Transaction on Network and Communication
ISSN: 2229-8711 Online Publication, June 2011
www.pcoglobal.com/gjto.htm
NC-N07 /GJTO

Global Journal of Technology & Optimization
Volume 2, 2011

DESIGN CONSIDERATIONS FOR EFFICIENT MULTICAST WDM NETWORK SCALABLE ARCHITECTURE

Rabi Yousif[1], Borhanuddin Mohd Ali[1], Mohd K. Abdullah[1], Kamaruzzaman Seman[2], Mohd Dani Baba[3]

[1]Faculty of Engineering, Universiti Putra Malaysia, Malaysia
[2]Faculty of Science and Technology, Universiti Sains Islam Malaysia, Malaysia
[3]Faculty of Electrical Engineering, Universiti Teknologi Mara, Malaysia
Email: rabi.habash@gmail.com

Received October 2010, Revised December 2010, Accepted February 2011

Abstract
In this paper, we present a method for designing a passive optical based single-hop wavelength division multiplexing multicast network architecture that can achieve a scalable structure and form the basis of a wavelength efficient single-hop WDM network. The proposed architecture minimizes the number of wavelengths required for efficient multicast service and also minimizes tunability requirement of the transceivers. The network size scalability is achieved by adding transmitters and receivers to the designated groups. We show that the proposed system can accommodate large tuning delays and keeps with suitable throughput when the number of wavelength is equal to the number of nodes. We also show that the design can lead to a scalable structure while minimizing the number of wavelengths and tunability of the transceivers required for an efficient multicast service resulting in an improved system throughput and delay performance.

Keywords*:* Multicasting, wavelength division multiplexing (WDM), single-hop, passive star, optical network architecture

1. Introduction

In recent years, the Internet traffic has increased tremendously, because multimedia traffic such as video streaming service, high resolution images, digital video and audio conferencing, and business data distribution becomes prevalent in the Internet. Some multimedia applications require strict quality-of-service (QoS) or multicasting. Current state-of-the-art dense WDM systems are using narrow 50-GHz (0.4 nm) channel spacing. In such systems, functions traditionally performed by electronics, such as switching, signal amplification, etc, are performed in the optical domain, therefore achieve signal transparency. Thus, the capability for multicast transmission has become a very important requirement for access networks [1, 2].
WDM technology has the potential to satisfy the ever-increasing bandwidth needs of network users on a sustained basis. Today, optical backbones with a transmission speed of 40 gigabits per second are deployed. This technology is reliable and will meet bandwidth needs for the next few years. However, considering that traffic is growing by 40 percent a year on average, even 40G networks will have to be expanded to 100G. WDM optical networks can efficiently support multicasting since splitting light is inherently easier than copying data into an electronic buffer. Applications of multicasting include multimedia conferencing, distance education, video distribution, distributed games and many others [3, 4].
For cost reasons each node in single–hop WDM networks deploys a rather small number of transceivers which is typically smaller than the number of wavelengths available for data transmission/reception. To increase the network efficiency all wavelengths should be used at any given time. This can be achieved if each wavelength is used by a different subset of nodes. For a single hop communication, the network must be able to establish any possible connection in one hop, without intermediate relaying or routing. This in effect implies that the network will have to change the connections it supports at different times. Multi-hop networks have the ability to circumvent the network capacity limitations. Each node is connected to only a few other nodes, as such only few wavelengths are required per node. This greatly reduces the wavelength bottleneck [5].
In single-hop WDM networks, the major issue is the coordination (scheduling) of the transmissions, because contentions may happen in such shared-media and shared-channel networks. One source of contention is so-called collision, when two or more transmitters want to transmit to the same wavelength channel at the same time. Another source of contention occurs when, in a system with tunable receivers, two or more transmitters want to transmit to the same destination node on different channels simultaneously. This situation is called a destination conflict [6, 7].
A number of multicast scheduling algorithms (MSAs) for transmissions have been proposed. These MSAs can generally be classified as random-access-based MSAs, pre-allocation-based MSAs, and reservation-based MSAs. In [8], some random-access-based MSAs are described. The system employs a centralized scheduler that operates in a slotted mode, maintains a request queue for each node, checks the request queues, and makes appropriate scheduling in each slot.

Preallocation-based MSAs are presented in [9]. These algorithms simply coordinate the transmissions according to some pre-determined schedule. The slots are preallocated for unicast purpose. In general, scheduling multicast transmissions is much more challenging than scheduling unicast transmissions, because the transmitter of the source node and the receivers of all the destination nodes in the multicast group need to be tuned to a common wavelength simultaneously. A multicast distance is used to determine whether an arrived multicast packet should be transmitted as a single multicast or multiple unicast packets. This information along with the multicast group of this packet is broadcast to all other nodes via a control channel. When the information for the multicast packet is received by all of the nodes, all of the nodes run the same scheduling algorithm to modify the preallocated slots to accommodate the multicast packet.

Reservation-based MSAs can be found in [10], where some partition schemes are proposed to address the problem of wasting the receiver resources. In particular, when the multicast group size is large, some receivers may have to wait for a long time without receiving anything because some other receivers in the same group are not available. Specifically, these MSAs allow a multicast transmission to be partitioned into multiple unicast or multicast transmissions and separate transmission is scheduled for each subgroup, in order to minimize the large receiver waiting time. Every node in the system model keeps track of the times beyond which each of the transmitters, receivers, and channels will be available.

For wide ranges of the traffic conditions and a wide range of the number of data channels in the network, a hybrid MSA has been proposed in [11]. The proposed algorithm dynamically chooses to employ a MSA which always tries to partition multicast transmissions or a MSA which does not partition multicast transmissions depending on the average utilization factors of the data channels and the receivers.

The paper is organized as follows. Section 2 provides key design requirements for WDM network Architecture. Section 3 describes the system and traffic model. Section 4 presents system assumptions that characterize the behavior of the system. In Section 5, we use an approximate analytical approach to analyze the system performance in terms of average packet delay, receiver throughput and blocking probability. Section 6 presents system performance and Section 7 presents some analytical results. Concluding remarks are given in Section 8.

