Manycast Service in Optical Burst/Packet Switched (OBS/OPS) Networks (Invited Paper)

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Abstract. Recently there is an emergence of many Internet applications such as distributed interactive simulations (DIS), and high-performance scientific computations such Grid computing. These applications require huge amount of bandwidth and a viable communication paradigm to coordinate with multiple sources and destinations. In this work we propose variation of multicasting called quorumcasting or manycasting. In manycasting destinations are to be determined rather than given unlike in the case of multicasting. We first present a need to support manycasting over OBS networks. Quality of Service (QoS) policies implemented in IP does apply does not apply for optical burst switched (OBS) networks, as the optical counterpart for store-and forward model does not exist. Hence there is a need to support QoS for manycasting over OBS networks. In this work we focus on QoS parameters such as contention, optical signal quality, reliability, and propagation delay. Burst loss in OBS network can occur due to contention or bit-error rate (BER). We propose algorithms to decrease the overall burst loss. We show that IP based manycasting has poor performance compared to our proposed algorithms. Our simulation results are verified with the help of analytical model. This work is further extended as to multi-constrained manycast problem (MCMP). In this problem, we address the burst scheduling for multiple QoS constraints. We propose algorithms to minimize burst loss based on given service requirements. The goal of this work is to develop service-oriented optical networks (SOON) for many emerging Internet applications.

Keywords: WDM, QoS, GoOBS, Manycasting.

1 Introduction

There has been an recent emergence of many Internet applications such as multimedia, video conferencing, distributed interactive simulations (DIS), and high-performance scientific computations like Grid computing. These applications require huge amount of bandwidth and a viable communication paradigm

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to coordinate with multiple sources and destinations. Existing communication paradigms include broadcast, and multicast. As optical networks are the potential candidates for providing high bandwidth requirement, supporting these paradigms over optical networks is necessary. QoS policies implemented in Internet Protocol (IP) does not apply for Wavelength division multiplexed (WDM) or optical burst switched (OBS) networks, as the optical counterpart for store-and forward model does not exist. Hence there is a need to provision QoS over optical networks. These QoS requirements can include contention, optical signal quality, reliability and delay. To support these diverse requirements optical networks must be able to manage the available resources effectively.

Destinations participating in the multicast session are fixed (or rather static). Due to the random contention in the network, if at least one or more destination(s) is not reachable, requested multicast session cannot be established. This results in loss of multicast request with high probability of blocking. Incorporating wavelength converters (WCs) at the core nodes can decrease the contention loss. However WCs require optical-electrical-optical (O/E/O) conversion, that increases the delay incurred by the optical signal. On the other hand all-optical WCs are expensive and increase the cost of the network if deployed.

Goal of this work is, to provide hop-to-hop QoS on an existing all-optical network (AON) with no WC and optical regeneration capability. In order to minimize the request lost due to contention in AON, we propose a variation of multicasting called *Quorumcasting* or *Manycasting*. In Quorumcasting destinations can join (leave) to (from) the group depending on whether they are reachable are not. In other words destinations have to to determined rather than given as in the case of multicasting. Quorum pool is defined as minimum number of destinations (k) that are required to participate in the session for successful accomplishment of the job. Providing QoS for manycasting over OBS has not been addressed so far in the literature. Contribution of this work is to provide necessary QoS for a given manycast request.

In this work we study the behavior of manycasting over OBS networks. In OBS networks packets from the upper-layer (such as IP, ATM, STM) are assembled and a burst is created at the edge router. By using O/E/O conversion at the edge nodes, these optical bursts are scheduled to the core node. Control header packet or burst header packet (BHP) is sent to prior to the transmission of burst. The BHP configures the core nodes and the burst is scheduled on the channel after certain offset time.

