Constraint-Based Loose Explicit Routing and Signaling for Inter-Domain Lightpath Provisioning in Wavelength Routed Optical Network

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ABSTRACT

In this paper, we propose a routing and signaling scheme to provision an end-to-end lightpath in a multi-domain optical network. The Constraint-Based Loose Explicit Routing (CBLER), the proposed routing algorithm, uses abstract network topology and resource information to compute an end-to-end constraint based loose explicit route. We propose a signaling scheme that can use either a forward wavelength reservation scheme or backward wavelength reservation scheme to set up the lightpath over the computed loose explicit route. In this paper we first describe OPSF-BGP model for routing in multi-domain optical network and the inefficiencies associated with the model followed by our proposed scheme. Using our simulation results, we compare the blocking performance of our proposed scheme with OSPF-BGP model.

Keywords: Dynamic routing, inter-domain routing, hierarchical routing

1. INTRODUCTION

When a connection request arrives in a Wavelength-Routed Optical Network, a route is computed and a free wavelength is searched over the computed route. A lightpath connection is setup if a free wavelength is available over the computed route; the request is blocked otherwise. Connection provisioning in traditional optical network is based on centralized infrastructure and involves many human interventions. Failure prone centralized management system and error prone human actions may result in slow, unreliable, and inefficient connection provisioning. Therefore there has been a strong motivation to develop a human-intervention-free optical network control plane. A significant work has recently been carried out to design an automatic and distributed control plane for optical networks. GMPLS protocol suite, Automatic Switched Optical Network (ASON) architecture, and User-to-Network/Network-to-Network Interface specifications are the main contributions towards developing an automatic and distributed optical network control plane [1,2,3].

Routing and signaling are the two important functions of an optical network control plane. A routing protocol gathers routing information in a network, which is used for route computations. A signaling protocol provisions resources and configures optical cross connects (OXC) on the computed route to provision a connection. The computed route must meet the wavelength continuity constraint (that is all the links constituting a route should have the same wavelength available) if there is no wavelength conversion in the network.

Optical networks are different from traditional IP networks in many aspects. IP networks are packet switched networks in which no connection setup is required to transfer a data between the two nodes. Further, IP networks use hop-by-hop routing in which each independently decides the next hop to reach a destination and the source node has no knowledge of the entire path and the resources available on the path to the destination. BGP is an example of inter-domain routing protocol used in the IP networks. Optical networks, On the other hand, are circuit switched and require an explicit connection setup between the two nodes before a data flow can start.

The explicit connection setup and routing constraints in optical networks require the use of source routing also known as explicit routing. In source routing, for a given connection request, an end-to-end path is computed at the ingress node and no intermediate nodes along the path perform any route computations [4,7]. An explicit route is called a strict
explicit route if that identifies every node along the path or is called a loose explicit route if that identifies a subset of the nodes along the path. The performance of explicit routing or source routing, when used for optical networks, is directly related to the network topology and link state information available at the source node. The more accurate, updated, and detailed, the network topology and link state information is, the more efficient and effective the source routing is.

Route computation in a single domain optical network is straightforward since all the nodes have more or less a coherent view of the network topology and link state information but it becomes a bit more complex in multi-domain networks where no network topology and link state information is shared across the domains. A network can be partitioned into subnetworks for variety of reasons such as scalability, administrative constraints, or technological differences. A route that spans multiple domains therefore can not be computed using source routing if there is absolutely no sharing of network topology and link state information across the domains [4,5,6,7,8]. However, if a summarized (abstract) network topology and link state information is shared across the domains in an optical network, an approximate (loose) route can be computed by the source node for a given connection request. The computed loose route likely has the resources needed to setup a connection successfully [8,9,10]. Computing an effective loose explicit route requires that the ingress node must have information of inter-domain connectivity and summarized topology and link state information of each domain in the network for which a hierarchical link state routing protocol can be used [6,11].

Recently a number of researches addressed the issues related to inter-domain routing in optical network. Authors in [8,9] discussed several applications of inter-domain routing, routing information categorization, and physical network topology abstraction. Authors in [12] described the guidelines for routing in multi-domain optical networks. In [13] authors proposed three algorithms named as End-to-End shortest path routing (E2E), concatenated shortest path routing (CSPR), and hierarchical routing (HIR). E2E and HIR algorithms assume that each node in the network has the full knowledge of topology and link state information both at the domain level and network level which can not be true when a network is partitioned for scalability, or administrative reasons. CSPR is similar to a BGP based hop-by-hop routing as proposed by authors in [14].

