Mesh Implementation of Light-trails: A Solution to IP Centric Communication

Ashwin Gumaste and Imrich Chlamtac
[1]Center for Advance Telecommunications Systems and Services
The University of Texas at Dallas, TX 75083, USA
{ashwin@student, Chlamtac@} utdallas.edu

Abstract: Light-trails communication [1] proposes a solution for implementing a conceptual framework for IP centric communication in the optical domain which is a combination of node architecture and protocol for realizing efficient optical communications from IP bursts to dynamic lightpaths. In this paper we introduce a Light-trails solution that is applicable to mesh networks. Contrary to existing proposals for IP type communication in the optical domain light-trail node architecture also presents the first practically implementable solution to enable optical transport with mature technology, non stringent optical switching requirements, and potentially presents a cost effective alternative to electronics in supporting IP networks.

I INTRODUCTION

The exponential growth in data traffic has brought to surface the near invincible power of IP based communication-as a method for providing, universal, low-cost and effective communication. On account of absolute flexibility and ability to provide efficient methods of traffic engineering, IP communication techniques have brought about a paradigm shift in the way broadband and wide area networks behave. The phenomenal growth of IP traffic has led to concentrated efforts in providing IP transport and enable dynamic switching and real-time provisioning. Coalesced with WDM this enables users to exploit the natural resources in terms of bandwidth offered by the optical fiber-the key media for backbone and regional networks. The approach of transporting IP over optical fiber, and allowing a multiple users to have access to optical bit-pipes on a real-time basis has resulted in strong investigations of IP over WDM. The fundamental problem in amalgamating IP with WDM for regional networks, lies in the absence of architectures and technologies that allow users to optimize networks for performance, price and protocol (3P-solution). One solution that allows the actual optimization of broadband networks on the lines of 3Ps is called light-trails [1]. Light-trails solution brings to the fore an architecture and a protocol that allows IP centric communication, that of dynamic reconfiguration of resources in an optical network. In addition light-trails, for the first time allows optical multicasting, a key requirement for bandwidth killer applications such as video broadcasting and video on demand as well allows users to exploit the granularity of a wavelength in time domain thereby creating a sub-lambda capable architecture. In [1] we proposed this solution for WDM rings on account of the massive deployment of ring architectures world-wide, especially in metropolitan areas. However the WAN phenomenon created by IP based networking has realized a great deal of curiosity and exploration into mesh networking [2], as a method to provide transport to traffic (both IP and otherwise) over national and regional backbones.

In this paper we propose an architecture and a protocol to fit the original light-trails concept to mesh networking, motivated by the tremendous growth of these regional networks as well as the ability of such a solution to carry about sub-lambda level optical communication-essential for supporting dynamically re-configurable mesh networks. In this paper, we show the method of implementing light-trails for transport of both optical bursts – a case of dynamic lightpath establishment for very short durations over mesh networks.

II SUMMARY OF LIGHT-TRAILS

The concept of light-trails proposed in [1] is to enable IP centric communication at the optical layer. This concept consists of an architecture and a protocol that allows dynamic opening of an optical path, or "trail" of length t, between any chosen source and destination node, while allowing optical communication (access) to all the nodes en route to the destination without the need for optical switch reconfiguration at individual nodes. With the principle of access to the all optical path by any node on the trail, a light-trail solution offers full optical connectivity between up to ${}^{t}C_{2}$ number of connections which can share the wavelength in time domain leading to dynamic and self regulating wavelength multiplexing. Thus the light-trails architecture can provide high utilization, low access delays and multicasting without the need for fast optical switching.

III THE MESH APPROACH

In order to demonstrate the light-trails for mesh networks, consider an N node mesh with degree of connectivity D at each node (for simplicity we consider D to be same for all the nodes in this paper but that need not be the case for generic light-trails in mesh). A light-trail of 't' nodes is a sequence of nodes using a wavelength $_{i}$. In a light-trail (N_1, ... N_t) node we call the first node, N_1, the *convener node*, and the last node N_t, the *end node.* A 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, contrary to lightpath or burst level path provisioned under conventional architectures.