2. Key Design Requirements

When designing a WDM network architecture and protocol, the following key requirements and properties have to be satisfied [12 - 16]:

- Provide point–to–multipoint connections in order to support multicast applications such as videoconferences and distributed games in an economical and bandwidth–efficient manner.
- Add or remove network nodes in an easy and nondisruptive way without significantly degrading the network performance.
- Traffic should not have to traverse a large number of intermediate nodes to ensure smaller resource requirements and smaller propagation delays.
- Provide some level of assurance that the service requirements for different types of traffic, e.g., for delay–sensitive, real–time, and interactive applications, are satisfied.
- Allocate network resources to all nodes which need to send data. In networks with fair channel access control each node ready to send data should have an equal opportunity to transmit.
- To cope with the resulting increased local traffic, metro networks have to be easily upgradeable. Advanced technologies, e.g., tunable transceivers with a wider tuning range and a smaller tuning time, have to be incorporated without network service disruption and reconfiguration.

3. System Description

The system under study is based on a broadcast-and-select WDM architecture consisting of N network nodes connected via optical fibers to a passive star coupler (PSC) as shown in Figure 1. There are W wavelength channels, where $W \leq N$. The bandwidth of a fiber is divided into W +1 channels, where $W \leq N$. One of the channels, λ_0, is used as a control channel which is shared by all nodes. The rest of the channels, $\lambda_1, ..., \lambda_W$, are used as data channels.

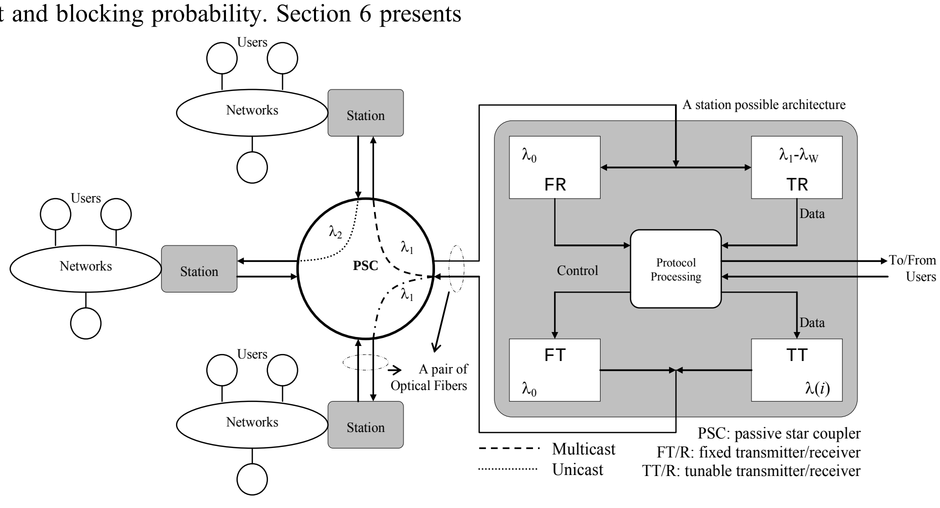

Figure 1: A broadcast-and-select star-based WDM optical system.

Each node in the network is connected to the PSC by a transmitting and receiving fiber, and each message is addressed (multicast) to a number of receivers (destination set size), randomly chosen from the N network nodes and each receiver tunes to one of the wavelengths that has a message addressed to it. Also, each node has one fixed transmitter and one fixed receiver in order to access the control channel. Moreover, in order to access data channels, each node has one tunable transmitter and one tunable receiver, so that full connectivity can be achieved by tuning transmitters to different wavelengths.

Tuning times are not negligible with respect to the slot time. A centralized network controller allocates slots in a WDM frame according to (long-term) bandwidth requests issued by users. When $W \leq N$, two or more nodes share one data channel. Each node is equipped with a buffer in which arriving data packets are stored. Deploying tunable transmitters and receivers at each node allows for load balancing since traffic between a given pair of nodes can be sent on any wavelength. In particular for nonuniform traffic, load balancing increases the channel utilization and improves the throughput–delay performance of the network [18, 29].

All stations can communicate with one another. In addition, a pair of fixed transceivers and control receiver both are tuned to the control channel is dedicated for pre-transmission co-ordination. However, communication between two nodes is possible only when the transmitter of the source node and receiver of the destination node are tuned to the same channel during the period of information transfer.

4. System Assumptions

The behavior of the system is characterized by the following assumptions:

- There are N network nodes and W wavelength channels in the system.
- Each node has a single–packet buffer, i.e., each node can store at most one data packet at any given time.
- After transmitting a data packet in a given frame the buffer becomes empty at the end of that frame.
- Each message is multicast to a set of l receivers where $l < W \leq N$.
- Whenever the receivers of a multicast group are ready to receive a data packet the source node's transmitter is ready to transmit.
- A packet that arrives at the start of a slot can be transmitted during that slot to any one of the other $(N - 1)$ nodes with equal probability.
- A node sends out its control packet in a frame with probability p, not only for retransmissions but also for first–time transmissions.
- Random selection of a destination node among the $(N - 1)$ nodes is renewed for each attempt of transmitting a control packet.

5. System Model

The proposed architecture aims to define a minimum group of network nodes for a local structure, assign a unique wavelength to a transmitter, and identify, for each transmitter, the minimum set of additional wavelengths needed to achieve communication with every other node in the local cluster and hence all the nodes in the network. Figure 2 shows the node structure of the system. Each receiver is able to tune to all the wavelengths assigned to the transmitters having direct links to it. Each processor can transmit data on a fixed number of wavelengths, but can receive data on a range of wavelengths by dynamically tuning to the wavelength of a transmitting station. All the processors are synchronized at the optical coupler. The use of the same structure for both the transmitter and receiver is strategic [16 – 19]. This will greatly simplify the coupling of the local structure. Each node can switch channels (wavelengths) during execution by dynamically changing the injection current to the laser.

