Providing QoS for Anycasting over Optical Burst Switched Grid Networks

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Abstract. This paper presents a mathematical framework to provide Quality of Service (QoS) for Grid Applications over optical networks. These QoS parameters include, resource availability, reliability, propagation delay, and quality of transmission (QoT). These multiple services are needed to ensure the successful completion of a Grid job. With the help of link-state information available at each Network Element (NE), the bursts are scheduled to its next link. This de-centralized way of routing helps to provide optimal QoS and hence decreases the loss of Grid jobs due to multiple constraints.

Keywords: WDM, QoS, GoOBS, Anycasting.

1 Introduction

The enormous bandwidth capability of the optical networks, helps the network user community to realize many distributed applications like Grid. These emerging interactive applications require a user-controlled network infrastructure [1]. This leads many researchers to investigate control plane architectures for optical networks. A comprehensive review of the optical control plane for the Grid community can be found in [2]. QoS policies implemented in IP network do not work in the optical network, as the store-and-forward model does not exist [3]. We thus see the need for an intelligent control plane in the optical network, which can provide the required QoS for Grid applications.

With the advent of many new switching techniques, researchers were able to tap the huge bandwidth capacity of the fiber. Fast and dynamic connection establishments using Optical Burst Switched (OBS) networks have been achieved at much lower switching costs. The Open Grid Forum (OGF) is a community that aims to develop standards, protocols and solutions to support OBS-based Grid networks [1]. A general layered Grid architecture and the role of OBS network is discussed in [4]. Delivering a Grid application effectively involves many parameters such as, design of efficient control plane architectures, algorithms for routing, providing QoS and resilience guarantees.

Anycast can be defined as a variation on unicast, with the destination not known in a-priori [5,6]. Anycasting is similar to deflection routing, except for the

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fact that different destination can be selected instead of routing the burst to the same destination in an another path. Routing can be accomplished by an label-based control frame work [7] using optical core network, such as OBS. Anycasting allows the flexibility for the Grid job to effectively identify the destination that meets the QoS parameters.

Incorporating an intelligent control plane and with the use of efficient signaling techniques, anycasting provides a viable communication paradigm to Grid applications. The rest of the paper is organized as follows: in Section 2 we describe notations used in the paper. The QoS parameters used for burst scheduling are discussed in Section 2.1. The mathematical framework for ordering the destinations, based on lattice theory is discussed in Section 3. We explain this mathematical framework with the help of a simple network example in Section 4.1 and finally we conclude this paper in Section 5.

2 Notations

An anycast request can be denoted by $(s, D, 1)$ where s denotes the source, D the destination set and the last tuple indicates that a single destination has to be chosen from the set D. This notation is a generalization of manycast [8]. Let $m = |D|$, denote the cardinality of the set. Each Grid job has a service class and we hence define the service class set as $\mathbb{S} = \{S_1, S_2 \ldots S_p\}$. There is an associated threshold requirement, for which the QoS parameters should not exceed this condition. We define this threshold parameter as $T^{(S_i)}$, where $S_i \in \mathbb{S}$.

2.1 Service Parameters

We define w_j, η_j, γ_j, and τ_j as the residual wavelengths, noise factor, reliability factor, and end-to-end propagation delay for Link j, respectively.

In wavelength-routed optical burst switched networks (WROBS), the connection requests arrive at a very high speed while the average duration of each connection is only in the order of hundreds of milliseconds [9]. To support such bursty nature of the traffic, it is always advisable to choose a path with more number of free wavelengths (least congested path). w_j indicates the number of free (or residual) wavelengths available on link j. We consider an All-Optical network (AON) architecture, where there is no wavelength conversion there, by resulting in wavelength-continuity constraint (WCC). Let $\mathbb{W}_i$ and $\mathbb{W}_j$ be the two free wavelengths sets available on the links i and j respectively. Without loss of generality we assume that $\mathbb{W}_i \cap \mathbb{W}_j \neq \emptyset$. We propose to select a path towards the destination, with more number of free wavelengths. We use an operation $|\cap|$ which gives the common number of wavelengths on each link. If we assume that each uni-directional link can support 5 wavelengths, then $|\mathbb{W}_i \cap \mathbb{W}_j|$ is an integer ≤ 5. The number of free wavelengths on the route is given by,

$$w_R = |\bigcap_{\forall i \in R} \mathbb{W}_i|, \tag{1}$$

where R denotes the route and w_R represents the number of free wavelengths available. If $w_R = 0$, then the destination is said to be not reachable due to contention.

