Progress Report

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Introduction

The outline of this report follows the task structure as given in the proposal.

Activities

After consultation with the ESnet researchers at Lawrence Berkeley National Laboratory (LBNL) we acquired the topology for the energy and sciences network (ESnet), on which we have implemented/simulated our proposed heuristics.

Progress/Accomplishments

In this section we describe the progress and accomplishments in each of the tasks labeled T1, T2 and T3 as outlined in the project proposal:

- T1: Multicast Request Provisioning

  Traditionally, in a WDM network, multicasting is supported by assuming that the optical cross-connects are multicast capable, i.e., they are capable of switching an incoming signal to more than one output interface. A naive method of supporting this functionality in a multicast incapable (MI) environment (such as the ESnet) is by creating a virtual topology consisting of wavelength routes from the multicast source to each destination of the multicast session. However for large multicast groups the network bandwidth consumed by such a scheme may become unacceptable because of the unicasting nature of the lightpaths.

  Work Performed: To support users' multicast requests (from the higher electronic layers) in a MI network, we propose two overlay solutions: Drop at Member Node (DAMN) and Drop at Any Node (DAAN). In these solutions, we achieve multicasting by creating a set of lightpath routes (possibly multiple hops) in the overlay layer from the source node of a request to each destination member. In the DAMN case, we allow a lightpath route to originate/terminate only at source and destination members of a request, whereas in the DAAN model we pose no such restrictions. We consider a static traffic model, wherein the set of multicast requests is known ahead of time. We present integer linear programs (ILPs) to solve these problems with a goal of minimizing the total number of wavelengths required to service the set. We also present an efficient heuristic and compare its performance to the ILP for a small network, and run simulations over real-world, large-scale networks. We also formulate an ILP for the naive solution of achieving multicasting and compare its performance to that of DAMN and DAAN. We also consider a dynamic traffic model, and propose efficient heuristics to solve the DAMN and DAAN problems with a goal of minimizing the total number of wavelengths required to satisfy the request. Moreover, we present a simple heuristic to approximate the baseline unicast approach (naive method).

We have performed extensive simulations on three real-world large scale networks for the above mentioned heuristics by also considering a dynamic traffic scenario, wherein multicast request arrive to the network following some stochastic process.

Findings:

We first compared the DAMN/DAAN ILPs to the MVWU ILP (for a static traffic matrix), and observed that the DAMN/DAAN uses 2 to 5 wavelengths fewer than MVWU at higher loads. Also we observed that our proposed heuristic performed well as compared to the ILPs. Note that for this comparison we used a simple six-node network, as the run-times of ILPs was unacceptable for higher loads. We then compared the heuristics for the MVWU, DAMN and DAAN on real world large-scale networks. It was observed that DAMN clearly outperformed the MVWU and achieved 20% to 50% improvement in average wavelengths. We also noted that the DAAN achieved an additional 4% to 5% improvement as compared to DAMN, but at the expense of a slightly higher average number of logical hops. This work has resulted in a conference paper [1] in the *International Conference on Computer Communication Networks - 2011.*

For the dynamic traffic case, a similar trend in results was observed. It was observed that DAMN clearly out-performed the MVWU, and achieved a 44 to 60% improvement. The DAAN achieved a further 3 to 5% improvement over the DAMN at the cost of higher number of logical hops. This work has been submitted to the GLOBECOM-2011 conference [2], and is currently under review. A complete set of the multicast overlay results can be found in [3].

- T2: Multi-layer/Multi-domain QoS

  In this task we examine the multi-layer quality of service in optical WDM networks. The purpose is to deliver a QoS framework to map input connection requests to a certain number of classes, wherein each of these classes gets a different treatment in the network.

  Work Performed:

  During this quarter we proposed a QoS framework for multi-layer networks and for hybrid immediate and advance reservation systems. The framework maps different connection requests to some predefined classes. By making use of diverse immediate and advance reservation scheduling algorithms, we are able to differentiate these classes within the network and provide to them, based on their requirements, the required quality level. In particular, in this task we performed an evaluation with 4 different classes, two for immediate reservation and the other two for advance reservation. The two immediate classes, which are devised for delay-sensitive applications use immediate reservation: the lowest priority class uses a simple IR holding time aware algorithm, while the other class uses lightpath switching. For the delay-tolerant applications we make use of advance reservation. Again, we separate these into two classes: the lowest uses a fixed advance reservation algorithm, while the highest priority class runs a flexible advance reservation algorithm.

