Performance Analysis of Optical Burst Switching High-Speed Network Architecture

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Summary

The development of wavelength division multiplexing opens a new horizon in optical networks and promises to be one of the best solutions for the high demand of the bandwidth. However, with this technology, many problems arise, especially those related to the architecture to be used in optical networks to take advantage of the huge potential of this technique. Many approaches and architectures have been proposed in literatures to carry information in optical domain. Among them, optical burst switching (OBS) and wavelength routed network seems to be the most successful. We propose a new novel architecture that uses both methods in order to overcome the limitations imposed by each approach. The proposed architecture deploys bursty traffic in a hybrid fashion where implicitly predicted and explicitly pre-booked traffic are dynamically allocated reserved end-to-end paths, inheriting the spirit of conventional wavelength routing; whilst, the non-predicted traffic is transmitted via classical OBS reservation mechanism(s) with the best efforts support. The complete network structure along-with load-balancing prior reservation strategy is presented. Simulation results reveal the performance of the proposed work by examining the blocking probability and delay characteristics. The encouraging results provide stimulation for further work on optimal traffic placement, QoS provisioning, and various a-priori resource reservation strategies.

Keywords: Optical transport networks, Optical packet switching, Optical burst switching (OBS) and Resource-reservation.

1. Introduction

Optical fiber has distinct advantages over other transmission media because it has extremely large bandwidth. For example, in the case of single mode fiber, there is 25THz of bandwidth that can be exploited by wavelength division multiplexing (WDM). With forecasts of Internet traffic doubling every nine months, optical fiber is the appropriate transmission medium to carry the bulk of future network traffic. However, much more than transmission is required in a network. Network architecture may have a profound impact on the ability to efficiently and economically harness the transmission capacity of optical fiber. The emergence of optical technologies for transmission, switching, and signal processing has created new opportunities for application to future networks. It is therefore critical that optical network research provide the "groundwork" to address how these new technologies might be applied to meet the challenges of future high speed networks. Innovation is driven from the "bottom-up" in the form of new or improved optical technologies, and from the "top-down" from network applications. Emerging optical technologies, such as Micro-Electro-Mechanical Switches (MEMS) and improved technologies, such as for optical burst switching offer potential for improving the capabilities of future networks to economically support applications and realize services. Future applications and value-added services will create different service requirements, ultimately shape network architectures and underscore critical devices for development. Novel network architectures should be synthesized that support anticipated requirements of future applications, exploiting emerging optical technologies as appropriate. This is best done by an iterative process whereby both top-down as well as bottom-up design methodologies are used. The process of network applications affecting network architecture and then device development and vice versa, requires interaction between the network application designers, network and system architects and device engineers. Experimentation is ultimately necessary to demonstrate the viability of any network architecture, but the economic cost is large. Therefore it is vital to generate and consider several alternative network architectures before a more substantial investment is made. Initial evaluation of candidate architectures should be made by analysis as well as through small scale demonstrations when appropriate.

An important attribute of future networks is the support of high bandwidth communication at reasonable cost. To meet the exponentially increasing traffic demands, future networks must be scalable in terms of bandwidth, number of users, volume of messages and message size. Though future networks will certainly be supporting voice, video and text traffic, it is likely that they must also support new types of communication. For example, new types of computer-to-computer communication may emerge and even dominate network resources. Future networks will have service requirements other than bandwidth requirements. They should support multicast as well as unicast communication. They may be required to be flexible so that they can carry communication using diverse signal formats. Provision of security and reliability are of paramount importance. Finally, universal connectivity is a key requirement for future networks. To achieve this, distributed/centralized ownership of network resources will likely be important. A framework where resources such as bandwidth can be freely traded may be crucial for addressing the scaling problems associated with universal connectivity.