The noise factor is defined as ratio of input optical signal to noise ratio ($OSNR_{i/p} \equiv OSNR_i$) and output optical signal to noise ratio ($OSNR_{o/p} \equiv OSNR_{i+1}$), thus we have

$$\eta_j = \frac{OSNR_{i/p}}{OSNR_{o/p}}, \tag{2}$$

where $OSNR$ is defined as the ratio of the average signal power received at a node to the average ASE noise power at that node. The OSNR of the link and q-factor are related as,

$$q = \frac{2\sqrt{\frac{B_o}{B_e}}\mathrm{OSNR}}{1 + \sqrt{1 + 4\mathrm{OSNR}}}, \tag{3}$$

where B_o and B_e are optical and electrical bandwidths, respectively [11]. The bit-error rate is related to the q-factor as follows,

$$BER = 2 \ \mathrm{erfc}\left(\frac{q}{\sqrt{2}}\right). \tag{4}$$

In our proposed routing algorithm, we choose a route that has minimum noise-factor. Thus the overall noise factor is given by,

$$\eta_R = \prod_{\forall i \in R} \eta_i, \tag{5}$$

The other two parameters considered in our approach include, reliability factor and propagation delay of the burst along the link. The reliability factor of the link j is denoted by η_j. This value on the link indicates the percentage of the reliability of the link and its value lies in the interval $[0, 1]$ The overall reliability of the route is calculated as the multiplicative constraint and is given by [8,10],

$$\gamma_R = \prod_{\forall i \in R} \gamma_i. \tag{6}$$

Propagation delay on the link j is denoted by τ_j and the overall propagation delay of the route R is given by,

$$\tau_R = \sum_{\forall i \in R} \tau_i. \tag{7}$$

3 Mathematical Framework

In this section we provide the mathematical formulation for selecting the destination based on the above mentioned service parameters. We define Network Element Vector (NEV), that maintains information about the QoS parameters at each Network Element (NE). This information is contained in the Optical

Control Plane (OCP). In the distributed routing approach, current GMPLS routing protocols can be modified to implement the service information [12,13]. A global Traffic Engineering Database (TED) at each OCP, which maintains an up-to-date picture of NEV.

Definition 1. *We denote the network element vector for a link i as,*

$$NEV_i = \begin{pmatrix} w_i \\ \eta_i \\ \gamma_i \\ \tau_i \end{pmatrix}. \tag{8}$$

Definition 2. *Let NEV_i and NEV_j be the two network element information vectors of links i and j respectively, then we define a comparison $\preccurlyeq$ given by,*

$$\begin{pmatrix} w_i \\ \eta_i \\ \gamma_i \\ \tau_i \end{pmatrix} \preccurlyeq \begin{pmatrix} w_j \\ \eta_j \\ \gamma_j \\ \tau_j \end{pmatrix} \tag{9}$$

The above equation implies that,

$$(w_i \geq w_j) \wedge (\eta_i \leq \eta_j) \wedge (\gamma_i \geq \gamma_j) \wedge (\tau_i \leq \tau_j). \tag{10}$$

Equation (10) is chosen such that, the path towards the destination has more number of residual wavelengths, low noise factor, high reliability and lower propagation delay.

Definition 3. *The overall service information of a destination $d_n \in D$, $1 \leq n \leq m$ along the shortest-path route $R(d_n)$ is given by,*

$$NEV_{R(d_n)} = NEV_{R(d_n)}[s, h_1] \circ NEV_{R(d_n)}[h_1, h_2] \circ \ldots \circ NEV_{R(d_n)}[h_k, d_n] \tag{11}$$

$$NEV_{R(d_n)} = \left[\left| \bigcap_{\forall i \in R(d_n)} \mathbb{W}_i \right|, \prod_{\forall i \in R(d_n)} \eta_i, \prod_{\forall i \in R(d_n)} \gamma_i, \sum_{\forall i \in R(d_n)} \tau_i \right]^T. \tag{12}$$

where in (11) n_k represents the next hop node along the shortest-path. The operation $\circ$ performs $| \cap |$ on wavelengths sets, multiplication on noise factor, multiplication on reliability, and addition on propagation delay. Equation (12) represents the overall QoS information vector for the destination d_n.