2 Manycasting Service

Distributed applications require multiple destinations to be co-ordinated with a single source, and thus multicasting is an approach to implement these distributed applications. However in multicasting the destination set is fixed and the dynamic behavior of the network cannot be implemented. A variation in this is to dynamically vary the destinations depending on the status of the network. Hence in distributed applications, first step is to identify potential destination candidates and then select the required number. This is called *manycasting* and the problem is defined as follows: given a network $G(V, E)$, with V nodes and E edges, edge cost function is given by $g : E \rightarrow R^+$, an integer k, a source s, and the subset of candidate destinations $D_s \subseteq V$, $|D_s| = m \geq k$, where $|D_s|$ is the cardinality of the set D_s. If $k = 1$, one destination is chosen from the set D_s and this is called *anycasting.*

A manycast request is simply denoted by (s, D_s, k). We have to send the burst to k destinations out of m ($|D_s| = m$) possible candidate destinations. Due to burst loss that occurs due to burst contention and/or signal degradation, there is no guarantee that exactly k destinations receive the burst. In general most multicasting solution approaches are largely applicable to manycasting. Networks that can support optical multicast can also support optical manycasting. Thus, manycasting can be implemented by multicast-capable optical cross-connect (MC-OXC) switches [1], that uses Splitter-and-Delivery (SaD) switch to split the optical signal [2]. Now when it comes to routing the burst, shortest-path tree (SPT) can be computed, using the following three steps:

- *Step 1*: Find the shortest path from Source s to all the destinations in D_s. Let $D_s = \{d_1, d_2, \ldots, d_{|D_s|=m}\}$ and minimum hop distance from s to d_i, where $1 \leq i \leq m$ is $\mathbb{H}^{(s)} = \{h_1, h_2, \ldots h_m\}$.
- *Step 2*: All the destinations in D_s are sorted in non-decreasing order of their path distance from Source s. Let D'_s be the new set in this order given by $\{d'_1, d'_2, \ldots d'_m\}$.
- *Step 3*: Select the first k destinations from D'_s.

For a network of size n, each step requires the time-complexity of $O(n^2)$, $O(1)$, and $O(n)$, respectively. If the shortest path distance to all the destinations are known, then the time-complexity of the SPT algorithm reduces to $O(n)$. We implement the SPT algorithm in a distributed manner. *Step 1* is implemented by the unicast routing table. *Step 2* sorts the destinations at the source node, in constant time. *Step 3* works as follows: First k destinations are selected from D'_m and BHP is sent to all next-hop nodes (or child nodes). Let the child nodes be $\{c_1, c_2, \ldots, c_j\}$ where $1 \leq j \leq k$. Maximum number of child nodes can be k, if for each destination the next-hop node is different. Upon receiving the BHP at the next-hop node, again the above mentioned three steps are implemented. The process ends when packet reaches all the k destinations or are dropped at intermediate nodes (due to data loss). Even though signal degradation along the shortest-path is low, it is however not necessary that BER is within the threshold requirement. This indicates the need to develop physical-layer aware manycasting algorithms, which are explained in the following section. Bursts for the manycast are assembled in the same way as the unicast. When a burst is ready to transmit, a BHP will be sent out along the route for the manycast request [3]. The well-known OBS signaling protocols for unicast traffic, such as tell-and-wait (TAW), tell-and-go (TAG), just-in-time (JIT), and just-enough-time (JET) [4], can be used for manycasting with the modifications described in the above centralized or distributed version of the SPT algorithm. In this paper we have studied manycasting with just-enough-time signaling (JET).

3 Impairment Aware Manycasting over OBS

Data loss in OBS network can occur either due to burst contentions or impairments in the fiber. *Burst contention* is a special issue in OBS networks, which occurs due to burstiness of IP traffic and the lack of optical buffering. Contention occurs when multiple bursts contend for the same outgoing port at the same time. Many schemes have been proposed to resolve burst contentions [3]. However all of these assume that the underlying physical fiber media is error-free. But in practice this not the case. Bursts are transmitted all-optically in the fiber; they traverse through many optical components, such as fiber, multiplexer, demultiplexer, splitters, and optical amplifiers. This causes the quality of the signal to degrade. Received signal have amplified spontaneous emission (ASE) noise due to optical amplifiers in the network [5]. The common metric to characterize the signal quality is optical-signal-to-noise ratio (OSNR), defined as the ratio of power of signal received to power of the ASE noise [6]. Multicast capable switches cause optical power to split depending on number of output ports. The power will be reduced as the signal propagates towards destination, thus decreasing OSNR. Bit error rate (BER) of the signal is related to OSNR. Decrease in OSNR causes an increase in BER. Thus a burst scheduled on a wavelength can be lost due to high BER of the signal. BER of the signal can be computed through q-factor [6]. If signal has low q, then BER of the signal is high and vice-verse. Thus a burst successfully scheduled on a wavelength, can be lost due to a low q. These impairments studies have been done extensively in past. Recent challenges are to develop impairment-aware routing algorithms before scheduling the data transmission [7]. As the first step toward implementing impairment-aware manycasting, in this paper we consider only the OSNR constraint. We develop algorithms that implement manycasting considering both *burst contention* and *optical impairments.*