1.1Optical Transport Network

An optical transport network consists of a collection of edge and core nodes as shown in Figure 1. The traffic from multiple client networks is accumulated at the ingress edge nodes and transmitted through high capacity WDM links over the core. The egress edge nodes, upon receiving the data, provide the data to the corresponding client networks. The three prominent optical transport networks architectures proposed to carry traffic over the optical core are optical circuit switching (OCS) (or wavelength-routed networks), optical packet switching (OPS), and optical burst switching (OBS). These switching techniques primarily differ based on how resources are allocated in the core and the degree of granularity for the resource allocations. In OCS networks, an all-optical connection, referred to as a lightpath [1] is established to create a logical circuit between two edge nodes across the optical core. These lightpaths may be established dynamically as connection requests arrive to the network or they may be provisioned statically based on estimated traffic demands. While OCS is suitable for constant rate traffic such as voice traffic, it may be unsuitable for highly dynamic traffic. Furthermore, as lightpaths must be established using a two-way reservation scheme that incurs a round-trip delay, the high overhead of connection establishment may not be well-suited for short bursts of traffic. Also, under bursty traffic, sufficient bandwidth must be provisioned to support the peak traffic load leading to inefficient network utilization at low or idle loads. In OPS networks [2], data is transmitted in the form of optical packets which are transported across the optical core without conversion to electronics at intermediate core nodes. OPS can provide dynamic bandwidth allocation on a packet-by-packet basis. This dynamic allocation leads to a high degree of statistical multiplexing which enables the network to achieve a higher degree of utilization when the traffic is variable and bursty. However, there are many technical challenges to implementing a practical OPS system. One of the limitations of OPS networks is that it is difficult to implement optical buffers. Furthermore, the requirement for fast header processing and strict synchronization makes OPS impractical using current technology. OBS [3, 4] was proposed as a new paradigm to achieve a practical balance between coarse-grained circuit switching and fine-grained packet switching. In OBS networks, incoming data is assembled into basic units, referred to as data bursts (DB), which are then transported over the optical core network. Control signaling is performed out-of-band by control packets (CP) which carry information such as the length, the destination address and the QoS requirement of the optical burst. The control packet is separated from the burst by an offset time, which allows for the control packet to be processed at each intermediate node before the data burst arrives. OBS provides dynamic bandwidth allocation and statistical multiplexing of data, while having fewer technological restrictions than OPS. By aggregating packets into large sized bursts and providing out-of-band signaling, OBS eliminates the complex implementation issues of OPS. For example, no buffers are necessary at core nodes, headers can be processed at slower speeds and synchronization requirements are relaxed in OBS. On the other hand, OBS incurs higher end-to-end delay and higher packet loss per contention compared to OPS, due to packet aggregation. Basic architectures for core and edge nodes in an OBS network have been studied in [5].Each of the three types of optical transport network architectures (OCS, OPS and OBS) may support different services. Packet traffic can be supported by any of the three architectures in either a connectionless or connection-oriented manner. OPS and OBS support these different types of packet services through different signaling protocol implementations. In order to support connection-oriented services on OBS, a two-way reservation protocol such as TAW can reserve the end-to-end path for the requested duration, prior to data transmission. Connectionless services on OBS can be supported by various one-way reservation protocols, such as JET, JIT and TAG [3, 4 and 6]. Similarly, OPS may support connectionless services by routing packets on an individual basis and may support connection-oriented services by assigning packets to flows and switching the flows based on labels applied to the packets. OBS differs from OPS primarily in that the signaling is done out-of-band in OBS networks, while signaling is done in-band via packet headers in OPS networks. OCS supports packet traffic by establishing a logical topology consisting of lightpaths and then switching or routing packets electronically over this logical topology. Signaling for establishing lightpaths in OCS networks is typically done out-of-band.

