Crosstalk-Aware Anycast Routing and Wavelength Assignment in Optical WDM Networks

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***Abstract*—In this paper we discuss the performance of physical-layer impairment-aware anycast communication over transparent optical networks. High-bandwidth applications, such as grid computing over optical networks will benefit from using anycast requests. From the simulation results we observe that the proposed anycast routing algorithms can significantly decrease the blocking probability of requests due to impairments, such as crosstalk and ASE noise.** [1]

Keywords: Anycast, Crosstalk, WDM, RWA, ASE, and OSNR.

I. Introduction

All-optical wavelength division multiplexed (WDM) networks are a promising solution for the Internet's increasing bandwidth demands. Connection provisioning in these transparent WDM networks is done via *lightpaths* (LPs), where the optical signal is transmitted from the source to the destination without any optical-electro-optical conversion (OEO). Lightpaths are configured using routing and wavelength assignment (RWA). A typical approach for solving the RWA problem is to divide it into two distinct problems, the first of which is the problem of identifying the route, and the second is the wavelength assignment satisfying the wavelength continuity constraint (WCC). Unfortunately, RWA does not account for the transmission impairments, i.e., it assumes the optical network to be ideal. In practice, the optical data transmission suffers from many physical-impairments in the fiber and optical components. As a result, it is necessary to make these RWA algorithms aware of the physical-impairments in order to have an accurate performance metric. This problem is called *quality-of-transmission (QoT)-aware RWA algorithms*. A comprehensive review of this work can be found in [1].

The major impairments that will reduce the optical-signal to noise ratio (OSNR) for a channel operating within 10 Gb/s are amplified spontaneous emission (ASE) noise in the amplifiers and crosstalk (XT) generated at the wavelength switches (at each node). The two types of crosstalk that exist are homo and hetero-wavelength crosstalk. It has been found that homo-wavelength crosstalk significantly impairs the optical channel compared to hetero-wavelength [2].

Several QoT-aware routing algorithms have been proposed for reducing the calls blocked due to impairments in transparent optical networks. Impairment-aware RWA proposed in [2] has been found to reduce the call blocking. Crosstalk-aware wavelength assignment proposed in [3] chooses a wavelength with minimum crosstalk for a given route and a source-destination pair. QoT-aware RWA algorithms also choose alternate paths that have minimal impairment for a given source-destination pair.

In this work, we propose anycast communication for transparent optical networks. The anycast communication paradigm is a variation of unicast, where the source node has a choice of picking a destination from a candidate set. Anycast RWA using genetic algorithms has been investigated in [4]. Anycast connection helps to find an appropriate destination that can satisfy the required QoT.

Anycast can be used by a client (source) to find an appropriate server (destination) when there are multiple servers. For example, in grid computing, a client requires necessary computing resources to be found from a set of servers. The established route between the client and the server should result in minimal transmission impairment. Anycasting has been investigated in the past for grid applications [5]. It has also been used for energy minimization for optical-burst switched networks in [6].

The remainder of this paper is structured as follows: Section II defines the problem. In Section III, the proposed crosstalk-aware anycast routing algorithm is described. Section IV discusses the simulation results. Finally, we conclude the paper in Section V.

II. Problem Definition

For a given source node s and the candidate destination set $D_s = \{d_1, d_2, \ldots, d_m\}$ with a cardinality $|D_s| = m$, anycast is defined as communication with which a source node s can choose any one among m destinations (C_1^m). We denote such an anycast configuration as $m/1$. In the case of unicast, $m = 1$ and is denoted as $1/1$. The algorithms proposed in this paper use source initiated routing (SIR); the source node chooses a destination based on the required threshold conditions on impairments. As the destination set size increases the time-complexity of the anycast routing increases exponentially. Hence, we propose heuristics based on the weight function of the edges in the network. Given a network, $G(V, E)$, where V is the set of vertices and E is the set of edges, an edge cost function given by $g : E \rightarrow R^+$, a source s, and the subset of candidate destinations $D_s \subset V$, $|D_s| = m$, where $|D_s|$ is the cardinality of the set D_s, then the anycast request is denoted by $(s, D_s, 1)$.