Definition 4. *A destination d_n is said to be feasible for a given service requirement $T^{(S_i)}$ if,*

$$NEV_{R(d_n)} \preccurlyeq T^{(S_i)}. \tag{13}$$

The comparison of two multidimensional vectors using $\preccurlyeq$ follows from the notion of lattices [14]. Using this ordering technique bursts can be scheduled to a destination that satisfies the service requirement if it is the best among the given set of destinations. In the next section we explain the proposed algorithm with the help of a network example.

4 QoS Aware Anycasting Algorithm (Q3A)

Below is the pseudo-code for the proposed algorithm. As we have considered service-differentiated scheduling, the threshold parameters of the particular service are know a-priori. In the initialization step, we consider the cardinality of the free wavelengths as the number of wavelengths the fiber can support. Other service parameters are considered to be 1 for multiplicative and 0 for additive, as indicated in the Line:1 of the algorithm.

For each destination $d_n \in D$, the next-hop node is calculated from the shortest-path routing (Line:2). By using the path algebra given in (11), the new network element information vector is computed and updated at the next-hop node for d_n as n_k. A destination node d_n, is said to be qualified for the assigned Grid job, when $NEV_{R(d_n)}[s, n_k] \preccurlyeq T^{(S_i)}$ (Line:4). If the required QoS are not met, then the anycast request is updated with the new destination set as given in Line:7. If the cardinality of D is zero, then the anycast request is said to be blocked for the given service threshold condition $T^{(S_i)}$. However the same anycast request can satisfy another service S_j, $i \neq j$, with lower threshold requirements.

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Input: $T^{(S_i)}$, $NEV_{R(d_n)}[s, n_{k-1}]$
Output: $NEV_{R(d_n)}[s, n_k]$
1: Initialization $NEV_{init} = [w_{max}, 1, 1, 0]^T$
2: $NEXT\_HOP\_NODE[s, d_n] = n_k$ /*$n_k$ is calculated from the shortest path */
3: $NEV_{R(d_n)}[s, n_k] \leftarrow NEV_{R(d_n)}[s, n_{k-1}] \circ NEV_{R(d_n)}[n_k, n_{k-1}]$
4: if $NEV_{R(d_n)}[s, n_k] \preccurlyeq T^{(S_i)}$ then
5:    The path $[s, n_k]$ is a feasible path and destination $d_n$ can be reached
6: else
7:    Update the destination set $D \leftarrow D \backslash \{d_n\}$ /* Since route to $d_n$ does not satisfy the QoS requirement of the service $S_i$ */
8: end if
9: If $|D| = \emptyset$, then anycast request is blocked or lost
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This algorithm calculates all the NEVs at intermediate and destination nodes. Intermediate NEVs check the threshold condition and discard the respective destination without further scheduling of the burst. Upon calculation of NEVs ($NEV_{R(d_n)}[s, d_n]$) at all the updated destination set, these are re-ordered and the destination corresponding to the optimal NEV is selected. The equations below show the ordering technique used in selecting the final anycast destination.

$$NEV = \{NEV_{R(d_1)}, NEV_{R(d_2)}, \ldots, NEV_{R(d_p)}\}\ 1 \leq p \leq n, \text{ (un-sorted)} \tag{14}$$

$$= \{NEV_{R(d'_1)}, NEV_{R(d'_2)}, \ldots, NEV_{R(d'_p)}\} \text{ (sorted)} \tag{15}$$

$$NEV_{R(d'_1)} \preccurlyeq NEV_{R(d'_2)} \preccurlyeq \ldots \preccurlyeq NEV_{R(d'_p)} \preccurlyeq T^{(S_i)} \tag{16}$$

From (16) d'_1 is the best destination among D that can meet the service requirement of S_i effectively.

This distributed Q3A approach can be implemented in a distributed way with help of a signaling approach [12]. Burst Control Packet (BCP) or Burst Header Packet (BHP) can be used to maintain the NEVs and update them as they traverse each NE. At each NE, TED is used to maintain the traffic engineering (TE) and can be modified to maintain the NEV.

