architecture for WDM optical networks to support traffic grooming capability and presented an integer linear programming (ILP) formulation of the traffic grooming problem. They partitioned the traffic grooming problem into four independent subproblems: (i) determine the virtual topology, (ii) route the lightpaths over the physical topology, (iii) optimally assign wavelength to the lightpaths, and (iv) route the low-speed traffic on the virtual topology. They proposed two heuristics namely, Maximizing Single-Hop Traffic (MST) and Maximizing Resource Utilization (MRU), to solve the traffic grooming problem with the objective of improving the network throughput in terms of total successfully routed traffic. The MST attempts to establish the lightpaths between source-destination pairs with the largest traffic demand subject to the availability of transceivers at the two end nodes and the availability of wavelength in the path connecting two end nodes. The MRU attempts to construct the lightpaths according to maximum resource utilization value which is a ratio between node-pair traffic and its hop-count. Yoon et al. [4] proposed static traffic grooming algorithm called Shortest-path First Traffic Grooming (SFT) in WDM mesh networks that improves performance compared to the previous MST algorithm. The SFT algorithm uses both fixed routing based on shortest path and adaptive routing. The algorithm first creates lightpaths for connection requests using shortest paths, and adaptive routing is used for those connection requests which are not established by shortest paths. Bhattacharya et al. in [5] proposed a traffic grooming algorithm to maximize the network throughput and reduce the number of transceivers used for wavelength-routed mesh networks. They used dynamic path selection strategy for routing requests which selects the path such that the load on the network gets distributed throughout. They claimed that the dynamic path selection based traffic grooming algorithm performs better than MST algorithm. In [6], Lee et al. proposed a traffic grooming algorithm that calculates every available shortest edge disjoint paths (EDPs) for each source-destination pair, and store in a table called EDPT. It then calculates the resource utilization rate per hop for each connection request and finally, considers a request with the largest value of the resource utilization rate, and if sufficient resources are available on any one of the path in EDPT corresponding to the selected request, then a lightpath is set up. If there are not enough resources to set up a lightpath, the algorithm tries the next connection request in the list. They claimed that EDP based static traffic algorithm performs better than MRU algorithm. In [7], De et al. studied the problem of static multi-hop traffic grooming problem with the objective of maximizing the network throughput for wavelength routed mesh networks. They mapped the traffic grooming problem into the clique partitioning problem and proposed a heuristic algorithm Traffic Grooming based on Clique Partitioning (TGCP), to handle the general multi-hop static traffic grooming problem. The algorithm TGCP performs better than the existing traffic grooming algorithms MST and MRU.

The dynamic traffic grooming problem using lightpath for wavelength routed WDM networks is considered in [8]-[10]. The problem of logical topology design using minimum network resource for dynamic traffic grooming to meet the given traffic blocking probability requirements is studied in [8]. They formulated this problem into an ILP and proposed a heuristic to obtain near optimal solution. Zhu et al. in [9], presented an auxiliary graph model and proposed an integrated grooming algorithm based on auxiliary graph model to solve the traffic grooming problem. They proposed several grooming policies and traffic selection methods based on this model and evaluated their performance for different network topologies. Yao et al. addressed the two-layered dynamic traffic grooming problem under resource utilization constraint and generalized wavelength continuity constraint i.e. use wavelength conversion facility in [10]. Authors introduced a link bundled auxiliary graph (LBAG) model and proposed the simplified auxiliary graph with link bundling (SAG-LB) method to find path and assign wavelength for a new lightpath. They proposed constrained integrated grooming algorithm (CIGA) based on LBAG model and showed that the grooming policy influences the resource utilization by determining the weight of the auxiliary graph. The dynamic traffic grooming under distributed environment is considered in [11]-[13]. Crouser et al. [11] provided distributed traffic grooming algorithm for path topology and a static virtual topology to support it. De et al. [12] presented a distributed algorithm for dynamic traffic grooming problem that allocates resources and perform grooming operation based on local information available on each node. Coimbra et al. [13] proposed a distributed algorithm for dynamic traffic grooming problem and explored the benefits of sparse grooming (i.e., only a subset of the network nodes have grooming capability). They used the non-grooming nodes with higher call blocking to be select the next grooming node.