Impairments, such as attenuation along the fiber and ASE noise from the amplifiers remain static, and are directly proportional to the physical distance on the route between any source-destination pair. Crosstalk among the wavelength switches is dynamic though, so impairments on the lightpath configured with shortest-distance will not necessarily remain minimum. Thus we see a need to search for alternate paths for a given source-destination pair. In this paper we focus on anycast routing, which instead of choosing an alternate path, configures the LP to a different destination if available, provided the OSNR falls within the threshold. This type of communication is particularly useful for distributed applications, such as storage-area networks (SAN), content distribution networks (CDN), and grid computing. Anycast communication can be initiated by the edge-route and the centralized control plane configures

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the wavelength-switches accordingly.[2]

III. Crosstalk-Aware Anycast Algorithms

In this section, we propose anycast routing algorithms based on minimum-distance (MD) and minimum-hop (MH) heuristics as described in Algorithm 1. The following are the steps involved with sorting the destinations in the anycast request $(s, D_s, 1)$,

- *Step 1*: Find the shortest distance (or hop-count) from source s to all the destinations in D_s. Let $D_s = \{d_1, d_2, \ldots, d_{|D_s|=m}\}$ and distance (or hop-count) from s to d_i, where $1 \leq i \leq m$ is $\mathbb{P}^{(s)} = \{p_1, p_2, \ldots, p_m\}$ ($\mathbb{H}^{(s)} = \{h_1, h_2, \ldots, h_m\}$ for hop heuristic).
- *Step 2*: All the destinations in D_s are sorted in the non-decreasing order according to the shortest distance (or smallest hop-count) from the source. Let D'_s be the new set in this order given by $\{d'_1, d'_2, \ldots, d'_m\}$.

The input to the algorithm will be an anycast request in the form $(s, D_s, 1)$. The destination set in the request is first sorted based on MH or MD heuristic as described in Step 1 and Step 2 above (shown in line 2). The first destination (d'_i) in the ordered set D'_s is chosen. The set of all the available wavelengths that satisfy the WCC for the calculated path (based on MD or MH) is denoted by Λ_A. A random wavelength $\lambda_i \in \Lambda_A$ is selected. Random wavelength assignment is found to minimize the impairments due to XT [3]. The calculated OSNR is compared to the threshold requirement as indicated in line 11. If the required threshold condition is met the anycast request is said to be successful and the LP is configured along the wavelength-switches on the (s, d'_i) path. If the threshold condition is not met, then the set Λ_A is updated (line 17) and another wavelength is randomly chosen from the set. When all the wavelengths are exhausted ($\Lambda_A == \emptyset$), the destination set is updated as indicated in line 19. The anycast request is said be to blocked if the LP cannot be configured to any destination on any wavelength.

IV. Simulation Results

In this section we evaluate the performance of the proposed crosstalk-aware anycast algorithm proposed in Section 1 on the National Science Foundation Network (NSFNET) shown in Fig. 1. We have scaled the distances to the order of hundreds of km (as opposed to the actual thousands of km). This scaling will decrease the impact of the ASE noise and fiber attenuation throughout the network, meaning the impairment will be primarily dominated by XT. We use discrete event simulations wherein requests arrive dynamically according to a Poisson process with exponential departure times. The network load in Erlangs is calculated as the ratio the arrival rate to the departure rate. The parameters used for the OSNR calculation are shown in Table I. The OSNR threshold in the table corresponds to the q-factor of 6 ($BER = 0.5 \times \text{erfc}(q/\sqrt{2})$). Each fiber supports 8 wavelengths with 100 GHz spacing (0.8 nm) in the L-band. We compare our proposed algorithm with various anycast scenarios $m/1$, where $1 \leq m < V$. However in this paper we show the results for $m \leq 5$. Blocking probability is calculated as the ratio of the number of anycast requests blocked to the total number of requests (in Table I).

[2] Due to page restrictions, details of the control plane architecture are omitted.