In order to provide impairment-awareness during burst transmission, we modify the manycast request as $(u, D'_u, k_u, P(u), P_{ase}(u))$, where the last two tuple indicate signal power and noise power, respectively. u can be a Source s or an intermediate node, with sorted destination set D'_u and intended number of destinations k_u.

3.1 Impairment Aware Shortest Path Tree (IA-SPT)

IA-SPT algorithm uses a pre-computed shortest path tree. Based on the three steps mentioned in Section 2, the tree is constructed for each manycast request. Recursive power relations given in [1] can be used to compute the OSNR of the optical signal along its path. If the link from the source node to one of the child nodes is free, then q is computed. If the q-factor is above the threshold value, q_{th}, then the channel is scheduled for burst transmission. Hence, the successful reception of the burst at the destination node guarantees that signal is error-free. This continues until k destinations are reached. If the burst reaches $< k$ destinations, then the manycast request is said to be blocked. As the IA-SPT is implemented on the pre-computed routing tree, it does not consider the dynamic nature of the network. This algorithm suffers from high burst loss, due to fixed routing along the shortest path tree and this is verified by simulation results. Other algorithms proposed, decrease the burst loss in the presence of optical layer impairments. Pseudo code for this algorithm is described with the help of an example in [8]. If $\mathbb{D}$ is the set of all destinations that can be reached from Node u. If $|\mathbb{D}| < k_u$, then the request is said to be blocked and probability of the request blocking is given by $1 - |\mathbb{D}|/k_u$.

3.2 Impairment Aware Static Over Provisioning (IA-SOP)

IA-SOP algorithm is similar to IA-SPT except that here we will not limit the number of destinations to k, but we send the burst to $k + k'$ destinations, where k' is such that $0 \leq k' \leq m - k$. With $k' = 0$, IA-SOP is similar to IA-SPT, i.e., no over-provisioning. In this algorithm, first $k + k'$, destinations are selected from the set D'_c. Sending the burst to more than k destinations ensures that it reaches at least k of them. However by doing over-provisioning the fan-out of the splitter increases, thereby increasing BER. In spite of decrease in the contention loss, there is no significant improvement in the overall loss. From the simulation results we see that IA-SOP shows slightly better performance than IA-SPT. The IA-SOP algorithm is similar to that of IA-SPT, but with k_u replaced with k_u+k'. Thus the probability of request blocking is given by $1 - \min(|\mathbb{D}|, k_u)/k_u$. This is because if all the $k_u + k'$ are free then the burst is sent to more destinations than intended (i.e., k_u), but from the user perspective we have only k_u to be reached. If $|\mathbb{D}| > k_u$ implies $\min(|\mathbb{D}|, k_u) = k_u$, then the request blocking ratio is zero.

3.3 Impairment Aware Dynamic Membership (IA-DM)

IA-DM takes the dynamic network status into consideration. Instead of selecting the destinations before the burst is transmitted, we dynamically add members as possible destinations, depending on contention and quality of the link. IA-DM will work with a distributed version of SPT. The set of k-destinations is tentatively set up at the source node. We do not discard the remaining $m - k$ destinations, but instead keep them as child branches at the source node. IA-DM is different from deflection routing, in the way that, in later the burst is routed to the same destination, but on the other route. Our simulation results show a significant decrease in burst blocking due to contention and BER for IA-DM. The pseudo-code for this algorithm is explained in [1].