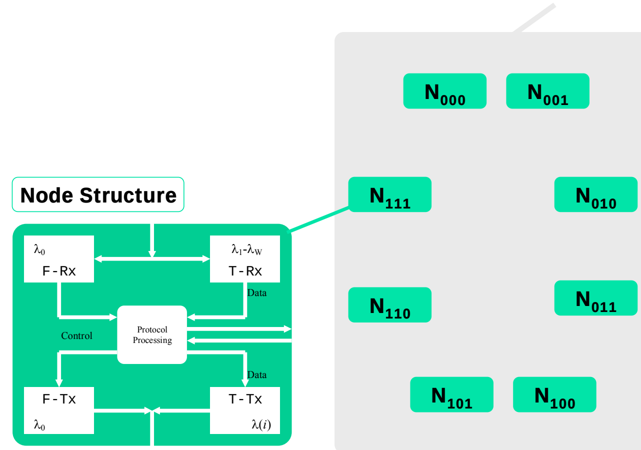

Figure 2: Network structure of the proposed star-based WDM system.

Additionally, transmission and reception can be performed on different channels. The single star topology consists of n inputs, to which one transmitter is connected, and n outputs, to which one receiver is connected. To achieve single-hop connectivity, a wavelength allocation mechanism needed to determine a path for a new request. Each transmitter group can have direct links to exactly two receiver groups. For any transmitter group, the two receiver groups that do not have a direct link to it consist of those that contain receivers with the same index notation as one of the transmitters in the transmitter group. For any transmitter/receiver group, there are two receiver/transmitter groups that can have direct links to it and two others that do not have direct links to it. The transmitter/receiver groups not having direct links to the same receiver/transmitter groups are mutually exclusive. Finally, half of the number of transmitters/receivers can be directly connected to half of the number of receivers/transmitters simultaneously. Figure 3 shows the connection establishment method among the network nodes in order to achieve single-hop communication.

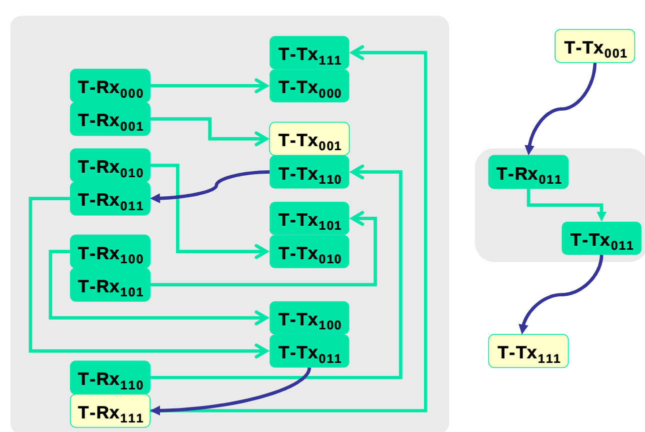

Figure 3: Connection establishment method.

If there are more than m access nodes, where m is the desired number of access nodes representing the regular local structure, a partition can then be accomplished by defining a minimum set of access nodes as the local structure and applying the partition mechanism that is explained above to achieve the partition set. The transmitter in a group needs to be placed according to the partitioning mechanism and same also for the receiver. Scalability here has two aspects. First, the transmitter and receiver of the new access node must be physically connected to the optical medium and second, the added access node must be incorporated into the MAC mechanism that controls the single hop connections [14 - 16].

In order to incorporate the added access nodes in the MAC mechanism, it requires only modifications for the control channel. This means that the number of added nodes must increase the number of control slots. To correctly reach each added node, all transmitters must be informed about its receiver configuration and its address. Since computer networks traffic changes rapidly, there is a need for a good mechanism to change the current situation of the network in terms of wavelength allocation (i.e., the current wavelength assignment into a new wavelength assignment). However, the number of channels is a limiting factor in a WDM network, and is typically less than the number of nodes in the network. Therefore, more than one receiver is assigned to one channel. This problem is called wavelength assignment problem [24].

There are basically two ways to achieve connections between nodes in an optical network, path multiplexing and link multiplexing. In the first the same wavelength has to be assigned all to the links between source and destination, while in the second, different wavelengths can be assigned on different links. Wavelength blocking is a major problem with path multiplexing. One obvious disadvantage with the link multiplexing is the use of wavelength converters at intermediate nodes to eliminate blocking. This however, increases the cost and complexity of the system [25].

In single-hop communication, all the nodes can reach any other node directly. This means that the transmitted data are not passed through any intermediate routing stages and remain in optical form all the way from the source node to the destination node. In such mode of communication, a lightpath is established before a communication starts and the data transmission is carried out in a pure circuit-switched manner. With dynamic traffic demands, new lightpaths need to be added to the logical topology each time an arriving connection request cannot be accommodated.

The WDM techniques enable extraction of a larger amount of usable bandwidth. Routing and wavelength assignment algorithms fine-tune the overall process by achieving orders of magnitude of performance improvement. The goal is to present an efficient dynamic distributed routing and wavelength allocation method that minimizes path latency, wavelength blocking and the number of wavelengths applied [17 - 20].

6. System Performance

In this section, we analyze the system performance in terms of average packet delay and throughput. We first calculate the average delay a packet experiences. This delay is due to the data packet transmission delay, control channel delay, data channel delay, and propagation delay. The length of data packet is fixed and equals to L control slots. Assume the receiver tuning time is T_r control slots. Thus, the data packet transmission delay equals to

$$D_d = L + T_r . \qquad (1)$$

Assume the arrivals are Poisson of rate A per control frame. The server process is deterministic with rate $\mu = 1$ per control frame, and the offered load $a_c = A/\mu$ [20]. Therefore, the average delay a data packet incurred before its corresponding control packet is sent can be given by

$$D_c = 1 + W/2 + a_c/2(1 - a_c) . \qquad (2)$$

When the receivers of a multicast packet are ready to receive a packet, a free channel is available for transmission. If the number of free channels is few, a free channel may not be available and the packet may be delayed. Thus, the offered load can be given as $a_{ch} = A(D_d)/W$. Therefore, the delay due to the data channel can be calculated as

$$D_{ch} = a_{ch} / 2W(1 - a_{ch}) . \qquad (3)$$

The total propagation delay between any node in the system and the passive star coupler is R and is assumed to be the same for all the nodes [21 - 23]. Thus, the propagation delay for a data packet is $D_R = 2R$.