Algorithm 1: Crosstalk-Aware Anycast Routing (CAAR).

```
Input  : Anycast Request: (s, D_s) = (s, {d_1, d_2, ..., d_m})
Output : Request Successful: TRUE/FALSE
1  begin
2      D'_s ← SORT[D_s]
3      while D'_s ≠ ∅ do
4          PATH → (s, d'_i) where d'_i ∈ D'_s; 1 ≤ i ≤ |D'_s|
5          while Λ_A ≠ ∅ do
6              for h ∈ PATH(d'_i) do
7                  PWR(h, λ_i) ← PWR(h − 1, λ_i) − LOSS(h, λ_i)
8                  ASE(h, λ_i) ← ASE(h − 1, λ_i) + ASE.SW(λ_i)
9                  XT(h, λ_i) ← XT(h, λ_i) + XT.SW(λ_i)
10             OSNR(d'_i, λ_i) = PWR(d'_i, λ_i) / (ASE(d'_i, λ_i) + XT(d'_i, λ_i))
11             if OSNR(d'_i, λ_i) ≥ OSNR_th then
12                 CONFIG.SD(s, d'_i)
13                 REQ.ID(s, D_s) ← TRUE
14                 exit        /* exit the algorithm */
15
16             else
17                 Λ_A ← Λ_A \ {λ_i}
18         if Λ_A == ∅ then
19             UPDATE.DES: D'_s ← D'_s \ {d'_i}
20             if D'_s == ∅ then
21                 REQ.ID(s, D_s) ← FALSE
22                 DROP.OSNR ← DROP.OSNR + 1
23             else
24                 CREATE.SD: (s, d'_{i+1})
```

TABLE I
Parameters used for computation of OSNR.

Parameter	Value
Channel bit rate	10 Gb/s
Optical bandwidth	7 GHz
Electrical bandwidth	10 GHz
Input signal power	1 mW (0 dBm)
Switch crosstalk ratio	25 dB
OSNR threshold for BER 10^{-9}	7.4 dB
Number of requests	10^6
Wavelengths	8

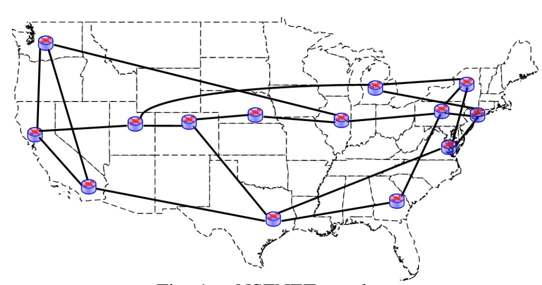

Fig. 1. NSFNET topology.

In Fig. 2 we compare the performance of anycast scenarios: $1/1$, $3/1$, and $5/1$ implementing the two cost-based, XT-aware heuristics discussed in Section III. From these graphs we observe that blocking probability (due to both WCC and impairments) of anycast communication is significantly reduced as the destination set size increases. In all configurations, we observe that MH-based CAAR produces a consistently lower blocking probability than MD. This is due to the fact that the dominant impairment (XT) is not directly related to the distance of the fiber; thus fewer hops can result in lower blocking.

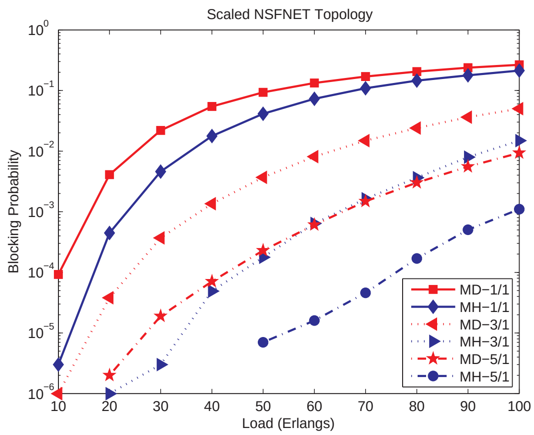

Fig. 2. Comparison of blocking probability for various anycast scenarios.