Our proposed approach for inter-domain path computation and lightpath setup in a multi-domain optical network is based on a hierarchical link state routing protocol and a signaling protocol. A hierarchical link state routing protocol [11,15] such as Domain-to-Domain Routing Protocol (DDRP) can be used to disseminate the inter-domain connectivity and resource information in the network and the summarized internal topology and link state information of each domain to other domains in the network. For a given connection request, the ingress node uses this summarized routing information to compute a loose explicit route to the destination node. A signaling protocol such as RSVP-TE is used to expand the loose explicit route into the strict explicit route and to reserve the desired wavelength on the expanded route using a forward or backward wavelength reservation scheme. For comparison, we also describe OSPF-BGP based approach for route computation and lightpath setup in a multi-domain optical network [13,14] and compare the performance of our proposed scheme with OSPF-BGP model in terms of blocking performance.

The rest of the paper is organized as follows: In Section 2, we describe OSPF-BGP model and its limitations. In Section 3, we describe our proposed scheme using both forward and backward wavelength reservation schemes. In Section 4, we conclude the paper.

2. OSPF-BGP MODEL

In OSPF-BGP model, each domain runs OSPF as Interior Gateway Protocol (IGP) and BGP as Exterior Gateway Protocol (EGP). BGP is a path vector routing protocol that advertises the inter-domain reachability information across the network. AS_PATH attribute in BGP identifies the list of autonomous systems to be traversed to reach a destination. Being a path vector protocol, BGP can not disseminate any link state or topology information across the domains in a network. A node in a domain therefore does not have any information about the topology and resource information of other domains in a network.

Consider the scenario shown in figure 1. Suppose node $A_1$ in domain $A$, needs to set up a connection to node $E_3$ in domain $E$. Using the reachability information in AS_PATH attribute, $A_1$ knows that $E_3$ can be reached traversing the AS path (B->E) via gateway $A_2$. $A_1$ calculates a local route to gateway $A_2$ and searches the wavelengths available on the computed local route. $A_1$ selects one of the available wavelengths and sends a connection request with the selected wavelength to $A_2$. Using the AS_PATH information, the egress gateway of each domain finds the next hop to reach the destination $E_3$. In each transiting domain, using internal topology and link state information, the ingress gateway computes a path to the egress gateway that meets the wavelength continuity constraint for the chosen wavelength. A connection setup request may fail at any node along the path if a node can not find a path to the next node for the requested wavelength. If the connection request fails anywhere along the path, an error message is sent to the source
node. The source node then attempts other wavelengths/routes to set up the connection. OSPF-BGP model is a trial and
error approach for setting up an inter-domain connection in a multi-domain optical network that may take several
attempts before a lightpath can be setup successfully. The OSPF-BGP approach therefore is inefficient both in time and
resources.

3. CONSTRAINT BASED LOOSE EXPLICIT ROUTING (CBLER)

For an inter-domain connection request, a source node can compute a loose explicit route to the destination node using
the abstract topology and resource information of the network available at the source node. Following information must
be shared across the domains in a network to ensure the computation of an effective loose explicit route that guarantees
the availability of maximum resources needed to set up the lightpath successfully.

- Inter-area links and their traffic engineering capabilities (e.g. available wavelengths)
- Summarized reachability information of nodes in the domains
- Information about virtual links across a domain

DDRP can be used to disseminate such information. Within a particular domain, a virtual link may be defined
between two border nodes. A virtual link is associated with one or more physical links on low-level hierarchy. A virtual
link (or the associated physical links on low level hierarchy) of a domain provides a transit path across that domain.
The free wavelengths associated with a virtual link of a domain are derived by aggregating the free wavelengths
available on the physical links associated with the virtual link.

Using this information, an ingress node of an intended lightpath can compute a loose explicit route to the destination
node that has the maximum number of wavelengths available. A signaling message such as RSVP-TE PATH message
can be used to expand the loose explicit route into the strict explicit route and to reserve a wavelength over the expanded
explicit route. A forward or backward wavelength reservation scheme can be used to reserve a wavelength on the
expanded route. If the connection setup fails at any node, a path error message is sent back to the source node and the
source node may compute alternate routes.