3.4 IP Manycasting

Selection of k destinations out of m by the IP layer is similar to the *random algorithm* in [9], we also present a simple analytical model for the manycasting with random selection of k destinations. Our results show that random selection of destinations has poor performance, hence supporting manycasting at the OBS layer is necessary. A manycast request is said to be blocked if the burst reaches less than k destinations.

4 Provisioning QoS for Manycasting over OBS

We study the behavior of manycasting over optical burst switched networks (OBS) based on multiple quality of service (QoS) constraints. These multiple constraints can be in the form of physical-layer impairments, transmission delay, and reliability of the link. Each application requires its own QoS threshold attributes. Destinations qualify only if they satisfy the required QoS constraints set-up by the application. We propose a decentralized way of routing the burst towards its destination. With the help of local-network state information, available at each node the burst is scheduled only if it satisfies multiple set of constraints. Correspondingly reception of the burst at the node ensures that all the QoS constraints are met and burst is forwarded to the next-hop. Due to multiple constraints, burst blocking could be high. We propose algorithms to minimize request blocking for Multiple Constrained Manycast Problem (MCMP). With the help of simulations we have calculated the average request blocking for the proposed algorithms. Our simulation results show that MCM-shortest path tree (SPT) performs better than MCM-dynamic membership (DM) for delay constrained services and real-time service, where as data services can be provisioned using MCM-DM.

We define η_j, γ_j, and τ_j as noise factor, reliability factor, and end-to-end propagation delay for the Link j, respectively. These service attributes can be used to maintain the local network information and by properly comparing these vectors, destinations can be chosen. Comparison of multi-dimension metrics can be done using the notion of lattices [10]. Lattices are explained using the ordering denoted by $\preccurlyeq$, which has the properties of reflexivity, antisymmetry, and transitivity. We denote the information vector at Link j as,

$$\Omega_j = \begin{pmatrix} \eta_j \\ \gamma_j \\ \tau_j \end{pmatrix}. \tag{1}$$

Definition 1. *Let Ω_j and Ω_k be the two information vectors for the links j and k, respectively. We define $\Omega_j \preccurlyeq \Omega_k$ and comparable if and only if*

$$(\eta_j \leq \eta_k) \wedge (\gamma_j \geq \gamma_k) \wedge (\tau_j \leq \tau_k). \tag{2}$$

Service attributes are either multiplicative (product) or additive (sum). The ordering condition in (2) is chosen such that, noise factor and propagation delay are minimum, and reliability is maximum. Each information vector is a 3-tuple and hence it is a 3-dimensional vector space over real field $\mathbb{R}$, which is denoted by $\mathbb{R}^3$. The operation over multi-dimensional vectors is given by,

$$\circ : \Omega_j \in \mathbb{R}^3,\ \Omega_k \in \mathbb{R}^3 \rightarrow \Omega_j \circ \Omega_k \in \mathbb{R}^3. \tag{3}$$

where the operation $\circ$ on two vectors Ω_j and Ω_k is given by,

$$\Omega_j \circ \Omega_k = \begin{pmatrix} \eta_j \eta_k \\ \gamma_j \gamma_k \\ \tau_j + \tau_k \end{pmatrix}. \tag{4}$$

4.1 Multi-Constrained Manycast (MCM) Problem

Multi-constrained manycast algorithms with the help of an example. We propose two algorithms, MCM-Shortest Path Tree (MCM-SPT) and MCM-Dynamic Membership (MCM-DM) for evaluating the performance of the manycasting with quality of service (QoS) constraints. These proposed algorithms are distributed wherein, each node individually maintains the network state information and executes the algorithm. Algorithms implemented in the centralized way, may fail due to a single failure and resulting in poor performance. Our proposed algorithms have the following functionality:

1. Handling multiple constraints with help of link state information available locally.
2. Service differentiated provisioning of manycast sessions.
3. Finding the best possible destinations in terms of service requirements for the manycast sessions.

We use BHPs as the control packets and we propose the new BHP field which provides information about the QoS. In previous works [1,8] the BHP was modified to accommodate q-factor (i.e., BER) and burst were scheduled based on the BER threshold. Table 1 lists possible fields associated with QoS based scheduling of bursts [11].