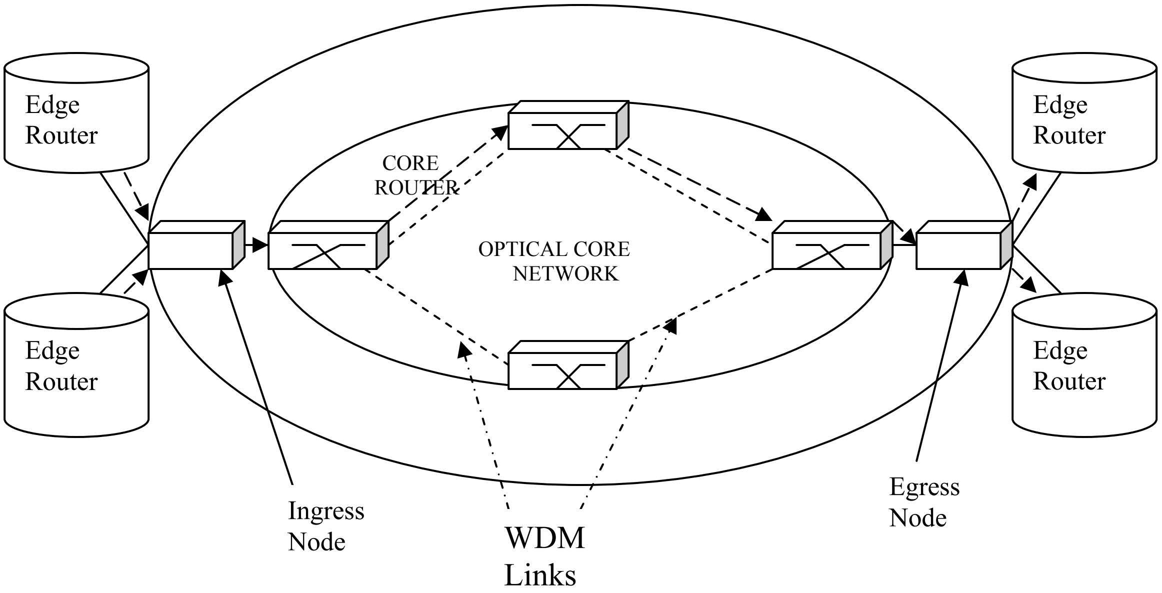

Figure1. Optical Transport Network.

1.2 Transport Network Design

There is an expectation that future optical transport networks will be exposed to not only increasing traffic volumes, but also the growing diversity of services and – an important assumption key to the design – dynamically varying traffic patterns. Research over the recent years has convincingly shown that wavelength-routed optical network (WRON) architectures could potentially simplify routing and processing functions in high-capacity, high bit-rate WDM networks [7-10]. The current research is focused on how best to design the optical network for the future and it can only be resolved by comparing the performance of different architectures, under equivalent operating conditions. The key performance parameters for a given network architecture and traffic load are the packet or burst loss ratio, the achievable delay and the number of wavelength channels utilized (important as wavelengths are a scarce network resource). The simplest approach to the design of an optical network which relies on wavelength functionality for routing would be to set up end-to-end lightpaths between all pairs of end-nodes, mapped appropriately over the physical topology to avoid wavelength contention. Given that the delay in these networks is zero, the key design parameters are the number of wavelengths (lightpaths) required to satisfy the traffic demand and the optimum allocation of these wavelengths according to the physical topology of the network, taking into account extra wavelengths required for restoration[11-16]. Whilst these quasi-static WRONs are relatively simple to analyze and design, current research has focused on establishing whether they are sufficiently flexible in adapting to dynamically varying and bursty traffic loads and service diversity. The fastest and most adaptive approach would be that of a pure optical packet network. However, the difficulties in achieving all-optical packet networks lie in the complexity of building large, fast single-stage all-optical packet switches (which must operate faster than the optical line rates) and lack of the equivalent of scaleable optical RAM/buffers, as well as the growing mismatch between electronic processors speeds (currently ~ 1 GHz) and the optical line rates - currently at 10 Gb/s and expected to exceed 40-160 Gb/s in the near future. The solution appears to be to multiplex data from different pairs of nodes on a single path though the network and to separate the logical ‘connection’ or ‘flow’ from the physical ‘path’ and there are several approaches to this, broadly falling into the category of *optical burst switched* (OBS) architectures, with different functionalities. Optical burst switching was proposed [17-23] as an adaptive optical network to reduce the processing in network nodes needed for packet forwarding. Typically, packets are aggregated at the edge of the network, to reduce the processing overhead and then routed over a buffer-less core. The research questions here address of how best to aggregate packets at the edge and on the optimum assignment of these to packets to wavelengths, to minimize packet loss and delay, whilst ensuring that appropriate quality-of-service (QoS) requirements are achieved and whether wavelength savings are possible under dynamic wavelength operation.