3.1 CBLER with forward wavelength reservation scheme

In CBLER with forward wavelength reservation scheme, the wavelength reservation is initiated by the source node. The
source node of an intended lightpath connection computes a loose explicit route to destination using Minimum Sum
Routing (MSR) algorithm [16] and chooses one of the wavelengths available on the computed route using the first fit
wavelength assignment scheme [17,18]. Source node sends an RSVP-TE PATH message with the loose route and the
chosen wavelength to the egress gateway of the source domain. The gateway forwards the message to the ingress
gateway of the next domain using the loose route information in the message. On each transiting domain, the ingress
gateway of the domain expands the loose route into the strict explicit route for the wavelength specified in the message.
The wavelength is reserved on the expanded route as the RSVP-TE PATH traverses the route. When the
RSVP-TE PATH message is received at the destination domain, the ingress gateway of the destination domain may or
may not find a route to the destination node for the requested wavelength. An end-to-end path is established if a route
exists from the ingress gateway of the destination domain to the destination node. If the gateway fails to find a route to the destination node for the requested wavelength, the destination domain gateway sends a path error message to the source node canceling all the wavelength reservations made on the route so far. Upon the receipt of an error message, the source node may attempt establishing path with other wavelengths available on the loose route. CBLER with forward reservation scheme may therefore take more than one attempts to establish a lightpath connection successfully. The maximum number of attempts to establish a lightpath on a computed loose route can be as many as the number of available wavelengths on the loose route.

Figure 2 shows a scenario of CBLER using forward reservation scheme. The node $R_0$ in domain $D_0$ needs to setup a lightpath connection to the node $R_{15}$ in domain $D_3$. Based on the abstract topology and link state information, $R_0$ computes a loose route $\{R_3->R_4->R_8->R_{13}\}$ and finds wavelength $\lambda_1$ and $\lambda_2$ available on the computed loose route. $R_0$ chooses $\lambda_1$ and sends a RSVP-TE PATH message carrying the loose route and the chosen wavelength information to the egress gateway $R_3$ of domain $D_0$. Using the loose route information, $R_3$ forwards the RSVP-TE PATH message to the ingress gateway $R_4$ of the transiting domain $D_1$. $R_4$ expands the loose route $\{R_4->R_8\}$ into the strict explicit route $\{R_4->R_5->R_7->R_8\}$ for the chosen wavelength $\lambda_1$ and the wavelength is reserved on the expanded route. When the RSVP-TE PATH message reaches the ingress gateway $R_{13}$ of domain $D_3$, $R_{13}$ fails to find a route to the destination node $R_{15}$ using $\lambda_1$. The gateway $R_{13}$, therefore sends a path error message to the source node $R_0$, canceling all the wavelength reservations made on the route so far. Upon the receipt of error message, $R_0$ re-sends the path setup message using the previously computed loose route with the next available wavelength $\lambda_2$ on the route. When the path setup message is received by the ingress gateway $R_{13}$ of domain $D_3$, $R_{13}$ successfully finds a route to node $R_{15}$ using $\lambda_2$. connection established

3.2 CBLER with backward wavelength reservation scheme

In CBLER with backward wavelength reservation scheme, the wavelength reservation is initiated by the ingress gateway of the destination domain. In this approach, the source node specifies the loose route and the set of all wavelengths available on the loose route, in the RSVP-TE PATH message. No wavelength reservations are made as RSVP-TE PATH message traverses the route towards the destination. Each gateway forwards the RSVP-TE PATH message to the next gateway using the loose route information in the RSVP-TE PATH message. A gateway also verifies the validity of wavelengths specified in RSVP-TE PATH message and removes any wavelength from the wavelength set that is not available any more. When RSVP-TE PATH message reaches the destination domain, the ingress gateway searches a path to the destination node for one of the wavelengths specified in the RSVP-TE PATH message. If a path is found, the destination domain gateway sends a RSVP-TE RESV message carrying the loose explicit route and the chosen wavelength back to the source node. On the way back to the source node, at each domain the loose explicit route is
expanded into the strict explicit route and the wavelength is reserved on the expanded route. A lightpath is established when the source node receives the RSVP-TE RESV message. However, an error message is sent to the source node if the ingress gateway of the destination domain cannot find a path to the destination node. The source node may then compute an alternate route.