Shown in Fig. 1 is the proposed node configuration that realizes light-trails in a mesh topology. Here we show for a node that supports four incoming fibers and four outgoing fibers (therefore degree of connectivity D=4). The node consists of 3 sections, a local drop section, a local add section and a wavelength blocker section. The composite WDM signal enters the node form the incoming fiber. An optical coupler acting as a splitter (of ratio 1:D+1) splits the optical power in a suitable (preset) ratio. A portion of the optical power reaches the drop de-multiplexer (shown in Fig 2 for clarity) while the remaining optical power is split into the remaining D output ports of the splitter. Each of the D outputs now has a copy of the composite WDM signal. These D outputs are each connected to a wavelength blocker device. The wavelength blocker is a standard off-the-shelf device [10], based on photonic crystal technology, such that from the set of wavelengths in a composite signal, an arbitrary sub-set of wavelengths can be blocked while the remaining wavelengths are allowed to go (pass) through. Such wavelength blockers have characteristic of 4-6 dB pass through loss, and have a tuning time in the micro-second range due to the inherent use of photonic crystal technology. The wavelengths that need to be blocked are done so at the wavelength blocker and the remaining signal reaches the combining coupler as shown in Fig. 2. Likewise, signal from other fibers reach the combining coupler in similar manner. At the combining coupler, is also available a local add port for adding any wavelength locally.

Function of Optical Multicasting: The composite WDM signal, is split at the splitter (1st coupler from left to right in Fig. 2) into D fibers. Each fiber feeds into a wavelength blocker. The wavelength blocker is connected to a combiner (2nd coupler from left to right in Fig. 2) and that is subsequently connected to the output port of the node. The wavelength blocker can select from the given set of wavelengths a subset of wavelengths that pass through and the remaining can be blocked. This function can be used for optical multicasting in the following way: Consider the 4 x 4 node configuration as shown in Fig. 1. For clarity let us name the four input ports as A,B,C,D and the four output ports as E,F,G,H, such that input fiber A corresponds to output fiber E and so on. Let the 16 wavelength blockers be named BL_1, BL_2, ….., BL_{16} such that BL_1, BL_2, … BL_4 correspond to the input port A and so on. Now assume a signal coming into the node on a wavelength say λ_1 at input port A. This signal is split into 5 portions (D+1) at the splitter. One part of the signal reaches the drop de-multiplexer, while the other four parts are fed individually to the four wavelength blockers BL_1 through BL_4. Let us assume blocker BL_2 and blocker BL_4 are in a state such that they are blocking the signal on wavelength λ_1 then the signal will arrive only at output ports that are connected to the 'pass through blockers' that is BL_1 and BL_3. That means ports E and G (connected to BL_1 and BL_3 at the output) get a copy of the signal at λ_1. Moreover, the local drop section at the input near port A also gets a copy of the signal. This means that we have achieved optical multicasting in form or tree. When we need to have multicasting such that we want to drop and continue the signal at each node in a multicast tree without having further branches at downstream nodes the procedure is still simpler and is as follows: The incoming signal is split in the ratio 1:D+1. One portion of the signal reaches the local de-multiplexer (exemplifying drop functionality), the remaining D portions reach the attached D wavelength blockers. Only one wavelength blocker (chosen according to the desired route) of the D blockers allows the signal to pass through while the remaining D-1 blockers block their portion of the optical signal. The passed through portion of the optical signal reaches the selected (according to multicast route) combiner and proceeds to the output port and hence back into the network completing the multicast tree thereby exemplifying in this case drop and continue functionality.

The only criteria for achieving optical multicasting in mesh for our proposed nodal architecture, is that when combining wavelengths from the different (D) wavelength blockers at the combiner we have to ensure that the blockers are so aligned that no wavelength coming into the combiner is fed by two blockers at the same time (each fiber cannot have two signals on the same wavelength).

From the above discussion the role of a protocol for configuring the wavelength blockers and for ensuring proper selection of wavelength at combiners is evident. In [1] we propose a protocol based on out of band approach aka GMPLS based for controlling the network elements as well as ensuring communication in the network both at burst and lightpath level. The protocol is run out-of-band on a control channel (discussed later). The control channel is dropped at each node, and electronic processing of control packets occurs. These control packets are typically few bytes long and hence the speed of the control channel depends on the minimum communication unit size (burst in this case) on the data channels amongst other influencing factors.