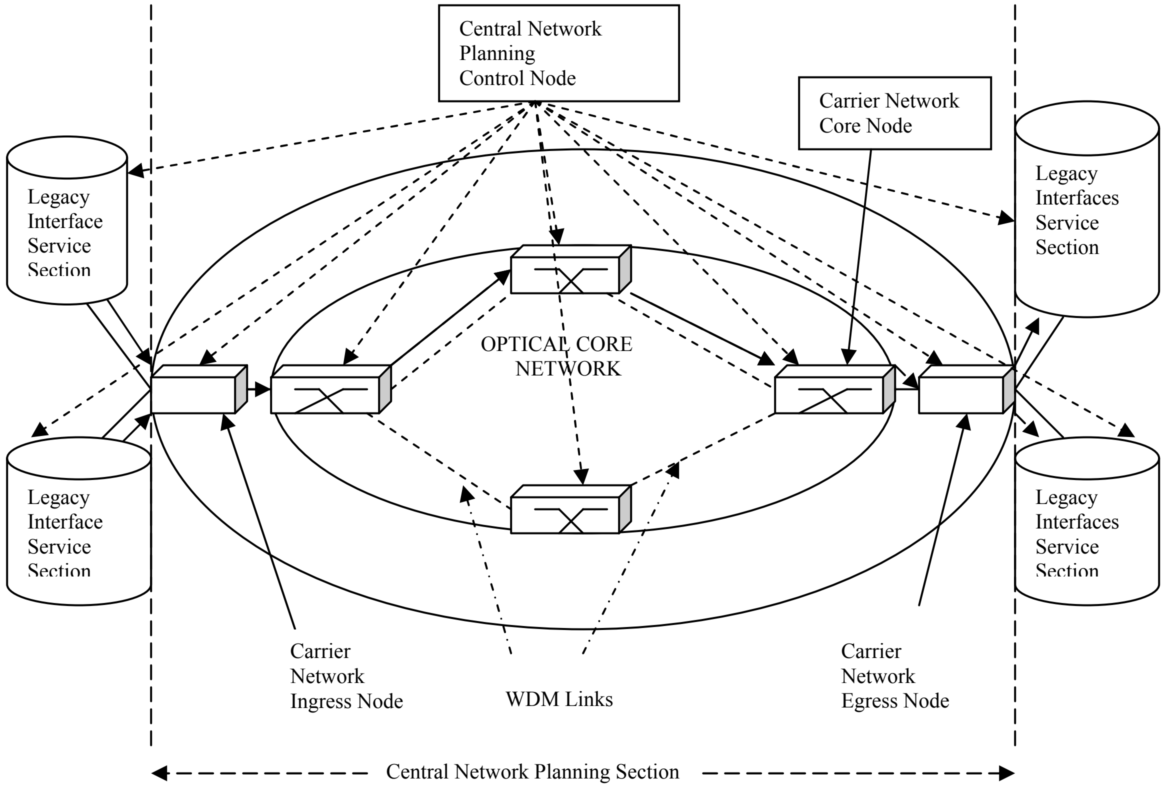

Figure2. Proposed novel network architecture

2. Proposed Network Architecture

In this paper, we propose an alternative OBS high-speed network architecture, analyze and compare it with different conventional OBS architectures. This architecture, shown in Figure2 assumes a fast circuit-switched end-to-end lightpath assignment with a guaranteed, deterministic delay, and requires an obligatory end-to-end acknowledgment. The packets are electronically aggregated at the network edge into bursts, according to their destination and class of service (CoS), but with timescale of milliseconds, which is a typical forwarding time of IP routers, making the reservation of resources along the path prior to burst transmission feasible. The aggregation time is strictly determined by the performance parameters such as delay at the edge or the required burst size for the network. At an appropriate point during the aggregation cycle, an end-to-end wavelength channel is requested from a network control node for transmission of the burst between edge routers. Once a free wavelength is found, the aggregated burst is assigned to it and is transmitted into the core network. Its further latency depends only on the propagation delay because buffering operations with associated nondeterministic delays in core nodes are not required. Concentrating all of the processing and buffering within the edge of the network enables a buffer-less core network simplifying the design of optical switches or routers/cross connects in the core significantly, which is particularly important for time-critical traffic and cannot be achieved with the currently implemented IP-router infrastructure that provides hop-by-hop forwarding only. This requires, however, that the bit rate at the input to the buffers at edge routers is sufficiently high to form bursts on a millisecond timescale. Following transmission, the wavelength channel is released and can be reused for subsequent connections. The network core can either be considered as a passive core or as a network of fast-reconfigurable optical routers/cross connects, where end-to-end lightpaths or circuits are dynamically set up by the same controller that allocates wavelengths. It is assumed that wavelength conversion in core nodes is not required, because, as previously shown, it brings little benefit to wavelength-routed networks with wavelength agility at the network edge [24]. A centralized network management was assumed in this work .A distributed control scheme would be preferred; however, such a scheme relies on synchronization and fast distribution of information on the state of the network. However, the major concern of this approach is its applicability in large backbone networks, where the scalability of this centralized solution is questionable under high traffic load conditions. The core principle of proposed scheme is that, network-planning components proactively reserve wavelength resources for implicitly predicted or explicitly pre-booked future traffic. This prior reservation concept inherits aspects of wavelength routing, providing end-to-end guaranteed paths and an efficient routing and wavelength allocation algorithm to place the anticipated traffic flows appropriately across the network resources. The actual traffic flows will be principally delivered via these reserved paths; however, if the demand exceeds the reserved path capabilities, the excess traffic can be delivered via classical OBS signalling with its inherent risks. This architecture takes advantage of traffic prediction to improve the wavelength routing efficiency. The proposed network structure is shown in Figure 2. The WDM backbone is operated by a Carrier Network Planning Section (CNPS) with various Legacy Interface Service Provider Sections (LISPS) placed at the edge. For scalability purposes, all the complexity is mainly placed at the boundary between the CNPS and the LISPS, allowing the core optical switches to be relatively simple devices.