At present, the traffic grooming problem using light-trail concept is an important research area for wavelength routed WDM networks and very few related work available [14]-[17]. The light-trail concept in optical networks was first proposed by Gumaste et al. in [14, 15]. The work presents details about different node architecture to support light-trail concept and procedure to setup light-trail for connection of dynamic in nature and the out-of-band control protocol does the task of connection management, i.e. out-of-band protocol arbitrates communication The protocol has also the responsibility of light-trail management for dynamic traffic grooming problem. Bhattacharya et al. in [16] proposed a traffic grooming algorithm to maximize the network throughput for wavelength-routed mesh networks using static light-trail. Zhang et al. in [17] study dynamic light-trail routing algorithm for WDM optical network. They present an efficient algorithm for establishing a light trail routing for a new connection request by using minimum network resources. Authors also study survivable network routing using the proposed light trail technology and present an efficient heuristic for computing a pair of working and protection light trails for a dynamic incoming connection request.

III. Problem Formulation

The traffic grooming problem based on light-trail is defined as follows: Given a network topology which is a directed connected graph $G(V,E)$, where V and E are the sets of optical nodes and bi-directional links (edges) of the optical network, respectively, a number of transceivers at each node, a number of wavelengths on each fiber, the capacity of each wavelength and a set of connection requests with different bandwidth granularities, our objective is to set up light-trails and multiplex low-speed connection requests on the light-trails such that the network throughput is maximized in terms of total successfully routed low speed traffic.

Assumptions:

We use the following assumptions and notations in this work.

1) Traffic demand is static, i.e., traffic requests are known a-priori.
2) A lightpath/light-trail must use the same wavelength on all the links along its path from the source node to the destination node.
3) All lightpaths/light-trail using the same link (fiber) must be allocated distinct wavelengths.
4) Each network node can work both as an access node and a routing node.
5) A connection request cannot be split into different low-speed connections and routed separately.
6) Granularity of low-speed traffic requests is *x*.
7) Each network node i is equipped with a fixed number of tunable transmitters (Ti) and receivers (Ri) such that $T_i \geq 1$ and $R_i \geq 1 \; \forall \; i$.
8) N, W, and C are the number of optical nodes, number of wavelength per fiber link, and capacity of each wavelength channel, respectively.
9) S^x_{kl} is the number of OC-*x* traffic requested from node *k* to node *l* that are successfully routed.
10) If there exists a light-trail between node *i* to node *j* then $b(i, j) = 1$; otherwise it is zero.
11) If the wavelength *k* has been assigned to the light-trail originating from node *i* and terminating at node *j* then $W^k_{ij} = 1$; otherwise it is zero.
12) Each node is capable of multiplexing/demultiplexing as many low-speed traffic streams as possible, without exceeding the capacity of a wavelength.

Objective:

Maximize the total successfully routed traffic.

$$Max \sum_{k=s}^{k=d-1} \sum_{l=s+1}^{d} x.S^x_{kl}$$

Where, *k* and *l* are any node between convener node and end including source and destination nodes, *l* lies in the downstream of *k*.

Constraints:

1) $\sum^k_{i,j} W^k_{ij} \leq b(i, j)$; i.e. using a single wavelength at most one light-trail between a node pair can be setup.
2) The total demand of all the connections that can be satisfied using all the light-trail cannot exceed the total capacity all the light-trail.
3) Traffic addition at any intermediate node of a light-trail is possible if transmitter is available on that node and traffic drop at any intermediate node of a light-trail is possible if receiver is available on that node.
4) Number of light-trails starting at node *i* is at most equal to the number of transmitters at node *i* and number of light-trails ending at node *j* is at most equal to the number of receivers at node

IV. Proposed Approach

The traffic grooming problem in unicast communication can be solve either using lightpath or light-trail concept in wavelength routed optical networks. The Longest Light-trail Maximum Load (LLTML) algorithm proposed here is based on light-trail concept to solve the static traffic grooming problem in wavelength routed optical networks. The basic idea of this approach is to setup light-trail for a node pair which has the longest distance (more number of physical hops) and larger amount of traffic requirement. The longer light-trail may satisfy traffic for other node pairs along the downstream path of this light-trail. So, the proposed algorithm LLTML try to satisfy our main objective i.e., maximize the total successfully routed traffic. At first, algorithm LLTML constructs a list L for node pair (having nonzero traffic) in descending order of their physical hop distance. If more than one node pair's having same hop distance then sort them in descending order of traffic bandwidth requirement. Now, setup the light-trail for the first node pair in the list L i.e., longest light-trail depending upon the availability of optical network resources like wavelength, transceivers and update the traffic matrix, network resources