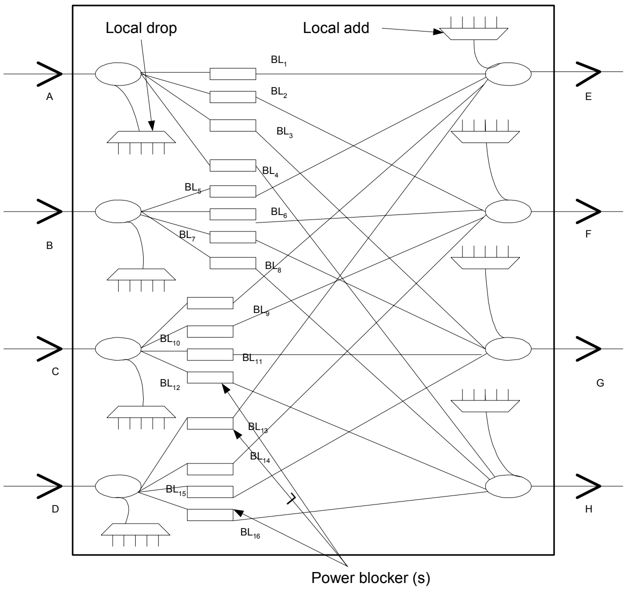

Fig. 1 Proposed configuration for light-trails: shown here with degree of connectivity D=4.

The Mesh Protocol

In [1] we proposed a protocol to establish light-trails and to provide optical connections within light-trails for ring networks, here we modify the protocol and suite it for mesh networks. Presented subsequently is a concise version of the protocol. For obtaining the signaling required to set up light-trails and for optical connections management within light-trails we assume there exists an out of band communication channel called optical service channel (OSC) within each fiber, and that it is dropped and processed at each node. The OSC carries information about all the light-trails in the network, and is responsible for provisioning connections within light-trails by providing a method for signaling as well as setting up light-trails etc..

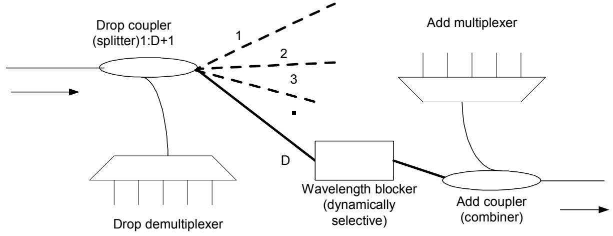

Fig. 2 Input to output port heuristic.

In light-trail communication OSC control packets are sent ahead of the data using an offset which is a function of propagation delay from ingress to egress node as well as the control packet processing time at each node. Note here that unlike classical burst switching, we do not need to consider switching time while calculating this offset.

Five types of control packets are defined in [1] and they are: *Setup packets(SP)* to set up light-trails. *Communication control packets (CCP)*: Are used to set up connections within a light-trail. CCPs carry information about the ingress node/egress node(s), light-trail number (a unique number which identifies the light-trail based on convener node, end node and wavelength used . *Dimensioning packets (DP):* Are used by the convener node to dimension light-trails. *Global Broadcast Packets (GBP)* analogous to 'hello' packets in OSPF, broadcast network resource status.

Local communication database: a single, time sensitive pointer at each node, indicating whether the light-trail is occupied or not at that point through the node's local multiplex section. (Determines if data is flowing through the trail).

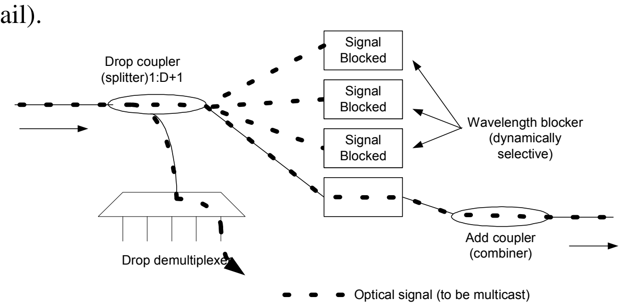

Fig. 3 Demonstrating optical multicasting: an inherent quality of the drop and continue philosophy.