Note that the average packet delay is measured from the time the packet is generated at the node until it is completely received by the destination. Therefore, the average packet delay can be given by

$$D = \frac{1}{aW} + \frac{N}{S} + \frac{2T + W}{W} \qquad (4)$$

where $1/\alpha W$ is the average time the packet stays waiting for generation (idle state), N/S is the average waiting time the packet experiences from the moment it enters the idle state to the moment it returns to it, S is the system throughput, and T is the transceiver tuning time. At the maximum offered load, we obtain

$$D = \frac{1 + 2R + 2T + W + 1/p}{W} \qquad (5)$$

where $1/p$ is the average time a node waits before it transmits its control packet in a current control slot.

We now can obtain the achievable throughput of the system as follows:

$$\frac{1}{S} = \frac{D}{N} + \frac{1}{\alpha WN} + \frac{2T + W}{WN} \qquad (6)$$

$$S = \frac{1/W + a + 1/N}{(a+1)D + 1/W + 2 + 2aT + aW + 2T/W} \qquad (7)$$

At the maximum offered load, we have

$$S = \frac{1 + (W+N)/2}{R + 4TWN + 2W^2N + N/2 + WN + WNT + W^2N/2 + NT} . \qquad (8)$$

6.1 Multicast Transmissions

The analysis that follows assumes that a new message arrives at the beginning of a time slot only when transmission of a previous message is completed at the end of the previous slot. A new message is destined to node i with probability l/N . If we now let Q^i_m be the number of messages addressed to node i at the end of m^{th} time slots, and since node i can only receive one message during any time slot, we the have

$$Q^i{}_m = \max(0, \quad Q^i{}_{m-1} + \alpha^i{}_m - 1) \qquad (9)$$

where $\alpha^i{}_m$ is the number of new messages arriving and destined to node i.

When the arrivals are Poisson of rate A, the average number of messages destined to a receiver can be expressed according to the M/D/1 queue system by

$$Q = A + \frac{A^2}{2(1-A)}\,. \qquad (10)$$

Since there are N nodes, each node has lW/N transmissions intended for it and it only receives one transmission at a time $\overline{T}$, the average number of transmissions required by a message can be given as lower bounded $\overline{T} > \max(W/N, 1)$. When $lW < N$ the system is channel limited, i.e., there are not enough channels to keep all the receivers busy, the receiver cannot be fully utilized because messages will have to be retransmitted many times. When $lW > N$ the system is receiver limited, i.e., number of receivers is too small to keep all the channels busy with new transmissions [21 - 27].

Let M_{max} be the number of messages waiting in the transmitter queue and let Q_{max} is the maximum number of messages waiting in the queue, then the number of new arrival messages can be obtained as

$$A_{max} = M_{max} - Q_{max}. \qquad (11)$$

In a slotted system, if there are new arrivals to the queue during a slot, half of these new arrivals will be placed ahead of the given message in the queue and half behind it. Hence, if $\overline{\alpha}_n$ is the average number of new arrivals to the queue, the average waiting time in the queue can be given by

$$\overline{T} = 1 + 2T + \overline{Q}_{\max} + \frac{\overline{a}_n}{2}\,. \qquad (12)$$

However, if the arrival rate is greater than unity, $\overline{T}$ will be infinite and S will be zero. Since the transmission takes place on W wavelength channels, the average number of completed multicast transmissions per time slot is $\overline{T}/W$ and the average arrival rate can be given by

$$\overline{\alpha}_n = Wl / N\overline{T}\,. \qquad (13)$$

It is shown in [28 - 31] that when the number of nodes with receiver busy time is equal to the multicast size, the behavior of the system could be described using an approximate Markov chain model shown in Figure 4, where σ represents the probability that the receiver is busy, and γ is the arrival rate of data packets per control slots. The maximum receiver busy time over all the nodes is assumed to be B_{Rmax}. If a node has receiver busy time less than B_{Rmax}, the receiver busy time equals to $B_{\text{Rmax}} - (L + T_r) = L'$.

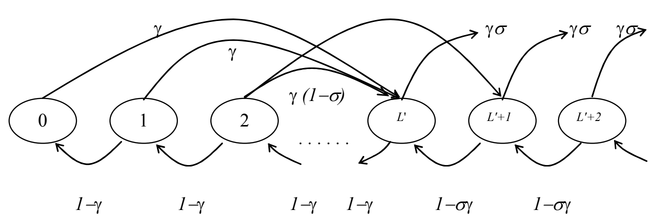

Figure 4: Markov chain transition probabilities.

The probability that the value of B_{Rmax} increases is given by σ and the probability that a multicast packet is transmitted in a current slot is given by γ. If $B_{\text{Rmax}} = 0$ or 1, the value of B_{Rmax} approaches L'. Therefore, there is only one forward transition from state 0 and from state 1 to state L'. For $B_{\text{Rmax}} < L'$, the receiver busy times of the nodes will either equals to B_{Rmax} or zero. Therefore, there are two possible probabilities [32]. The first is ($\gamma\sigma$) if at least one node participating in the multicast has receiver busy time equals to B_{Rmax}, and in this case the next state is $B_{\text{Rmax}} + L' - 1$. The second is $\gamma\,(1-\sigma)$ if all the nodes in the multicast have receiver busy time equals to zero, and in this case the next state is L'.

6.2 Channel Blocking Probability

Channel blocking probability is defined as the probability that there is no sufficient capacity for a channel in a finite link. For a finite buffer case, the system throughput equals the arrival rate multiplied by (1 - blocking probability) [33].

In the following we make the assumption that the multicast size has a uniform distribution. The throughput is then limited by a form of blocking results from a channel being efficiently used while the message being transmitted on that channel is waiting for receivers to become available.