Table 1. Control Packets Frame Fields

BHP Field	Description
Manycast Id	Manycast request identification number
Burst Id	Burst identification number used for sequencing
Source (u)	Initial or starting node of the burst
Quorum members (D_u)	These are the probable destinations to which burst can be reached.
k_u	Number of members in manycast session
$\top^{(\theta_p)}$	Threshold information vector for Service θ_p.
$\Omega_{\langle u-1,u\rangle}$	Link information vector corresponding to the link between $\langle u-1, u\rangle$.
Ingress Channel	Wavelength used for the data burst
Duration	Duration of the data burst in seconds
Offset	Time offset between the control packet the data packet

The manycast request $(id, u, D_u, k_u, \top^{(\theta_p)}, \Omega_{\langle u-1,u\rangle})$ arrives at the Source Node u with a candidate destination set D_u, along with the k intended.

5 Simulation Results

In this section we present our simulation results. We consider *average request blocking* as performance metric. We define average request blocking ratio as given

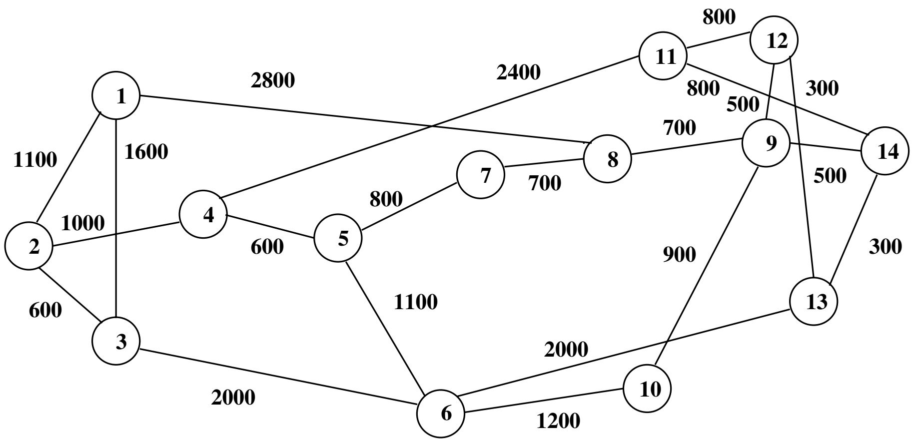


Fig. 1. NSF network with 14 nodes and 21 bi-directional links. The weights represent distance in km and the corresponding reliability factor of the links respectively.

by [3]. Let f be the total number of manycast requests used in the simulation. Consider a manycast request (s, D_s^f, k). Let $\mathbb{D}$ be the set of destinations which actually receive the data. Then *average request blocking* is given by,

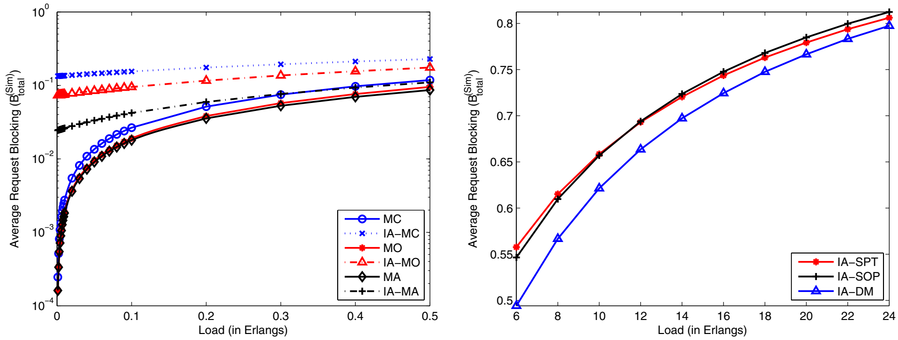
$$B_{avg} = \sum_{f} \left[1.0 - \min(|\mathbb{D}|, k)/k\right]/f. \tag{5}$$

NSF network shown in the Fig. 1 is used for our simulation. All the links are bi-directional and have same transmission rate of 10 Gb/s. Burst arrivals follow Poisson process with an arrival rate of λ bursts per second. The length of the burst is exponentially distributed with expected service time of $1/\mu$ seconds.