A. Setting up Light-trails in a mesh network:

The procedure in mesh is different as that in rings for setting up light-trails. Ring networks, considered as a super-special case of mesh, have much lesser complexity and hence the switching requirements (degrees and routes) are much lesser. For creating a light-trail between nodes N_1 to N_t downstream (flow-wise) of N_1, node N_1 selects an available wavelength $_{t,}$ based on the light-trails database information. Node N_1 sends a control packet (SP) through the OSC requesting opening of this optical connection to N_t through the intermediate nodes N_2, N_3, ... N_{t-1}. Node N_t upon receiving the SP from N_1 replies through the OSC in the fiber (in the opposite direction) with an ACK. This ACK is validated by intermediate nodes also. If node N_t cannot allow the light-trail to be established, it indicates so. Nodes N_2, N_3, ... N_{t-1} upon receiving the control packet (SP), switch the corresponding wavelength blockers in the required position thereby blocking or continuing the impending optical signal. Nodes N_1 and N_t keep the wavelength blocker corresponding to the input port (add multiplexer) in block position specific to $_t$. In this way a light-trail is created whose member nodes are N_1, N_2, ... N_t enabling downstream communication between them. Moreover the light-trail so created on $_t$ is spatially separated from the network meaning that the light-trail is a communication media opened between nodes N_1, N_2, ... N_t only and nodes not part of this trail do not have access to information in the trail. Importantly, to establish virtual connections (over time) in the light-trail there is no further need for any configuration of wavelength blockers or switches, as each node has access to the data sent by any upstream node. In other words we create a trail that allows for unidirectional high speed connection to be set up (without switching).

B. Communication within Light-trails: Setting up optical connection: The mesh approach

If node N_j desires to send data (to set up dynamic lightpath or burst) to downstream node N_k, both nodes of the same light-trail, it proceeds as follows: To avoid conflict of usage of same light-trail by an upstream node within the same trail, the initiating node N_j determines availability of the light-trail by examining the "local communication database", and finds out the occupancy of the light-trail at its own port (multiplex section). If no upstream node is using this light-trail for communication then N_j can initiate communication to node N_k by sending a control packet (CCP) to be followed by the data after an offset interval**.** Nodes N_{j+1}, ... $N_{k-1,}$ ...N_t now become aware of this communication. Note that after sending a connection set up control packet, node N_j is guaranteed successful connection to downstream node or multiple destination nodes (as in case of multicasting), since all the destination nodes can detect the data as a part of the optical power is split through to the local drop de-multiplex section of each node.

If a connection in a light-trail is in progress, and a node that is upstream to the source of this connection wants to start another connection: Then the previous connection has to be called off to facilitate the new connection initiated by the upstream node. Such kind of connection overlapping can happen in light-trails and several solutions are possible to deal with "overlapping" connections. Node N_j which is upstream of node N_q can access the optical path, even when N_q is transmitting information. If such does happen, then N_j requests for opening of an optical connection in the light-trail. Node N_q upon realizing the possibility of conflict inhibits its data and allows the data from node N_j to pass through. In this event, the downstream node (N_q) may either send its data after the upstream node (N_j) has finished its data transmission or send the data on another light-trail. However for delay-sensitive applications, it may not always be possible to inhibit the local transmission. In that case, the downstream node (N_q) may switch the corresponding wavelength blocker for $_t$ (for that light-trail) in the BLOCK position and collect the data from the upstream node (N_j) (through its drop coupler). It may then either buffer this data or send it on another light-trail usually involving O-E-O from the initial light-trail to the new light-trail. In this process of re-transmission (either over time or over different light-trail) the incumbent node does not restraint its data flow into the light-trail.