Now consider a single channel λ_i using $W_{i,on}$ and $W_{i,off}$ to denote the mean *on* and *off* periods in a finite system, respectively. Hence, the blocking probability of channel i can be given by

$$P_B = \frac{\lambda_i \overline{T}_{i,off} - 1}{\lambda_i \overline{T}_{i,on} + \lambda_i \overline{T}_{i,off}} \qquad (14)$$

where the numerator denotes the mean number of failed attempts to subscribe to W_i during a time slot and the denominator represents the mean total number of attempts during a time slot. When the channel is *off*, we have

$$P_B = (1/\lambda_i \overline{T}_{i,off}) - 1\,. \qquad (15)$$

The request for connection between any two users will be blocked if there is no wavelength which is available on every link between them. We assume that a node will select one message randomly when there are many transmissions to choose from. This means during each slot, W messages are chosen for transmission from among N nodes.

Let C be the average duration of a connection, and λ_i is the arrival rate on the i^{th} link of the path. The average offered load on the i^{th} link of the path α_i is then $C\lambda_i$. Thus, the probability that all the W channels are busy on that link connecting source and destination which represents the probability of blocking is finally obtained as

$$P_B = \frac{(C\lambda_i)^W}{W!} = \left(\alpha_i^W \big/ W \right) \Bigg/ \sum_{j=0}^{W} \alpha_i^W \big/ j!\,. \qquad (16)$$

7. Results and Discussion

In this section, we analyze the performance of the proposed PSC based single–hop WDM optical system, first we take a look at a single-hop network capacity growth and number of wavelengths required. Then, we examine the effect of the proposed wavelength allocation method and partitioning mechanism using analytical formalization on the number of tunings and number of wavelengths required for efficient multicasting taking into consideration different number of network nodes and other performance parameters. We also evaluate the system performance analytically in terms of average message delay, tuning time, versus receiver throughput characteristics. The effect of system parameters is also investigated as it affects the system throughput. Finally, we examine the blocking probability as a function of the mean arrival rate and packet transmission time.

Figure 5 depicts a linear relation between the number of required wavelengths and the number of simultaneously transmitting nodes. Hence, it is advisable to equip PSC based single-hop networks with acousto-optic transceivers in order to provide wider tuning range.

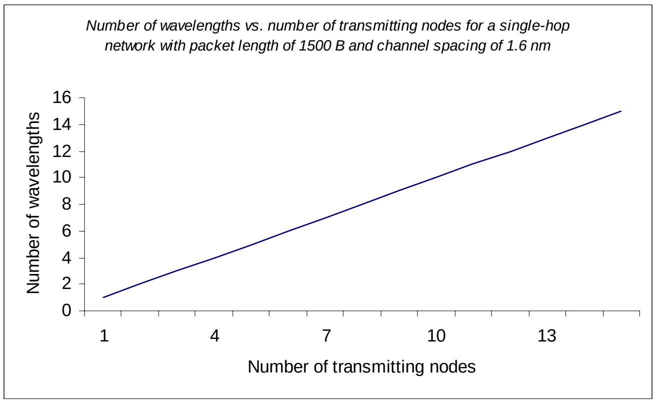

Figure 5: Number of required wavelengths vs. number of simultaneously transmitting nodes for a PSC single-hop network with packet length of 1500 bytes and channel spacing of 1.6 nm.

The effect of the tuning time on the average packet delay and system throughput is shown in Figure 6 and Figure 7. Note that when the tuning time increases the packet delay gets larger but the system throughput does not change because there is enough bandwidth available to accommodate all of the traffic demand.

The reduction in throughput is caused by the control packet time slots period needed for the channel connection establishment when tuning time gets larger. The increase in this period leads to more interference among the transmission attempts of different users to send their packets. However, with larger tuning time the maximum throughput of system stops at a lower value when the offered load equals to 1 since more users in the system are waiting for transmitting or receiving packets.

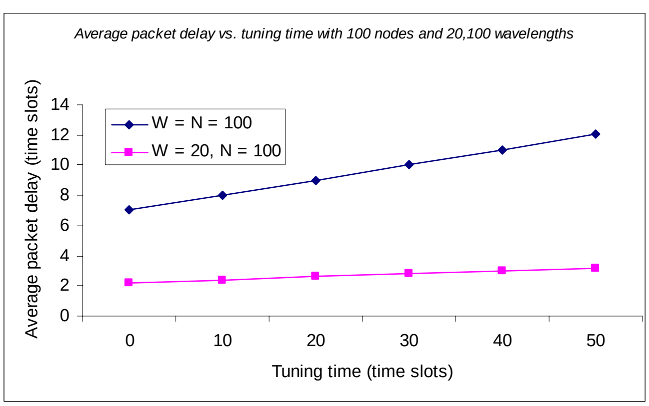

Figure 6: Average packet delay vs. tuning time for a network with 100 nodes and 20, 100 wavelengths.

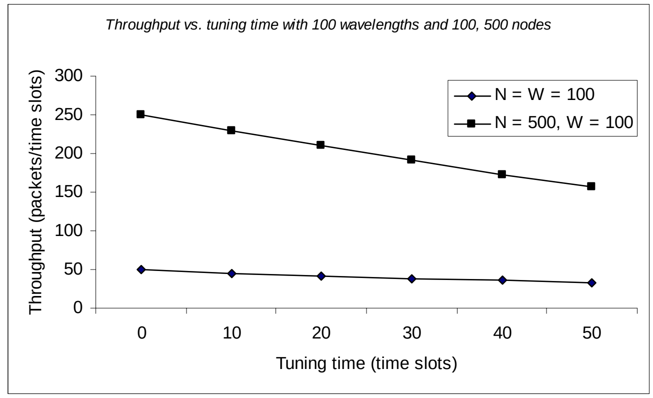

Figure 7: Throughput vs. tuning time for a network with 100 wavelengths and 100, 500 nodes.

In Figure 8 and 9, we examine the effect of tunability and wavelength allocation parameters on the performance in terms of the average delay versus offered load for a network with 200, 400, and 1200 nodes, and the tunability is set to 2 and 3 wavelengths. The results show that with a higher tunability, the average delay is reduced, though only slightly. The reduction in delay is achieved because more channels help to reduce the blocking probability, since the transmitters have only a small tuning range.