2.1 Legacy Interface Service Provider Section

Service Provider Sections at the edge of the carrier network manage Legacy traffic and are responsible for burst assembly, burst delivery and QoS selection. The main challenge for them is to adopt an appropriate strategy of resource subscription from the CNPS and allocation of these resources across their customers. In the proposed approach, each LISPS (as shown in Figure3) consists of two key parts – a resource reservation mechanism and a resource allocation unit. The prior resource reservation centre acts as a resource request agent, liaising with the CNPS. It accepts explicit future pre-booking from customers via a long-term pre-booking clerk; it also predicts future end-to-end traffic demands based on historical traffic patterns and other implicit means available to it. The pre-booking and implicit prediction information will then used to formulate reservation requests stipulating parameters such as reservation time, duration and pre-emption level. These requests are then sent to the central network planning control node on the CNS side to ask for suitable resources to be reserved, as required. The resource allocation part of LISPS is responsible for feeding the actual burst traffic into the reserved resources at the pre-booked time(s) they become available. In the case, when the reserved resource is insufficient, the resource allocation part will typically arrange to issue the classical OBS signalling to deliver those bursts on-demand. In terms of QoS provisioning, it is proposed to set aside more resources for loss sensitive traffic, such that the higher class of traffic has more reserved resources thus lowering the risk of burst blocking / loss. The motivation the prior resource reservation scheme proposed here is to be able to help service providers to dynamically reserve network resources based on explicit customer pre-booking and estimated demand. However, determining the frequency of prior reservations including their start time and duration remains a challenging task especially for implicit predicted traffic, where the source destination traffic matrix is non-stationary. For example, a service provider can predict with varying degrees of certainty the average traffic load in next one hour, or in next five minutes; the service provider can also alternatively predict the detail of each burst within the next few seconds.

