End-To-End Signaling and Routing for Optical IP Networks

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Abstract-**This paper outlines an approach (called OBGP) of extending the BGP routing protocol to support light path setup and management across an optical network. OBGP is a distributed approach, which gives more control to the edge customer and allows customers to better manage their optical wavelengths. It provides an interdomain routing/signaling solution that integrates heterogeneous domains into an end-to-end optical network and can coexist with most of the existing intradomain solutions. OBGP has the capability of setting up light paths in both networks with wavelength converters as well as in networks without wavelength converters. By combining routing with signaling in OBGP, signaling functions can leverage some features of existing routing functions and thus provide a lightweight solution. The development of OBGP has been discussed by reviewing current BGP behavior and design requirements for OBGP. An implementation of OBGP using simulation tools has been presented, along with initial test results, which have shown that a seamless migration from BGP to OBGP is possible.**

I. Introduction

The demand for bandwidth in today's Internet infrastructure has led to the deployment of a large number of high capacity fiber optic networks. To compliment these high bandwidth optical networks, intelligent methods of provisioning and control are required to enable greater flexibility and to reduce operation cost. A convergence is taking place between IP-based routers and multi-wavelength optical equipment to create an intelligent end-to-end integrated network.

Traditionally, as stated in [1], end-to-end circuit connections have been set up via network management systems (NMSs), which issue commands (usually under the control of a human operator) to the various network elements involved in the circuit via an equipment vendor's element management system (EMS). So far this has been the carrier's responsibility and the light path setup and configuration have been based on a centralized model. By moving this responsibility from the carrier to the customer and using a distributed approach, we can simply and easily allow customers to better manage their optical wavelengths. This distributed approach gives more control to edge customer.

Optical networks are *circuit switched networks* in nature due to their high traffic capacity and relatively slow switching speed. The Internet on the other hand is a connectionless packet switched network. Methods of integrating optical networks with the Internet are becoming the key issue of optical network architecture. We will show how the Border Gateway Protocol (BGP) can be extended to allow an edge customer to set up a light path to another site across multiple AS domains. This new flavor of the traditional BGP routing protocol will be called Optical Border Gateway Protocol (OBGP). *The goal of OBGP is to provide an edge network customer with a control method for establishing a light path through an optical network.*

This paper will describe the development and implementation of OBGP by outlining the following areas: a) The design requirements for creating OBGP, b) The necessary extensions to BGP to create OBGP, c) The implementation of OBGP into a standard BGP framework, d) The benefits of using the OBGP approach, as a way for setting up light paths and finally, conclusions and recommendations for future work are presented.

II. Optical BGP Architecture

There are several reasons why we chose BGP as the basis for our research towards a protocol for a light path setup and control. BGP is the current standard for interdomain routing in the Internet today. Utilizing the interdomain properties of BGP is fundamental to the design of OBGP, as many of the issues that external gateway protocols such as BGP were designed to deal with are similar to the management of multiple light paths in an optical network [3]. The widespread deployment of BGP is another important factor. It is easier to build something new based on a protocol that has been proved successful. It is very difficult to integrate a completely new protocol into the existing Internet. If we minimize the modifications to be made to the existing BGP, we have a better chance to integrate OBGP into the Internet.

BGP is a routing protocol while the setup and control of light paths are the functions of a signaling protocol. There are advantages to integrate routing and signaling into one protocol. Both signaling and routing protocols are jointly used to carry information through the network. Signaling typically requires routing information, for example source routing. For failure protection and restoration, the interactions between signaling and routing are critical. Currently there exist various routing protocols and signaling protocols that need to interwork in order to provide an end-to-end solution. In some cases this interworking of multiple protocols is complicated and results in poor scalability. It also requires that every router along the path implement the required routing and signaling protocols. Therefore, a better approach may be to tightly integrate the routing and signaling function into one protocol.

By combining routing with signaling in OBGP we provide a lightweight solution. Signaling functions can leverage some features of existing routing functions. For example, both routing and signaling messages can share a common transport connection (i.e. same TCP connection is used to exchange

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both routing and signaling messages). Thus no extra overhead is required for setting up a separate communication channel for signaling messages. OBGP can also access directly the database of BGP and therefore eliminate the synchronization requirement if two separate databases are used.