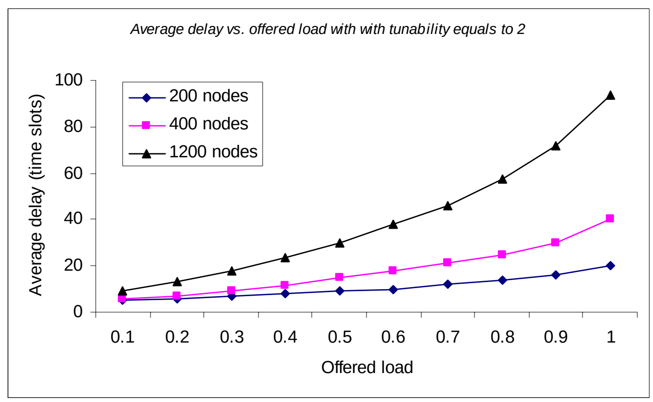

Figure 8: Average delay vs. offered load for a network with 200, 400, and 1200 nodes, and tunability sets to 3.

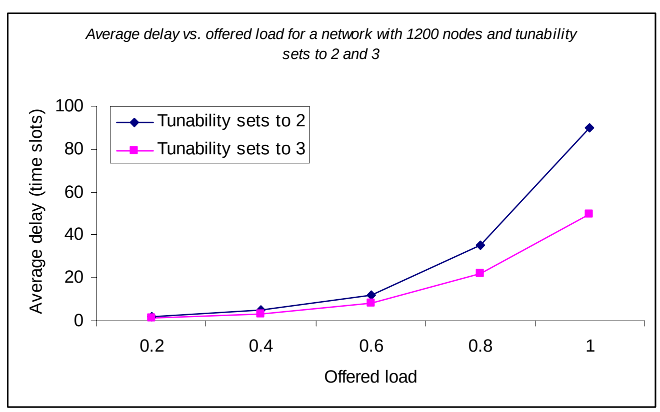

Figure 9: Average delay vs. offered load for a network with 1200 nodes and tunability sets to 2 and 3.

7.1 Multicast and Receiver Throughput Performance

Mean multicast throughput is defined as the mean number of multicast completions in steady state. The mean multicast throughput is equal to the ratio of mean transmitter throughput and mean number of required transmission in steady state in order to reach all receivers of a given multicast packet. Thus, multicast throughput measures the multicast efficiency of each packet transmission. Mean transmitter throughput is defined as the mean number of transmitting nodes in steady state. Mean receiver throughput is defined as the number of receiving nodes in steady state. For this study we consider multicast traffic, i.e., each packet is destined to a multicast group. The size of the multicast group, i.e., the number of destination nodes, and the members of a given multicast group are independently randomly drawn for each packet.

The multicast set size is uniformly distributed over [1, $N-1$] network nodes and the multicast group members are uniformly distributed over all network nodes [1, N] except the transmitting source node, as is typically considered in multicast studies. The destination nodes of a given multicast packet are not renewed when the corresponding control packet fails and is retransmitted.

Figure 10 shows the average packet delay versus number of wavelengths characteristics. We can observe that for the same number of wavelengths and average waiting time for a node, the average packet delay is very small for a system with a small tuning time compared to a system with a large tuning time. The maximum packet delay occurs when the number of wavelengths is small.

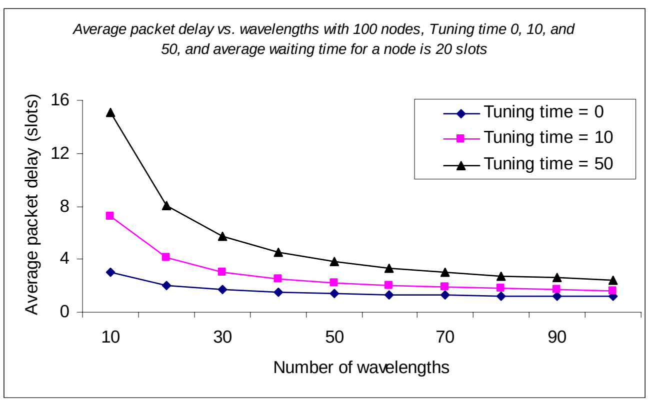

Figure 10: Average packet delay vs. number of wavelengths for a network with 100 nodes, tuning 0, 10, and 50 slots, and average waiting time for a node is 20 time slots.

Figure 11 shows the average packet delay versus throughput characteristics of multicast, transmitter, and receiver for a PSC based single-hop WDM network with 200 network nodes and retransmission probability equals to 0.5. The network receivers are divided into two groups allowing wavelength reuse, which is possible during the reservation phase, i.e., the first slots of every frame when the control packets are transmitted.

As can be seen the transmitter throughput is affected by the many destination conflicting multicast transmissions. However, with two partitions multicast copies destined to the coupler will likely experience receiver conflicts since on average each copy is destined to more receivers for two partitions than for more partitions.

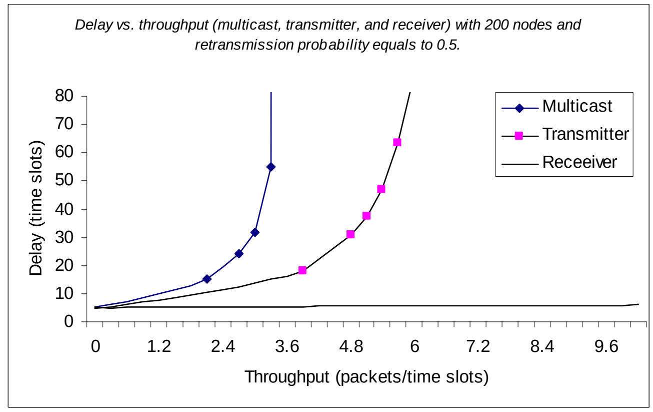

Figure 11: Delay vs. throughput (multicast, transmitter, and receiver) with 200 network nodes and, 2 partitions, and retransmission probability equals to 0.5.