C. Dimensioning light-trails: Expanding and Contracting: The Linear Way for Mesh

As seen earlier light-trails can efficiently support dynamic optical communication, such as bursty IP centric traffic as they do not require the resetting of optical switches along the light-trail for connections within the trail. If a connection cannot use an existing light-trail a new trail needs to be established, a procedure that takes additional time. It is therefore desirable, from this point of view, to have the longest light-trail possible. However, since only one connection is active per trail at a time, light-trails that are too long would lead to underutilization while too short trails lead to deterioration of the concept. Therefore, light-trails may require dimensioning (expanding or contracting) to optimize performance in terms of utilization, set up times, etc. In mesh networks, trails can be grown linearly or in tree formation depending on the requirement. The latter is not considered on account of complexity

A node N_a upstream of node N_1 and not part of a trail LT_1={ N_1, N_2, ..., N_t }, may request communication to a node in LT_1. The convener node by virtue of its dominant status may allow N_a to join the trail provided there is a route (single or multi-hopped) from N_a to N_1. If it does so, it shifts the convener status to node N_a and the new trail LT_{NEW}= {N_a, N_{a+1}, ... N_1, ...N_t } is formed and this information is broadcast through the network by use of GBP. The act of expanding a light-trail is similar to setting up a light-trail.

Similarly, if the end node, through the local communication database learns it is no longer recipient of information, it may use a DP to the convener requesting to relive itself (or the group) from the light-trail. In that case, the first node from the end node in the reverse direction which is still an active member of the light-trail now becomes the end-node of the light-trail and configures its shutter accordingly.

IV LIGHT-TRAIL EVALUATION

As pointed out in the Introduction there are important benefits to light-trail communication in provisioning wavelength sub-lambda allocation through time based wavelength multiplexing, supporting variable length bursts and variable length packets within a burst, allowing very fast optical connection set up, being technologically feasible, and providing multicasting. In this section we provide a basic evaluation of light-trails by a comparison to classical burst switching which is a premier solution for dynamic bandwidth allocation.

Generic Simulation model: We model the topology as shown in Fig. 4. Distances shown are in km. Each link is bi-directional, with two fibers and each fiber has 40 wavelengths. The speed of each link is assumed to be 1Gb/s. The control channel is assumed to be 155 Mb/s. The control channel is dropped at each node, and a central processor switches control packets (all in the electronic domain) between the 4 incoming and 4 outgoing fibers. Each node has 16 wavelength blockers and the time to configure a wavelength blocker is 100 microseconds based on [10]. Burst are aggregated at each node and aggregation policy is based on accumulation of voice and data packets so that the size of the burst depends on the arrival mechanism as well as the maximum delay bound allowable for these packets. Voice flow is simulated as a Poisson distribution while data flow is modeled on a Pareto arrival process. Load is calculated as the ratio of the occupation of the system with real bursts as compared to the maximum capacity that the system can theoretically support. This gives a normalized value of load.