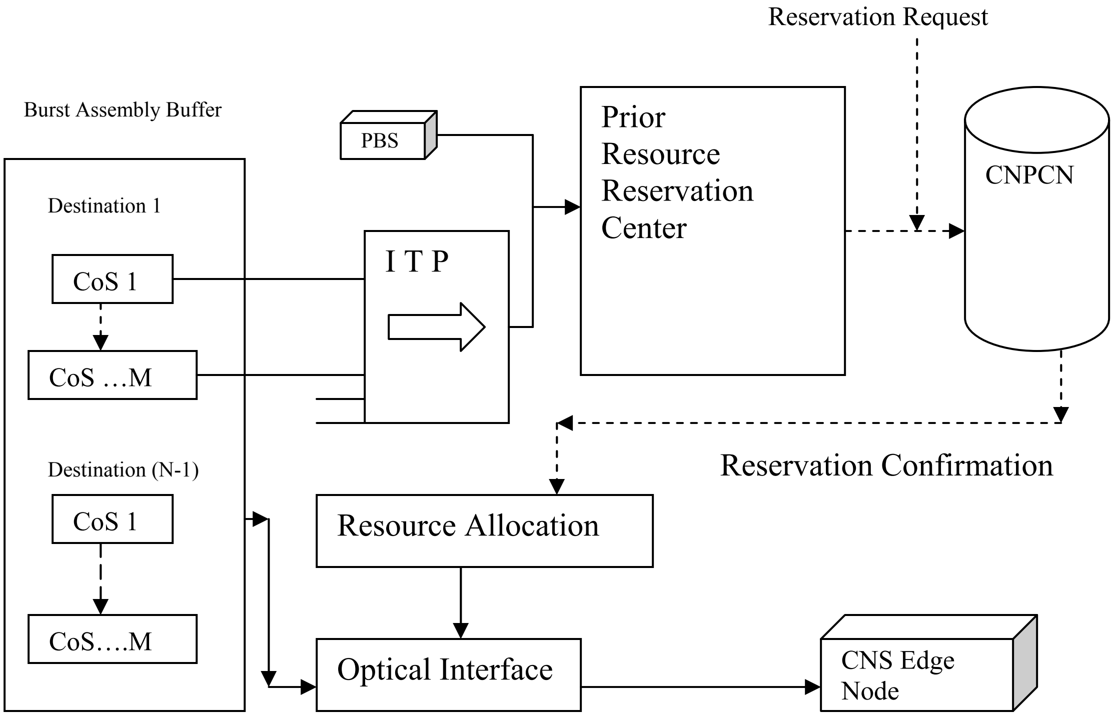

Figure3. Structure of Legacy Interface Provider Service Section
CoS (class of service), ITP (Implicit traffic predictor), CNPCN (Central Network Planning Control Node), PBS (Pre-booking Section)

2.2 Carrier Network Section (CNPS)

In the CNPS, the major concern is how to place the traffic in an optimal way such as to maximize the traffic volume carried and avoid situations there certain parts of the network are unnecessarily congested while other parts are under-utilized. The CNPS accepts and handles the prior resource reservation requests via a central network planning node. The central network planning node (as shown in Figure 4) collects all the prior reservation requests from LISPS into N*(N-1)*M reservation request queues, where N refers to the number of edge nodes, and M refers to the number of priority service classes. It then tries to optimally place the subscription requests by running an efficient routing and wavelength allocation algorithm or formulating the provisioning as an Integer Linear Programming (ILP) problem. Based on the results, a sequence of acknowledgement-required two-way reservation will then be issued to finally confine the reservation. Given that these requests pertain to future requirements, the optimization algorithm does not need to operate "on-the-fly". Indeed, depending upon the remoteness of the reservation times, iterative of differing placement mechanisms could be supported.

Apart from the central node, the CNPS infrastructure also has the ability to support classical OBS reservations. As classical OBS requires topological knowledge at the ingress, each edge node maintains a periodically updated link state database and a source-routed forwarding table, which specifies routes from a source to each destination egress point. The source-routed forwarding table is updated in response to changes in the link state database. The link state database is also influenced by knowledge of confirmed reservations from the central network-planning node.