This problem is mitigated by dividing the receivers into more groups so more transmitters are likely to find receivers free. In terms of multicast throughput which means the mean number of multicast completions, it is better to have two partitions so each transmitted multicast copy is received by more destinations which leads to higher receiver throughput and fewer required transmissions of given multicast packet.

7.2 Blocking Probability Characteristics

The blocking probability as a function of packet transmission time is shown in Figure 12. The data is obtained for a network with $N = 10$ and 20. Note that, in the PSC based network, new arriving packets find buffers already full with a high probability which translates into a higher blocking probability. For larger N the blocking probability rises due to the longer frame size. Note that in real systems such high packet loss rates are not acceptable. To handle this situation a single-packet buffers are replaced with larger buffers. This will make arriving packets to be stored resulting in smaller blocking probability while providing an acceptable throughput.

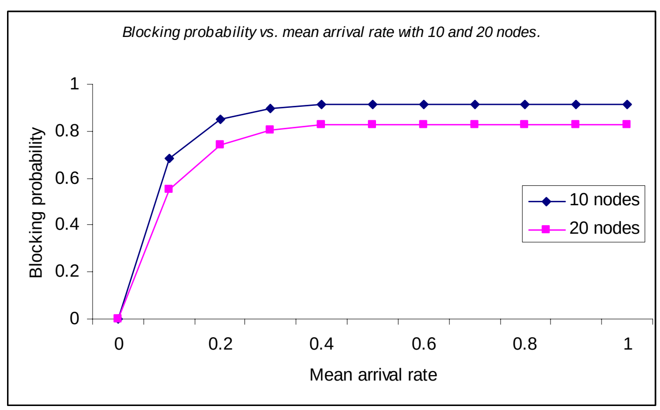

Figure 12: Blocking probability vs. mean arrival rate (packet/packet transmission time) for a network with 10 and 20 nodes

In Figure 13, we evaluate the system performance in terms of blocking probability against offered load for a system with 100 nodes and at different number of channels. Note that for the same load, the maximum blocking probability decreases as the number of channels increases.

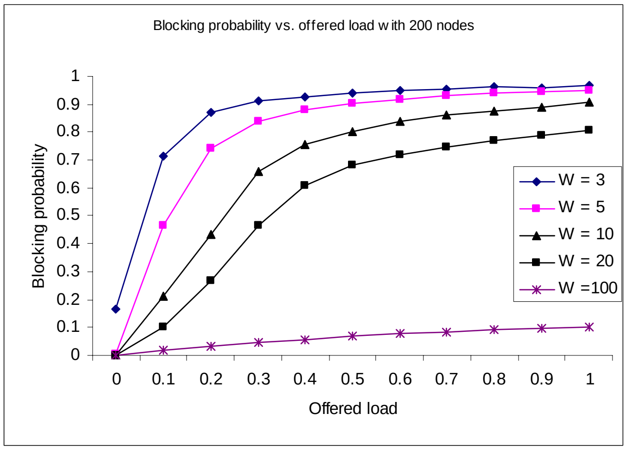

Figure 13: Blocking probability vs. offered load for a network with 200 nodes and different number of wavelengths.

This is because when the number of channels in a system increases, the probability that every user in the system will find an available channel also increases, and hence the blocking is reduced. However, if the system is run only at light traffic loads, this will not be attractive since at low loads the aggregate throughput is small as well. Recall that the packet arrival process is assumed to be Poisson. Due to the randomness of the arriving process, packets are lost, especially at high arrival rates.

8. Conclusions and Future Work

The proposed method of designing a PSC based single-hop WDM multicast architecture can achieve a scalable structure that can form the basis of a wavelength efficient single-hop WDM network. The proposed architecture minimizes the number of wavelengths required for efficient multicast service and also minimises tunability requirement of the transceivers. The network size scalability is achieved by adding transmitters and receivers to the designated groups. Wavelength scalability is achieved through wavelength spatial re-use. The problem of updating the wavelength assignment in single-hop WDM networks is considered where the traffic demand changes frequently and changing the channel assignment becomes necessary. Minimizing the number of tunings required can be achieved by exchanging one of the receivers, which is assigned to the channel with high load, with the appropriate receiver in the channel with minimum load. Tuning is carried out to equalize as much as possible the most loaded channel and the least loaded channel. In this environment, the problem is finding an allocation of wavelengths to receivers such that the number of transmissions of a multicast message is minimized. Since the number of wavelengths is limited by technology, the problem then becomes in finding the best partitioning scheme for the receivers in the network. The proposed system can accommodate large tuning delays and keeps with suitable throughput when the number of wavelength is equal to the number of nodes. When the number of wavelengths is comparable to the number of users the tuning time influence on the packet delay increases.

In the context of wavelength allocation, a study on increasing the number of exchanges by taking into account the channel which comes right after the most loaded channel can be considered for future work. Typically, this will include the optimization of the communication, analysis of the communication patterns, and connection scheduling and communication phase analysis. Also a study the impact of large tuning delays on reconfiguration process and on the network performance is required.

References

[1] Han, K.E. and Yang, W.H. Design of AWG-based WDM-PON Architecture with Multicast Capability, In the Proceedings of the HSN'2008 Workshop, vol. 1, USA, 2007.

[2] Zhone Technologies. Zhone WDM Optical Transport Equipment Chosen to Extend Fiber Capacity and Increase Reliability for Pure Packet Network. Press Release, 2007.

[3] http://www.zhone.com/about/news/2007/on-telecoms-greece.en-us.n2n?print=1

[4] Huang, S., Dutta, R., and Rouskas, G.N. Traffic Grooming in Path, Star, and Tree Networks: Complexity, Bounds, and Algorithms. IEEE journal on Selected Areas in Communications, vol. 24, no. 4, 2006.

[5] He, J., Chan, S.-H., G., and Tsang, D. H. K., 2002. Multicasting in WDM Networks. In IEEE Communications Surveys. IEEE Communications Society Publication.