Backward wavelength reservation scheme is more efficient than the forward wavelength reservation scheme since it takes only one attempt to establish a path on a given computed loose route.

Figure 3. CBLER with backward wavelength reservation scheme

CBLER with backward wavelength reservation scheme is shown in figure 3. As shown in the figure, node R₀ in domain D₀ needs to set up a lightpath connection to node R₁₅ in domain D₃. Having computed the loose explicit route \( \{R₃\rightarrow R₄\rightarrow R₈\rightarrow R₁₃\} \) using MSR algorithm and searched the available wavelengths \( \{λ₁, λ₂\} \) on the computed route, R₀ sends an RSVP-TE PATH message to the destination node with the loose route and the available wavelengths encoded in the message. RSVP-TE PATH message is forwarded towards the destination using the loose route information in the message. When the RSVP-TE PATH messages reaches the ingress gateway R₁₃ of the destination domain D₃, R₁₃ chooses the wavelength \( λ₂ \) from the wavelength set \( \{λ₁, λ₂\} \) since it can reach R₁₅ via R₁₄ using \( λ₂ \). R₁₃ sends RSVP-TE RESV message towards the source node with the loose route and the chosen wavelength information. The loose route is expanded into the strict explicit route and the wavelength \( λ₂ \) is reserved on the expanded route in each domain along the route. R₁₃ also sends a RSVP-TE RESV message towards the destination R₁₅ to reserve the wavelength \( λ₂ \) on the route \( \{R₁₃\rightarrow R₁₄\rightarrow R₁₅\} \). A lightpath connection is established as R₀ receives the RSVP-TE RESV message.

4. SIMULATION RESULT

To evaluate the blocking performance of OSPF-BGP model and our proposed approach CBLER for both forward and backward wavelength reservation schemes, we developed a simulation model using C. In our simulation model, we used a network comprising four domains and using NSFNET (14 nodes) topology in each domain as shown in Figure 4. We assumed that both local and inter-domain connection requests arrive at each node in the network following a Poisson process with arrival rate of \( λ \) calls per unit of time. The connection holding time is exponentially distributed with a mean of \( 1/μ \). We assume \( μ = 1 \) unit of time therefore \( λ \) represents the traffic load (Erlang) in the network. We assume no wavelength conversion at any node in the network. All links in the network are assumed to be bi-directional with a total of 32 wavelengths available on each link. Each node in a domain is assumed to have the full knowledge of topology and link state information of its domain and a summarized topology and link state information of the entire network. We gathered the simulation results keeping the inter-domain traffic load constant while varying the local traffic (intra-domain traffic) from 0.2 to 2.0 Erlang to evaluate the inter-domain traffic blocking probabilities for each routing
policy. For all routing policies, we used the MSR algorithm for path computations. Our simulation results are shown in Figures 5 and 6.

Figures 5 and 6 compare the blocking performance for inter-domain and intra-domain traffic respectively when BGP, CBLER with forward wavelength reservation scheme (FRS) and CBLER with backward wavelength reservation scheme (BRS) are used for inter-domain route computations and connection setup. For all the three routing schemes, we limited the number of attempts to setup an inter-domain path to one. The CBLER with BRS has the lowest inter-domain blocking probability under all traffic load conditions (Figure 5) and has a little higher intra-domain blocking probability when the local traffic load is more than 1.0 Erlang (Figure 6). The reason for higher intra-domain blocking probability under CBLER with BRS is the higher number of inter-domain lightpaths traversing multiple domains leaving fewer resources available for local traffic.
Intra-domain blocking Probability vs. local traffic load

5. CONCLUSIONS

In this paper we discussed issues, requirements and approaches for route computation and connection provisioning of an inter-domain lightpath connection in a multi-domain-all-optical network. We explained our proposed approach CBLER for both FRS and BRS and showed that CBLER with BRS scheme can be used as an effective and efficient approach for an inter-domain lightpath setup in an all-optical network.

The performance of CBLER (with BRS or FRS) in general depends on the degree of abstraction of network topology and link state information and the accuracy of information. The more accurate, detailed and updated the information is, the more efficient the path computation is. However, for updated and accurate routing information there need to be frequent routing updates that increase the routing traffic. To avoid the unnecessary routing traffic, routing-update timer and a pre-defined threshold based routing techniques can be used [19].

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