From Fig. 3 we observe a drastic reduction in number of requests blocked due to WCC in $3/1$ over $1/1$ (unicast). This is because anycasting helps to pick a destination that has larger wavelength set (Λ_A), thus creating more wavelength channels with minimal XT. Due to the crosstalk-awareness in wavelength assignment, there is a significant decrease in the impairment blocking for $3/1$ over $1/1$ as shown in Fig. 4.

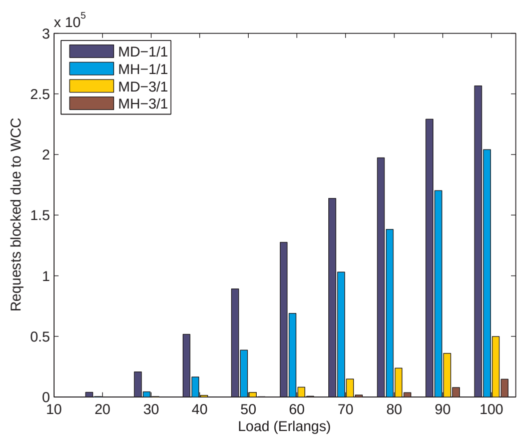

Fig. 3. Comparison of requests blocked due to wavelength continuity constraint for unicast and $3/1$ anycast.

Fig. 5 compares the execution times of the CAAR algorithm for both MD and MH routing heuristics using a 2.33 GHz Quad Core Xeon processor with Hyper-Threading and 8 GB RAM. Algorithm execution time increases proportionately to the size of the destination set if load is kept constant. It is always a trade-off to choose the destination size depending on the network load. For instance, if the network load is high and there is high-priority request, then the edge-router can create a larger destination set for successful connection provisioning.

The destination size can be chosen by the application (grid task) depending on the requirement. For example, in the case of a high-priority task, the application could initiate a request

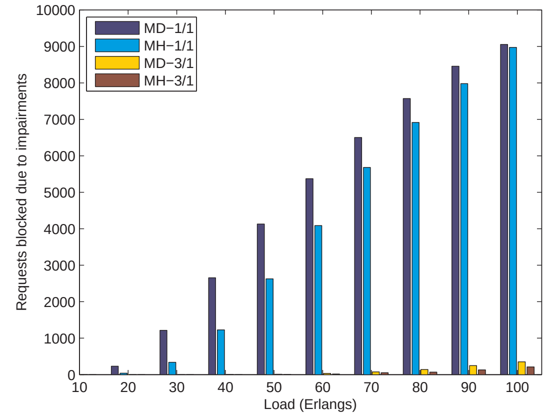

Fig. 4. Comparison of requests blocked due to transmission impairments (dominated by XT) for unicast and $3/1$ anycast.

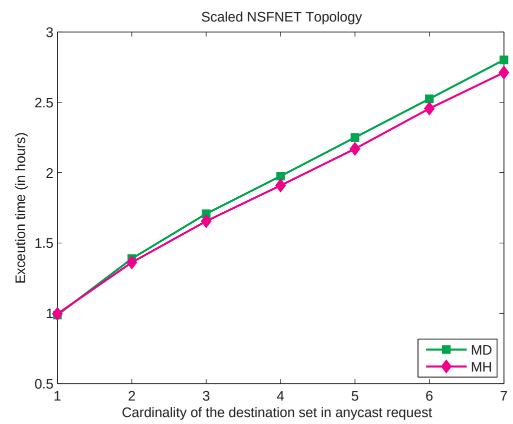

Fig. 5. Execution time for simulation of 10^6 requests for each anycast configuration at a network load of 100 Erlang.

to the edge-router with specific constraints. The control plane will create the anycast destination set and route the task to a destination such that the requirements are met.

V. Conclusion

In this work we have presented a crosstalk-aware anycast routing algorithm applicable to transparent optical networks. The proposed algorithm can significantly decrease the blocking probability in distributed applications, such as grid computing. Our work presents a novel approach to providing required transmission quality on the physical optical fiber for bandwidth sensitive applications.

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