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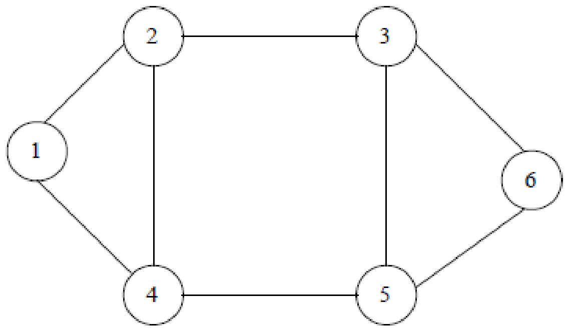
accordingly. The traffic (for those node pairs along the downstream path of this light-trail) is routed over the light-trail depending on the availability of wavelength channel capacity of the light-trail and transceivers. Finally, the process is repeated until the list L is empty or unavailability of resources or no leftover request can be satisfied. The steps of the proposed algorithm are as follows:

Algorithm *Longest Light-trail Maximum Load (LLTML)*

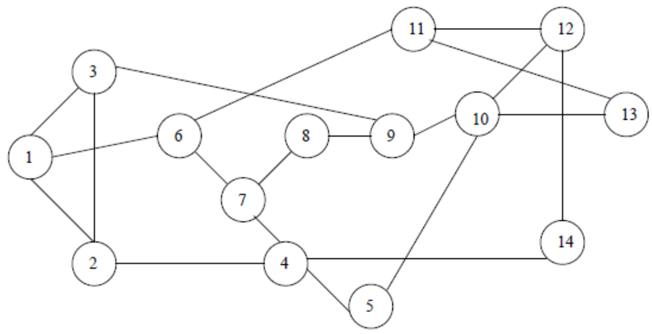
Begin

1. Find out the shortest path of each of the node pair having nonzero traffic in traffic matrix T and store it in list L.
2. Sort the list L according to descending order of their physical hop distance. If more than one node pair's having same hop distance then sort them in descending order of traffic bandwidth requirement.
3. Try to construct the light-trail (LT_{sd}) for the first node pair (s,d) from list L without violating wavelength, wavelength channel capacity and transceiver constraints. Use the First-Fit wavelength assignment for this light-trail.
4. **If** light-trail (LT_{sd}) setup is possible **then**
   - 4.1 Route as much as traffic possible for traffic t_{sd} over the light-trail LT_{sd} without violating wavelength channel capacity.
   - 4.2 Update the traffic matrix T by $t_{sd} = \max\{ t_{sd} - C, 0\}$
   - 4.3 Update the transmitter of node s and receiver of node d.
   - 4.4 Update the wavelength channel capacity throughout the path of light-trail LT_{sd}.
   - 4.5 **If** traffic t_{sd} is fully routed over the light-trail LT_{sd} **then** delete (s,d) pair from list L.
   - 4.6 **For** every nonzero traffic node pair (t_{ij}) belongs to the downstream path of light-trail LT_{sd}
     - 4.6.1 Route as much as traffic possible for traffic t_{ij} over the light-trail LT_{sd} without violating the wavelength channel capacity and transceiver constraints.
     - 4.6.2 Update the traffic matrix, transceiver, and wavelength channel capacity along the path of light-trail LT_{sd}.
     - 4.6.3 **If** traffic t_{ij} is fully routed over the light-trail LT_{sd} **then** delete (i,j) pair from list L.
5. **Repeat** step2 to step4 until unavailability of resources (like wavelength, transmitter, receiver, etc.) **OR** List L is empty, i.e. all requests are satisfied.

End of algorithm LLTML.



(a) A small network with 6-nodes and 8-links



(b)NSFNET with 14-nodes and 20-links

Fig. 2 Network topologies used

Complexity Analysis:

Let us assume N is the total number of nodes in the optical network and M is the total number of node pair having nonzero traffic requested. Let W is the total number of wavelength supported by a single fiber link. In step1 of this algorithm need to compute the shortest path for all the node pair having nonzero traffic requested using Dijkstra's algorithm takes time in worst case order of $O(MN^2)$. To sort the list L in step2 need in worst case order of $O(M \log_2 M)$. The light-trail (LT_{sd}) setup in step3 takes time in order of $O(NW)$. Since, every node pair having nonzero traffic along the downstream path of the light-trail (LT_{sd}) is checked in step4, so this step takes time at most order of $O(N^2)$. Finally, step2, step3 and step4 are repeated M times in worst case. Actually, in average case these steps are repeated far less than M, because most of the cases more than one node pair having nonzero traffic are satisfied over a single light-trail, so the size of the list L is decremented by more than one instead of one. Therefore, the worst case time complexity of the LLTML algorithm is $O(MN^2) + O(M^2 \log_2 M) + O(MNW)$.