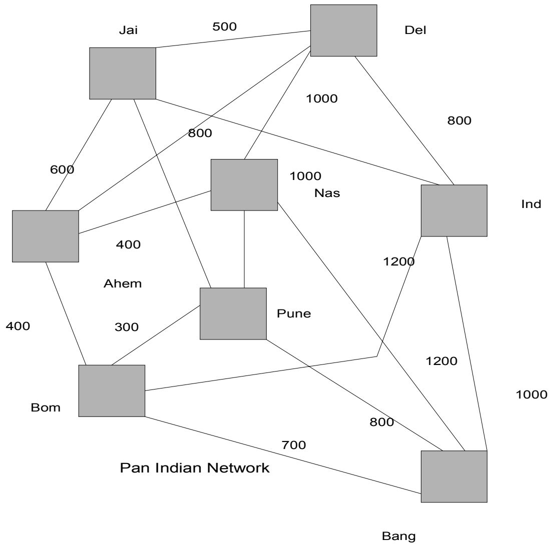

Fig. 4 Indian Reliance Infocom network

A. Provisioning time in Light-trails for optical (bursts) connections

For efficient burst type communication the ratio of burst set up time to duration is a key parameter for effective burst switching. Burst transport algorithms due to the constraints on switching speed and uncertainty of resource availability due to the distributed nature of a network, have relied on pre-allocation of resources to create an end-to-end optical path. JET[2] is a leading burst transport algorithm based on pre-allocation of resources ahead in time, using an out of band signaling approach. In light-trails because the optical connection does not need to reset switches, one can expect an advantage in provisioning time. Shown in Fig. 5 is the provisioning time for light-trails, including connections established within a light-trail and those that require establishing a new trail, For both light-trail and JET burst switching we consider the provisioning time to be a function of the hop length, switch configuration time and control packet processing time Optical bursts are generated by multiplexing different classes of traffic (namely voice and data). In the simulation study we assume Poisson and Pareto distributions for burst aggregation. Scheduling policy for bursts that are delay sensitive is shown in [5]. In the simulation we use line rate of 1Gbps and bursts of 22 ms in length (average). Fig. 5 shows a significant benefit in the provisioning times for light-trail communication. Quantitatively we see that even if a contemporary fast switch [3] having configuration time of 0. 1 ms is assumed for JET we still see an approximate 350% decrease in provisioning time for single connection using light-trails. If we further assume that the light-trail is already set up and burst transport is the act of communication (creating connections) within a light-trail we observe results such that there is on an average an order of two advantage in provisioning as compared to the provisioning using JET, showing the importance of optimized light-trail length. This validates the light-trails architecture as a method for providing high bandwidth on demand to end-users on a real time basis.

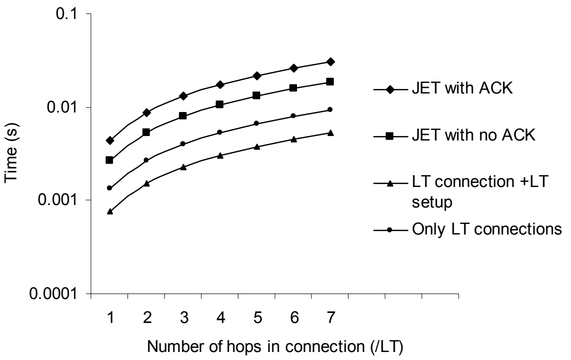

Fig. 5. Comparison of provisioning times for conventional burst based communication algorithm JET and for Light-trails.

B .Network Utilization benefits of Light-trails

A major advantage of using light-trails for burst transport as compared to classical optical burst switching solution is the benefit observed in network utilization. In classical optical burst switching, the data burst is sent upon the successful reservation of bandwidth in the path. That is, for every burst to be broadcast, a control packet has to be sent, and switches have to be configured. This procedure is cumbersome and lengthy. By requiring an exclusive wavelength path to be set up for each burst, long voids are created within the channel since there is no utilization of the channel when the control packet is in transit, or when switches are being configured. In contrast, for a light-trails solution, we do not have to configure any switches. This leads to excellent provisioning times as seen in the previous sub-section. Moreover this also leads to better utilization of the system. Shown in Fig. 6 is a comparison of utilization of a single wavelength for different loads for both light-trails as well as classical burst switching. We assume 1Gbps channel in both cases. Bursts are aggregated according to algorithm in [5]. The average length of the path (for both light-trails and OBS) is 4 hops (considering the network shown in Fig. 4). Load is computed stochastically in Erlangs. Utilization is defined as the ratio of capacity used over time for actual data transmission to the total capacity. Switching time for classical OBS switches are 0.1 ms which are very fast by today's standards [3]. We observe that utilization in OBS is severely degraded as compared to that in light-trails. On an average the utilization of light-trails is a single order of magnitude better than that seen in OBS under similar conditions.

C. Blocking probability for light-trails as compared to Classical Optical Burst switching.

The third parameter of interest to us is the blocking probability of light-trails as compared to optical burst switching. From Fig.5 we see that utilization is much better in a light-trails solution as compared to an OBS implementation on account of the excellent provisioning times we observe in setting up connections using light-trails. This means that as the load trying to enter the network increases the ability of light-trails to take this load is better than the ability of any other classical OBS solution. We simulate for the same network as shown in Fig. 4 and observe that as load increases an OBS solution falters on account of its poor utilization. On the other hand a light-trails solution sees lesser of blocking than an OBS implementation for even higher loads. While calculating blocking in light-trails we also take into account the blocking encountered when a node is sending data but an upstream node blocks its transmission (before completion) thereby creating undue fairness problems. However quite in contrast to intuition, the super fast provisioning feature in light-trails leading to good utilization nullifies the fairness constraints in light-trails especially when compared to an OBS solution. Shown in Fig. 7 is blocking probability versus load for classical burst switching solution as well as for light-trails solution. For light-trails we consider with equal probability cases when a new light-trail has to be set up as well as cases when a light-trail already exists for supporting connection between two nodes. As the load increases beyond 0.5 the blocking probability of classical OBS solution severely degrades. That means that the wait for a burst to enter the network is just too long (in our case time-out condition is 0.1 sec). On the other hand we see that while using a light-trails solution the blocking probability becomes excessively high only around loads of 0.9. This means that a light-trail based network can support more load than a classical OBS based network.