5.1 Assumptions

1. Only one wavelength is considered for analysis. Hence the dependency of q-factor on the wavelength is ignored.
2. Wavelength converters are not used in the network.
3. Calculation of noise factor is based on, losses due to attenuation, mux/ demux, tap and split loss. Only amplified spontaneous emission (ASE) noise can be considered for OSNR. Shot noise and beat noise are ignored.
4. Effects of offset time are ignored.
5. In line amplifiers along the links are placed, with spacing of 70 km between the amplifiers.
6. There are no optical buffers or wavelength converters in the network.
7. Reliability factor is same along both directions of the fiber.

Using discrete-event simulations we compute B_{avg} using (5) and compare our results for without impairment-awareness, as given in [3]. Fig. 2a show the comparison of impairment-aware average request blocking to regular algorithms.

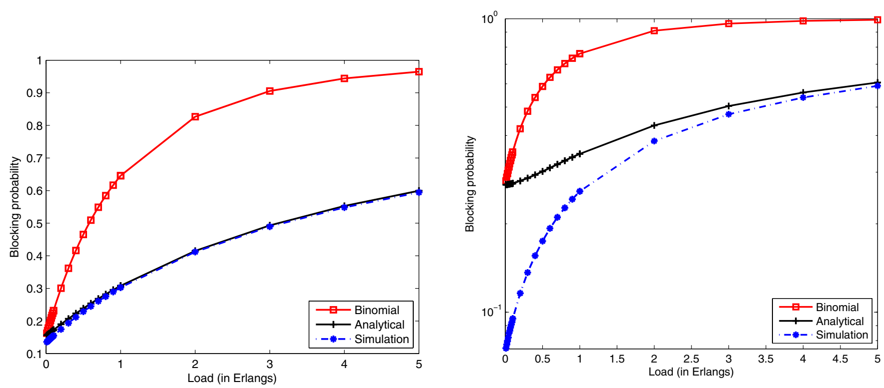


(a) (b)

Fig. 2. (a) Comparison of algorithms with and without impairment awareness. (b) The blocking performance comparison between IA-SPT, IA-SOP and IA-DM for manycast configuration 7/4 under High load.

From these graphs we observe there is significant difference in B_{avg} under low load conditions. This is because under low load conditions, contention blocking will be less and hence regular algorithms used in [3] does not provide the correct estimate of blocking. From the Fig. 2a we also observe that IA-DM has lower blocking than IA-SPT and IA-SOP and thus, impairment-aware manycasting over OBS, can be improved by using IA-DM. From the Fig. 2a we observe that without impairments all the three algorithms perform almost similar. However in the presence of impairments there is is significant reduction in the burst loss, when IA-DM is used. Our simulation results show that even under high loads IA-DM is better than the other two as shown in Fig. 2b.

We validate our simulation results with the analytical model explained in [8]. Fig. 3a shows that our model is accurate for IA-SPT. This graph also indicates



(a) (b)

Fig. 3. Comparison of Binomial, Analytical and Simulation results for overall blocking probability for (a) IA-SPT (b) IA-SOP with $k' = 3$ under low load

that random selection of k destinations from D_c (IP-Manycasting) has poor performance compared IA-SPT. Significant reduction in the blocking can be achieved by using IA-SPT.

From Fig. 3b we observe that our analytical model over-estimates the blocking probability of IA-SOP at low loads. This is due to the size of intended destinations. In our case we have $k' = 3$, which is equivalent to multicasting. However at high loads these results converge.

Finally we validate our simulation results for IA-DM using Poisson-splitting. From Fig. 4 we observe that Poisson split model slightly over-estimates the blocking probability than simulation. This is because of the (5) does not distinguish between primary and secondary destinations as in Poisson split. However the difference being very small, it provides a good estimate for the impairment-aware manycasting. Also by using Poisson-splitting we maintain the arrival process to secondary destinations as Poisson distribution and this makes analysis computationally efficient. In the Fig. 4 we also compare our results without split, which clearly validate our simulation results.