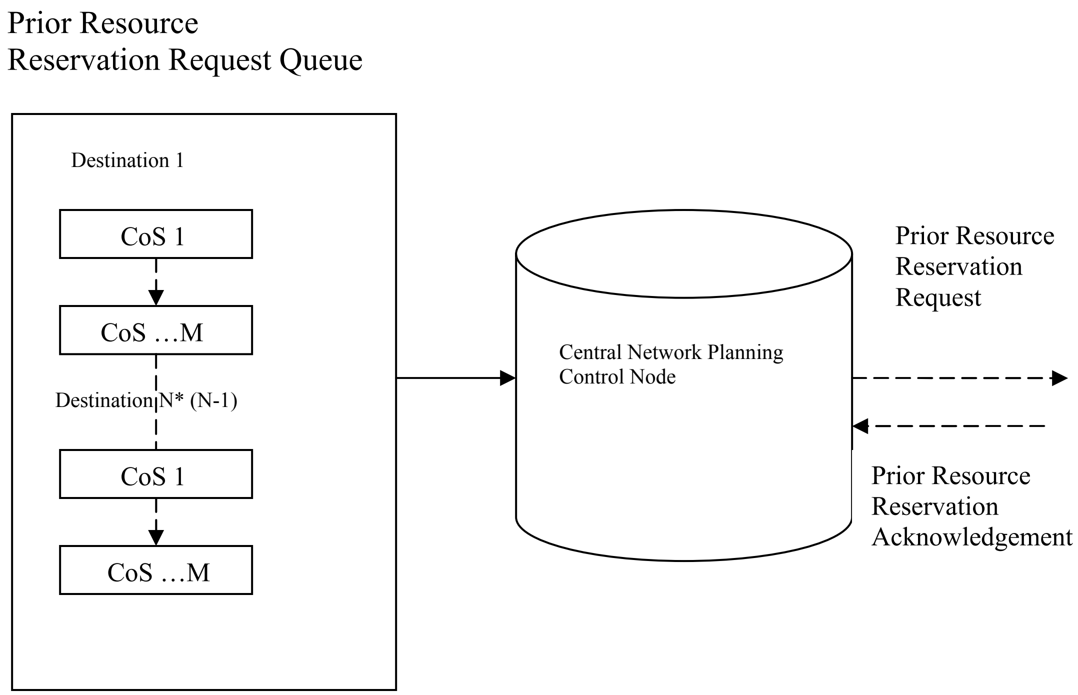

Figure4. Structure of Central Network Planning Control Node

2.3 The Interval Average Load Prior Reservation Strategy

As it has been mentioned that service providers can adopt various prior reservation strategies in terms of subscription granularity and composition e.g. Interval load-balancing prior reservation strategy. In this strategy, a service provider predicts the average end-to-end traffic load over a large time interval, such as every hour and puts the minimum wavelength requirements into the prior reservation request. The prior resource reservation then has to reserve required amount of lightpaths for the one hour duration. The minimum end-to-end wavelength requirement is calculated as the following formula, where *'ξ' is* the smallest integer that is greater than or equal to the real value in the bracket:

$$\textit{Wavelength requirement}=\xi\ [\textit{Predicted End-to-End load (Gb/s)} \div \textit{Wavelength rate (Gb/s)}] \quad \ldots\ldots\ldots\ldots (1)$$

The reason for developing an interval load averaging prior reservation scheme is that, with the current state of prediction technology [6], it is much easier to forecast large interval average traffic load due to the relatively stable daily traffic patterns; whilst it is very difficult to predict the characteristics of each burst. On the CNPS side, the traffic placement is based on a modified form of Dijkstra's algorithm, where the link weight is increased once the reservation is placed on the link. This facilitates load balancing, but it does necessarily yield an optimal solution.

2.4Wavelength Assignment without Wavelength Conversion

Another important issue needs to be noted is that in order to be more realistic, the wavelength continuity constraint is applied in the current implementation. Therefore, all the prior reservations correspond to continuous single - wavelength lightpaths. This raises the wavelength selection problem once the path is determined. In the current implementation, for traffic that can be carried on prior reserved resources, it employs the *latest available unused channel with void filling* (LAUC-VF) algorithm to select the wavelength on the first link. Because a prior reservation is end-to-end guaranteed, the resource availability along the whole path can be guaranteed if the resource is available on the first link. Conversely, in classical OBS reservations with the wavelength continuity constraint, the optimal wavelength selection on the first link can hardly bring significant benefits because it is a one-way best effort reservation and the selected optimal wavelength on the first link can be occupied by other bursts along some later links. Therefore, the current implementation chooses to randomly select a wavelength at the ingress node for classical OBS reservations.

3. Simulation with NS-2

To verify the correctness of the models, computer simulation is a very useful and effective method. By comparing simulation results with collected real data or mathematical analysis, we can modify corresponding parameters related to the performance of networks. The network simulator NS-2 is a discrete event simulator targeted at networking research. NS-2 provides substantial support for simulation of TCP, routing and multicast protocols over wired and wireless (local and satellite) networks.

3.1 FTP traffic generation

FTP uses 2-TCP connections. One for control information and another one for data transfers. The control connection uses an image of the TELNET protocol to exchange commands and messages between hosts. Telnet uses the TCP transport protocol to get a virtual connection between the client and the server. The connection is followed by a negotiation that determines the options that they support. Following commands are used to attach an ftp application to the TCP as shown below (figure 5)

```
 set tcp [new Agent/TCP]
 set ftp [new Application/Traffic/ Poisson]
 $ftp set packetSize_200
 $ftp set burst_time_500ms
 $ftp set idle_time_1s
 $ftp set rate_1000k
 $ftp set shape_1.4
 $ftp attach-agent $tcp
   …
```