[6] Sue, Chuan-Ching and Kuo, Sy-Yen, 2002. Design and Analysis of Accelerative Preallocation Protocol for WDM Star-coupled Networks. In Journal of Lightwave Technology, vol. 20, no. 3. IEEE/OSA Publication.

[7] Baldine, I. and Rouskas, G. N., 2001. Traffic Adaptive WDM Networks: A Study of Reconfiguration Issues. In Journal of Lightwave Technology, vol. 19, no. 4. IEEE/OSA Publication.

[8] Kitamura, T., Iizuka, M., and Sakuta, M., 2001. A New Partition Scheduling Algorithm by Prioritizing the Transmission of Multicast Packets with Less Destination Address Overlap in WDM Single-Hop Networks, In GLOBECOM'01, IEEE Global Telecommunications Conf., USA. IEEE Publication.

[9] Tseng, W.-Y. Kuo, S.-Y., 1998. A Combinational Media Access Protocol for Multicast Traffic in Single-Hop WDM LANs. In GLOBECOM'98, IEEE Global Telecommunications Conference, Sydney, Australia. IEEE Publication.

[10] Jue, J. P. and Mukherjee, B., 1997. The Advantage of Partitioning Multicast Transmissions in a Single-Hop Optical WDM Network. In ICC'97, IEEE Int'l. Conf. on Communications, USA. IEEE Publication.

[11] Lin, Hwa-Chun and Wang, Chun-Hsin, 2001. A Hybrid Multicast Scheduling Algorithm for Single-Hop WDM Networks. In Journal of Lightwave Technology, vol. 19, no. 11. IEEE/OSA Publication.

[12] Ramamurthy, B., 1998. Efficient Design of Wavelength Division Multiplexing (WDM) Based Optical Networks. In Ph. D. Dissertation, Faculty of Computer Science, University of California, USA.

[13] Nina, S. Multicast Routing and Wavelength Assignment in WDM Networks: A Bin Packing Approach, Optical Society of America Publications, 2006.

[14] Maier, M., Scheutzow, M., and Reisslein, M. The arrayed-waveguide grating based single-hop WDM network: an architecture for efficient multicasting. IEEE Journal on Selected Areas in Communications, 21(9), 2004.

[15] Ramaswami, B., 2002. Optical Networks: A Practical Perspective. Morgan Kaufmann Publishers, Inc. 2nd Edition.

[16] Wang, Y. and Yang, Y., 2002. Multicasting in a Class-Capable WDM Networks. In IEEE Journal of Lightwave Technology, vol. 20, no. 3. IEEE/OSA Publication.

[17] Jia, X. et al. 2002. Multicast Routing, Load Balancing, and Wavelength Assignment on Tree of Rings, IEEE Commun. Letters, vol. 6, no. 2, 2002, pp. 79–81.
[18] Sendag, R. Chuang, P., and Du, H.C. 2002. Routing and Wavelength Assignment in Optical Passive Star Networks with Non-uniform Traffic Load, In the Proceedings of the GLOBCOM'02, vol. 3.
[19] Okorafor, E., and Lu, M. Efficient Distributed Control Routing and Wavelength Assignment Mechanism for a Scalable Hierarchical Single-Hop WDM All-Optical Interconnection Network. In Proc. 6th Joint Conf. on Information Sciences (JSIC), pp. 276 – 282, 2004.
[20] Feiling, Jia and Mukherjee, B., "A High-Capacity, Packet Switched, Single-Hop Local Lightwave Network," Global Telecommunication Conference, 1993, GLOBCOM, IEEE, pp. (1110-1114) vol. 2.
[21] Hamad, A. Tao, W. Kamal, A., Somani, A.K. Multicasting In Wavelength-Routing Mesh Networks, Computer Networks 50 (16): 3105-3164, 2006.
[22] Rouskas, G.N. Hierarchical Traffic Grooming, Chapter Book, 2008.
[23] Rouskas, G.N. Optical Layer Multicast: Rationale, Building Blocks, and Challenges, IEEE Network, vol. 17, no. 1, pp. 60-65, 2005.
[24] Pointurier, Y. and Brandt-Pearce, M. Routing And Wavelength Assignment Incorporating The Effects Of Crosstalk Enhancement By Fiber Nonlinearity. 2005 Conference on Information Sciences and Systems, The Johns Hopkins University, 2006.
[25] Banerjee, A., Park, Y., Clark, F., Song, H., Kim, K., and Mukherjee, B. Wavelength-Division-Multiplexed Passive Optical Network (WDM-PON) Technologies For Broadband Access: A Review, Journal of Optical Networking, vol. 4, no. 11, 2005.
[26] Luekijna, K. and Saivichit, C. Multicast Traffic Reconfiguration in WDM Network for Single Node Failure Design, In the Proceedings of ICACT'2007, pp. 1833-1838, 2007.
[27] Mukherjee, B., 2000. WDM Optical Communication Networks: Progress and Challenges. In IEEE Journal on Selected Areas in Communications, vol. 18, no. 10. IEEE Communications Society Publication.
[28] Mukherjee, B. 1997. Optical Communication Networks, McGraw-Hill, New York.
[29] F. Jia, Mukherjee B. "The Receiver Collision Avoidance (RCA) Protocol for a Single-Hop WDM Lightwave Network" Journal of Lightwave Technology, 1993.
[30] Modiano, E., 1999. WDM-Based Packet Networks. In IEEE Communication Magazine, vol. 37, no. 3. IEEE Communications Society Publication.
[31] Modiano, E., 1999. Random Algorithms for Scheduling Multicast Traffic in WDM Broadcast-and-Select Networks. In IEEE/ACM Transaction on Networking, vol. 7, no. 3. IEEE/ACM Publication.
[32] Laxman, H. S., and Mukherjee B., 1997. Probability Distribution of the Receiver Busy Time in a Multicasting Local Network. In ICC'97, IEEE International Conference on Communications, Montreal, Canada. IEEE Publication.
[33] Vastola, K. S., 1996. Performance Modeling Analysis of Computer Networks. Retrieved January 2000, from Rensselaer Polytechnic Institute Web Site: http://networks.ecse.rpi.edu/~vastola/.