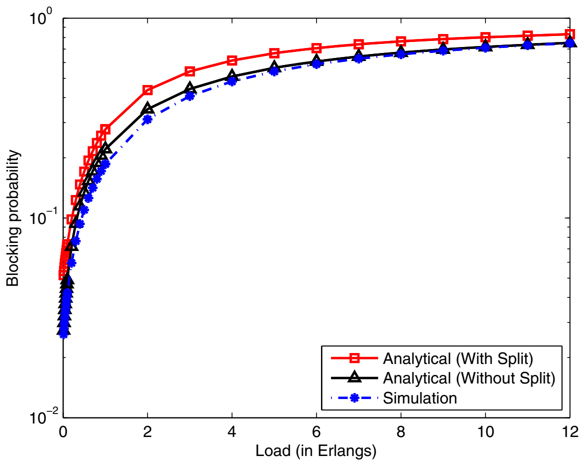
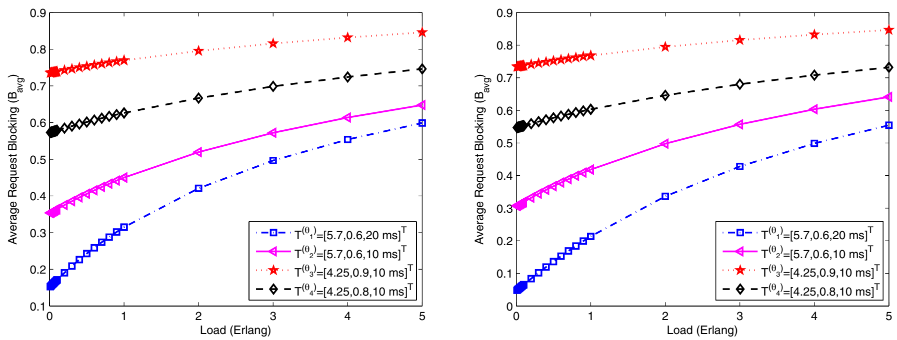


Fig. 4. Comparison of Analytical (with and without Poisson split) and Simulation results for overall blocking probability for IA-DM under low load

We now discuss the performance of Manycasting over OBS for different QoS requirements. We differentiate among service requirements, i.e., different services put different constraints. Differentiated services considered for simulation are $\top^{(\theta_1)} = [5.7, 0.6, 20]^T$, $\top^{(\theta_2)} = [5.7, 0.6, 10]^T$, $\top^{(\theta_3)} = [4.25, 0.9, 10]^T$ and $\top^{(\theta_4)} = [4.25, 0.8, 10]^T$. We consider $\top^{(\theta_2)}$ as the real-time service, since it has more stringent delay requirement. Service $\top^{(\theta_1)}$ can be for data service as it has less relaxed delay requirements. Other two services have high threshold requirements.

Figure 5a shows the performance of the MCMP-SPT for different set of services. More the requirements of the service, more is the blocking. As MCM-SPT uses shortest-path routing, one can expect to have a lower QoS blocking, but



(a) (b)

Fig. 5. Blocking Probability performance of (a) SPT and (b) DM for different service thresholds

however due to the random contention along the links, if any one of the destination is not reachable, entire manycast request would be blocked. On the contrary, MCM-DM adds or removes destinations based on the contention in the network. However destinations which are added to the quorum pool can be at a longer distance than the destination which is not reachable. As the result, QoS of this destination can be decreased. In spite of decrease in values, if the path-information vector is with in the threshold condition of the service, the request can be satisfied. Fig. 5b shows average request blocking for MCM-DM under different service thresholds. At high loads, most of the blocking would be contention blocking and hence the effect of QoS will not be understood much. As our aim is show the effects of QoS, all the results are simulated under medium network load conditions.

6 Summary

In this paper we have evaluated the performance of manycasting over optical burst-switched networks for providing QoS. Algorithms were proposed in a view to decrease the average request loss for manycasting. Performance of these algorithms has been studied under differentiated services. This work proposes the necessity of providing QoS to the manycasting over OBS networks. This work can be further extended, by considering sparse wavelength regenerations. By using wavelength regenerations we can decrease noise factor for the routes that traverse longer paths.

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