Xgraph can be used to create graphic representations of simulation results:

```
set nf [open out0.tr w]
proc finish {} {
global nf
close $nf
exec xgraph out0.tr –geometry320x240 &
exit 0
}
…
```

Figure5.FTP traffic generation

3.2 Simulation results

The blocking probability and delay of the proposed architecture is evaluated and compared with conventional OBS architectures using NS-2 on a random mesh network with 8 nodes and 4 wavelengths. The setup for the simulation is based on the following assumptions:

(1) The burst arrivals to the network edges follow Poisson process with inter-arrival time 100ms.
(2) The burst length is exponentially distributed with an average rate of 40μs.
(3) The bursts are sent only by the edges and the destination is uniformly distributed over all the edges
(4) The routing table is static, the burst takes the shortest path from source to destination
(5) The transmission rate is 1 Gbps.

In this simulation we focus on two parameters; the lost ratio which is the number of dropped burst over the number of burst sent by the edge and the average delay which is the mean time of all the received burst from source to destination.

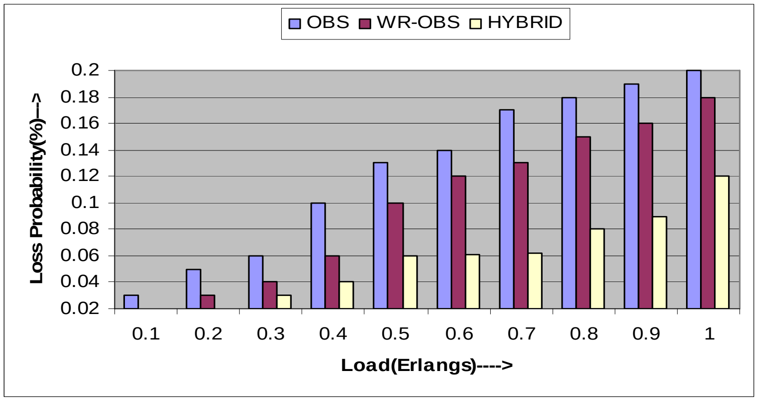

Figure6. Loss Probability for OBS, Routed Wavelength and Hybrid (Proposed) Architecture

The Figure6.shows that the blocking probability is always better with the proposed (hybrid) architecture and the delivery is improved by almost 50%. This enhancement is due to the fact that a part of the traffic is routed over a deterministic sub-network where there is no contention. The new architecture also improves the average of a delivery delay as shown in Figure7. The delay is the average time from source to destination for all received bursts. This average includes the queuing time and the propagation delay. The offset time between the optical header and bursts is negligible (ignored) in this simulation.

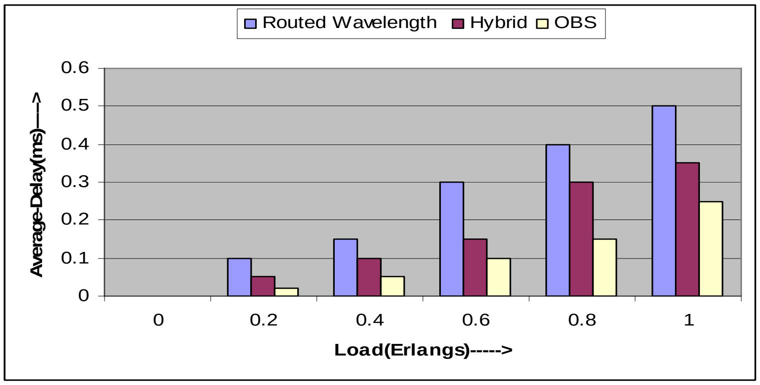

Figure7. The Average Delay of Routed Wavelength, Hybrid (Proposed Architecture) and OBS

4. Conclusion

In this paper, we proposed a novel high-speed architecture that uses both OBS technique and wavelength assignment using central planning control node to take advantage of the big capacity of optical networks. With this technique, the network can provide both wavelength services and bandwidth services and carry different classes of traffic, using either the deterministic way with routed wavelength or the spontaneous way with OBS. An area for future work is the investigation of the optimum partition of the network in order to determine the percentage of the available wavelengths to be used with OBS and with routed wavelength as well. Another concern is the policy used by the edges to dispatch traffic over OBS and wavelength routed sub-network. To reduce the burst loss and decrease the delay, one needs to classify and compare different dispatching policies.

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