V. Experimental Results

We have evaluated the performance of our proposed algorithm LLTML for the traffic grooming problem using simulation and compare the results with the well-known algorithms MST [3] and SFT [4].The experiments are conducted on the 6-node small network shown in Fig. 2(a) and 14-node NSF network shown in Fig. 2(b). We assume that each physical link is bidirectional with equal length. In this simulation, the capacity of each wavelength is assumed to be OC-48 and allowed traffic bandwidth requests were assumed to be OC-1, OC-3, and OC-12. The traffic matrices are

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randomly generated (approach used in [7]) such that the number of connection requests on OC-1, OC-3, and OC-12 for all possible node pairs, are generated as random numbers between 0 and 2^r, between 0 and $2^{(r-1)}$, and between 0 and $2^{(r-3)}$, respectively, where r is a suitable integer value. In this simulation, we have assumed r = 5 and r = 4 to generate traffic matrices for the 6-node network and NSF network, respectively. All the simulations are performed 100 times to generate each result.

Fig. 3 and Fig. 4 shows the relationship between the network throughput and the number of wavelengths per link for the proposed algorithm LLTML and the existing algorithms MST and SFT under 6-node network and 14-node NSF network, respectively. We observed that the network throughput increases with the increase of wavelengths per link and there is no significant change in network throughput after the number of wavelength per link reaches a certain limit for all the algorithms. The reason behind that is the transceiver constraint, there may be wavelength is available, but transceivers get exhausted. The proposed algorithm LLTML provides significantly higher network throughput than the existing algorithms, because the algorithm LLTML allows to adding traffic between the intermediate node pairs towards the downstream path of a light-trail in an efficient manner.

The relationship between the network throughput and the number of transceivers per node for the proposed and existing algorithms is shown in Fig. 5 and Fig. 6. We observed from both the figures that initially the network throughput increases with the number of transceivers and there is significant change in network when the number of transceivers increased beyond certain value, due to wavelength and/or capacity of wavelength is exhausted. The result shows that the proposed LLTML algorithm significantly improves the network throughput than existing algorithms MST and SFT.

The performance of the network throughput with respect to total requested bandwidth under 6-node network and 14-node NSF network is shown in Fig. 7 and Fig. 8, respectively for the proposed algorithm LLTML and the existing algorithms MST and SFT. We observed that the algorithm LLTML returns much better network throughput than existing algorithm MST and SFT.

VI. CONCLUSION

The problem of static traffic grooming problem with the objective of maximizing the network throughput based on lightpath and light-trail concepts in wavelength routed optical network is studied in this paper. We have proposed an algorithm Longest Light-trail Maximum Load (LLTML) using single hop grooming in static traffic grooming problem. The performance of the proposed algorithm is evaluated through extensive simulation on different sets of traffic matrices with different bandwidth granularities under different network topologies. From the simulation results it has been established that the proposed approach LLTML significantly improve the network throughput (with respect to wavelengths per link, transceivers per node, and total requested bandwidth) than the existing well-known static traffic grooming algorithms MST and SFT.

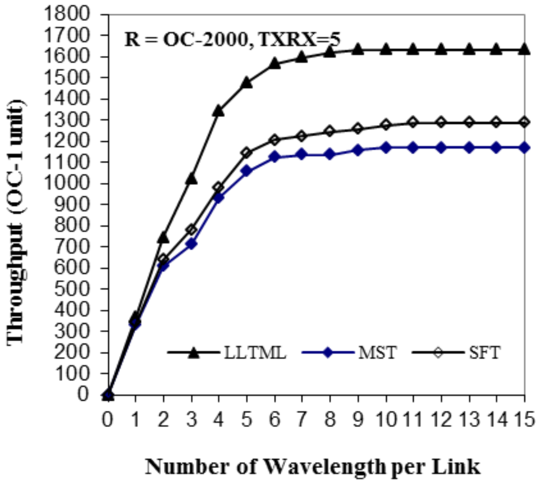

Fig. 3 Relationship between throughput and number of wavelength per link for 6-node network