  Findings:

  With the aforementioned QoS framework we performed several simulations to check its performance. We found out that the proposed framework is able to achieve a very well defined relative quality differentiation among the four classes defined. Due to the book-ahead of AR, delay-tolerant applications obtain a better blocking probability from the network. Also, the highest priority class, which makes use of the flexible AR obtains a better blocking than the other AR class. As for the delay-sensitive applications is concerned, these obtain a higher blocking than their AR counterparts. However, by using the LPS algorithm, we are also able to provide differentiation within the IR classes. This work resulted in an accepted paper [4] in PMECT 2011, collocated with ICCCN 2011.

- T3: Immediate Reservation System with Light Path Switching

  Work Performed:

  We examine provisioning holding-time-aware dynamic circuits using a technique called lightpath switching (LPS). Instead of using the same lightpath for the duration of the data transmission, in LPS we allow a request to switch lightpaths over time. Data transmission may begin on one lightpath from the source to destination, then at a later time a different lightpath from the source to the destination may be selected to continue data transmission. The lightpath switches are transparent to the user and are managed by the network. Allowing LPS creates a number of segments that can use independent lightpaths. We propose a heuristic to solve the LPS problem and compare its performance to a simple All-Segments (AS) heuristic which does not allow LPS.

  Findings:

  We first observe that the blocking probability is significantly reduced when lightpath switching is allowed. The number of lightpath switches ranges from two to four, meaning each segment is on average four timeslots at low loads and over two timeslots at higher loads. These results show there is a trade off between reduced blocking and increased network signaling (number of lightpath switches). We also ran simulations for different k (Yen's k shortest path algorithm parameter) values and for different networks. With $k = 1$, the performance improvement between AS and LPS is not as significant because here only wavelength switching would be possible. For all other values of k, the relative improvement of LPS to AS is about the same. As the value of k increases, the number of lightpath switches also increases while the blocking probability decreases with LPS. We also note that depending on the networks average nodal degree, there is a maximum value of k for which no further improvement occurs. This work resulted in a conference paper in the *Fourth International Symposium on Advanced Networks and Telecommunication Systems (ANTS)* conference, [5]. We would also like to point out that our work in [5], has received an invitation for a potential publication in the *Elsevier Journal on Optical Switching and Networking.*

NOTE: All the above work which has resulted in conference proceedings have acknowledged the DOE-COMMON project.

Cost Status & Unexpected Funds

See attached document

Next Quarter Deliverables

- Formulate the static Manycasting Overlay in Multicast-Incapable (Split-Incapable) networks.
- Develop Heuristics to solve the dynamic traffic scenario for the Manycasting Overlay problem.
- Analyze the problem of Anycasting with Lightpath-Switching.
- Develop a mathematical model of hybrid immediate and advance reservation.

References

[1] A. Gadkar, J. Plante, and V. Vokkarane, "Static multicast overlay in WDM unicast networks for large-scale scientific applications," in *Proc. ICCCN*, July. 2011.

[2] A. Gadkar and J. Plante, "Dynamic Multicasting in WDM Optical Unicast Networks for Bandwidth-Intensive Applications," in *Proc. of GLOBECOM 2011*, Houston, TX, USA, Dec. 2011, under review.

[3] "Static multicast overlay in WDM unicast networks for large-scale scientific applications," 2011. [Online]. Available: http://www1.umassd.edu/engineering/cis/reports/report.cfm?r=39

[4] J. Triay, D. R. Rousseau, C. Cervelló-Pastor, and V. M. Vokkarane, "Dynamic Service-Aware Reservation Framework for Multi-Layer High-Speed Networks," in *Proc. 5th Workshop on Performance Moldeling and Evaluation in Computer and Telecommunication Networks (PMECT) collocated with ICCCN 2011*, Maui, HI, USA, Jul. 2011, to appear.

[5] N. Charbonneau and M. Vokkarane, "Dynamic circuits with lightpath switching over wavelength routed networks," in *Proc. of IEEE ANTS*, Mumbai, India, Dec. 2010.