4.1 Network Example

In this section we discuss the Q3A with help of a example to show the effectiveness of the algorithm in providing the QoS parameters. Consider the network shown in the Fig. 1. Consider the anycast request as $(6, \{2, 3, 4\}, 1)$. The dotted lines in Fig.1 represent the shortest-path distance from source node 6 to the respective destination. The weights on each link represent, fiber distance in kms, noise factor, reliability factor and propagation delay in milli-seconds[1]. Table 1 shows an set of free wavelengths on the links at the time of the anycast request.

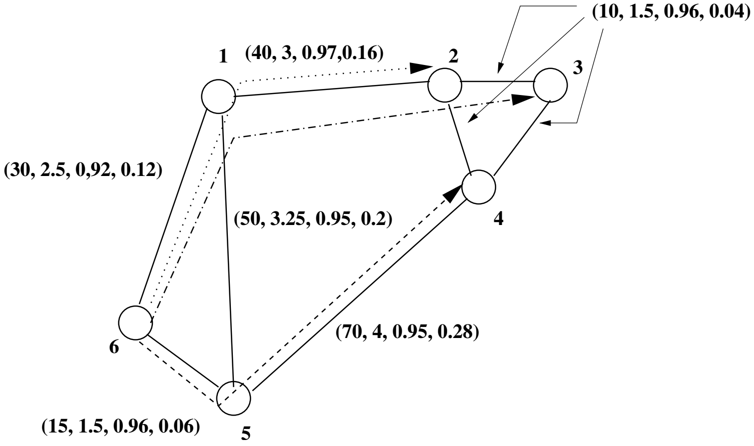

Fig. 1. Network example used to explain the proposed Algorithm

The NEVs for each destination can be calculated as given in below equations,

$$\begin{aligned} NEV_{R(2)} &= [\mathbb{W}(6,1), 2.5, 0.92, 0.12]^T \circ [\mathbb{W}(1,2), 3, 0.97, 0.16]^T \\ &= [|\mathbb{W}(6,2)|, 7.5, 0.89, 0.28]^T \\ &= [2, 7.5, 0.89, 0.28]^T \end{aligned} \tag{17}$$

The free wavelengths on each link are obtained from Table 1 and the cardinality of the common wavelengths is represented in (17). This ensures the WCC in the all-optical networks, where there is an absence of wavelength converters.

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[1] Propagation delay is the ratio of distance (km) to the velocity of light (250 km/ms).

Table 1. Residual wavelengths available on links to all destinations

#	**Link** $(i \rightarrow j)$	**Residual Wavelength set** $(\mathbb{W}(i,j))$
1	$6 \rightarrow 5$	$\{\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5\}$
2	$5 \rightarrow 4$	$\{\lambda_1, \lambda_2, \lambda_3\}$
3	$6 \rightarrow 1$	$\{\lambda_1, \lambda_2, \lambda_5\}$
4	$1 \rightarrow 2$	$\{\lambda_2, \lambda_5\}$
5	$2 \rightarrow 3$	$\{\lambda_3, \lambda_4, \lambda_5\}$

As the route towards the destination 3 shares the common path until node 2, NEV is given by,

$$\begin{aligned} NEV_{R(3)} &= NEV_{R(2)} \circ [\mathbb{W}(2,3), 3, 0.97, 0.16]^T \\ &= [\mathbb{W}(6,2), 7.5, 0.89, 0.28]^T \circ [\mathbb{W}(2,3), 1.5, 0.96, 0.04]^T \\ &= [1, 11.5, 0.85, 0.32]^T \end{aligned} \tag{18}$$

$$\begin{aligned} NEV_{R(4)} &= [\mathbb{W}(6,5), 1.5, 0.96, 0.04]^T \circ [\mathbb{W}(5,4), 4, 0.95, 0.28]^T \\ &= [3, 6, 0.91, 0.32]^T \end{aligned} \tag{19}$$

From (17), (18), and (19) we observe, that destination 4 has an optimal QoS parameters.[2]. This confirms the benefits of specifying the service requirements, whereby a destination can be chosen rather than selecting it at random.

5 Conclusion

In this paper we discuss the provisioning of QoS for anycasting in Grid optical networks. By using the information vectors available at each NE, QoS parameters are computed. We have considered parameters that can be additive or multiplicative. Providing QoS to anycast communication, allows the Grid application to choose a candidate destination according to its service requirements. This flexibility helps realize a user-controlled network. Our proposed algorithms also helps in service-differentiated routing.

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[2] Except the propagation delay, which is slightly more than that of $NEV_{R(2)}$.

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