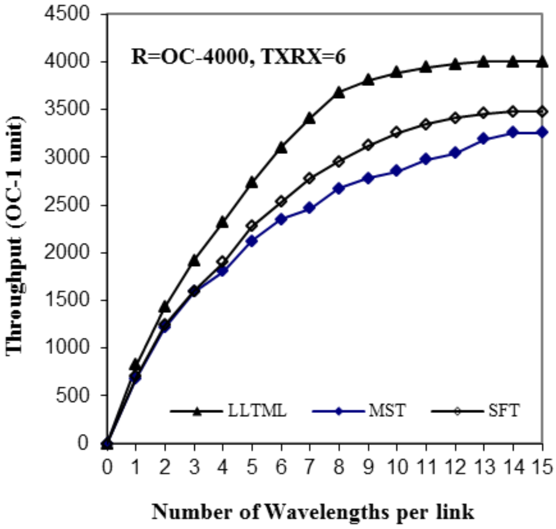

Fig. 4 Relationship between throughput and number of wavelength per link for14-node NSF network

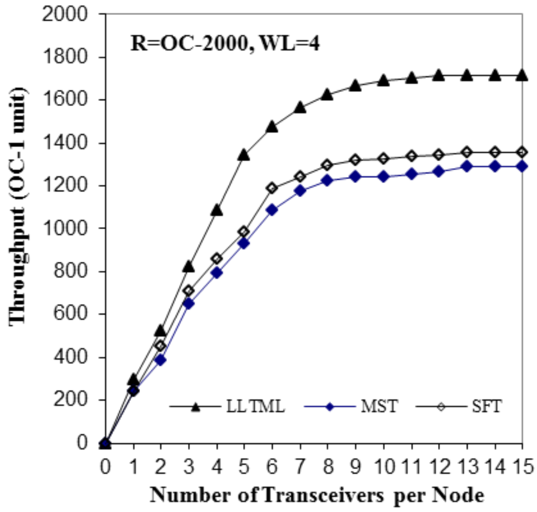

Fig. 5 Relationship between throughput and number of transceivers per node for 6-node network

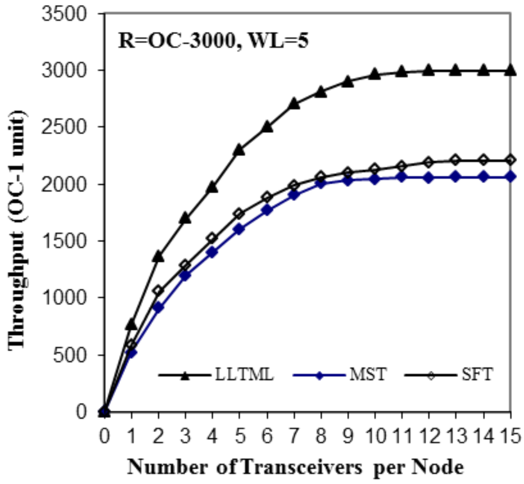

Fig. 6 Relationship between throughput and number of transceivers per node for 14-node NSF network

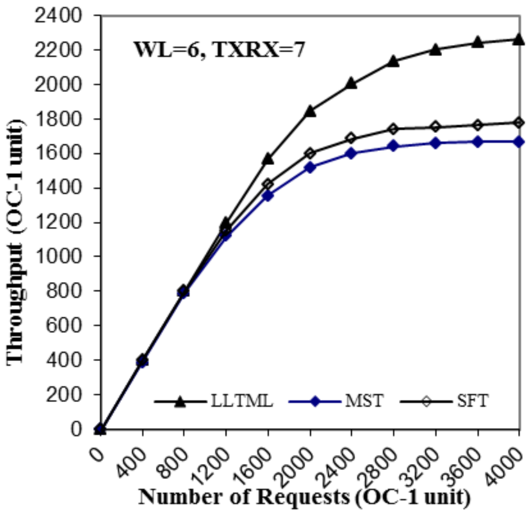

Fig. 7 Relationship between throughput and number of requests in OC-1 unit for 6-node network

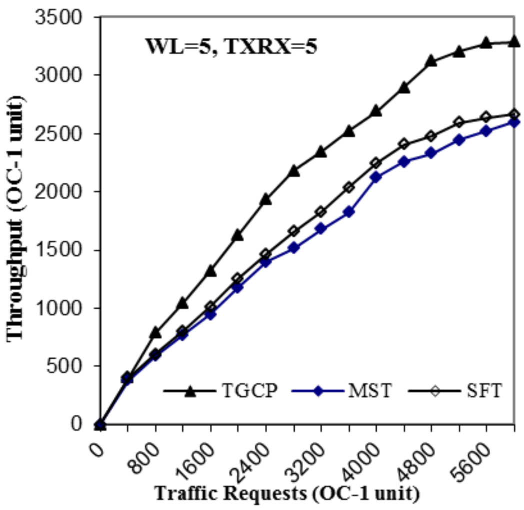

Fig. 8 Relationship between throughput and number of requests in OC-1 unit for 14-node NSF network

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