V CONCLUSION

In this paper we have introduced an adaptation for mesh networks, of the conceptual framework called light-trails, which showcases as an efficient method for provisioning IP centric communication at the optical layer. We have demonstrated the feasibility of mesh networks, with the drop and continue concept of light-trails and subsequently have verified the concept through simulation. As a result we note the ability of mesh based light-trails solution to provide the same benefits as seen in ring networks namely optical multicasting, dynamic provisioning and burst transport, conforming to the industry demands of migrating from ring to mesh topologies.

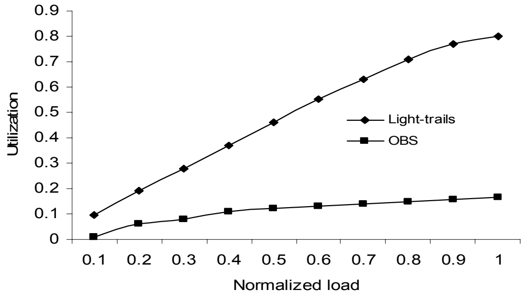

Fig. 6. Utilization of a wavelength using Light-trails and compared to classical optical burst switching.

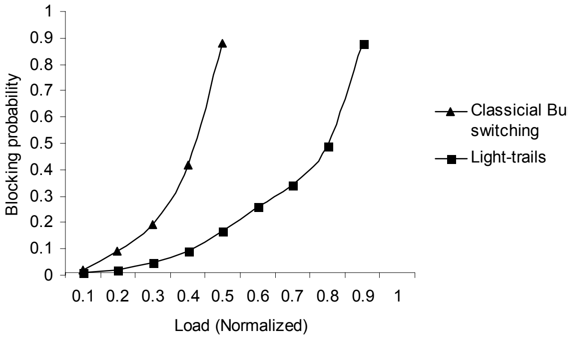

Fig. 7. Blocking probability versus normalized load for light-trails as well as OBS.

REFERENCES

[1] I. Chlamtac and A. Gumaste, Light-trails: A Solution for IP Centric Communication at the Optical layer, ' Invited Paper, QoS IP Milan Feb 26th 2003.

[2] M. Yoo, C. Qiao and S. Dikshit, ' Optical Burst Switching for Service Differentiation in the Next-Generation Optical Internet,' *IEEE Communications Mag*. Feb. 2001 pp 98-104

[3] A. Gumaste and T. Antony 'DWDM Networks Design and Engineering Solutions,' *McMillan Publishers.*

[4] M. Bouda et. al. ' Tunable AOTF switches' *Proc of OFC* Baltimore 2000

[5] A. Gumaste and J. Jue, 'Burst aggregation strategies based on according QoS for IP traffic,' First International Conference on Optical Communications and Networks, Singapore Nov. 2002

[6] R. Ramaswami and G. Sasaki, Limited Wavelength Conversion in Optical WDM ring networks', IEEE/ACM Trans. On Networking, Vol 3 No 5 Oct. 1995 pp 1152-1162

[7] I Chlamtac and A. Gumaste, 'Bandwidth Management in Community Networks,' Key note address, IWDC 2002, Calcutta, Dec 2002

[8] B. Humblet, ; Computation of Blocking probability in optical networks with and without wavelength converters, ' June 1996 JSAC Vol 12. No. 6.

[9] A.Gumaste et al, 'BITCA: Bifurcated Interconnection to Traffic and Channel Assignment in Metro Rings' Proc of OFC 2002 Anahiem CA TuG 5

[10]www.avanex.com/~powerblocker, http://www.jdsu.com/site/images/products/pdf/WavelengthBlocker_030502.pdf