Another reason, which makes BGP ideal for signaling, is the AS_PATH attribute of a route. The AS_PATH gives an end-to-end view, which is necessary for setting up a light path. The AS_PATH also allows for better distribution of OBGP messages in the network. For example not all OBGP speakers in the network need to see this message if they are not in the specific AS_PATH thus reducing the amount of signaling traffic in the network.

OBGP provides an interdomain solution that integrates heterogeneous domains into an end-to-end optical network. Different domains still can use their own intradomain solutions. Therefore OBGP can coexist with most of the existing solutions.

Finally, as mentioned in the introduction the distributed nature of OBGP moves the responsibility of setting up a light path from carriers to edge customers. This allows the customer to set up a light path faster without having to wait for carriers to provision their connections which in most cases is a complex and time consuming task.

A. OBGP Requirements and Design

BGP does not contain any functionality or attributes for maintaining information on light paths across a network. However, BGP does contain *complete autonomous system (AS) path information* to reach a particular network, which makes it unique when compared to other routing protocols. This full path visibility enables routing policy decisions to be made as well as preventing routing loops. Having full path visibility is a useful feature of BGP and can be leveraged for setting up a light path from one AS to another [3].

There are four types of messages specified for BGP [4]: OPEN, UPDATE, NOTIFICATION, and KEEP-ALIVE. An UPDATE message is used to provide routing updates within a network. These messages allow BGP routers to maintain consistent information regarding network reachability. UPDATE messages can add or withdraw routes from the Routing Information Base depending on the content of the message.

The basic high-level requirements for OBGP to work as a *light path setup* and *control* protocol are the following: i) Provide a wavelength table to maintain light path information, ii) Carry light path reservation requests and responses between OBGP speaking devices, iii) Propagate up to date information on the status of resources in the network.

Making minimum changes to BGP while meeting these requirements is a very important consideration. Leveraging current BGP properties is key to meeting these requirements. A typical OBGP Router consists of three components, illustrated in Figure 1. The first component is a Border Gateway Router that can be found at the gateway of an AS. This router performs the BGP Peering and sits at the control plane for OBGP.

The Switch Control Server (SCS) is the control interface between the router and the OXC. This interface maintains connection state for the OBGP process in the router. The Optical Cross Connect (OXC) can be any type of cross connects, but for this paper we will focus on the more general case where the OXCs do not have the capability of wavelength conversion. Wavelength converters, as stated in [5], are devices, which take the data modulated on an input wavelength and transfer it to a different output wavelength. Wavelength converters improve network-blocking performance since it is not required to establish a common wavelength across all links in the route.

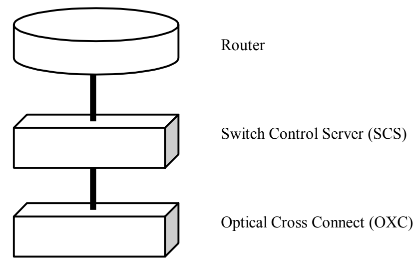


Fig. 1. Diagram of OBGP Router

Initially the UPDATE message was considered for carrying the light path setup information in addition to normal reachability information [9]. This would require a few small extensions to be made to the normal UPDATE message. Given though that optical networks are continuously evolving, we decided that it is more efficient to introduce a new message type to BGP. By using a separate message for the Optical part of OBGP it will be easier to make changes to the protocol. Furthermore, the changes required for supporting light path setup, are isolated without affecting the operation of the other messages, and allowing traditional BGP routers and OBGP capable routers interwork seamlessly. Thus, although the UPDATE message is sufficient for OBGP, by introducing a new message type we provide more flexibility to the OBGP approach.

The new message used, is called the OBGP message. The format of this message will be described in the next section. Another extension that must be made to provide traditional BGP with the functionality to setup light paths is the wavelength table at each OBGP router. This is required to store wavelength availability and setup information. The format of the wavelength table is described in section C.

B. OBGP Message Format

The OBGP message contains the standard fixed size header, which is common to all BGP messages. This header as described in [4] contains the Marker, Length, and Type fields. In order to distinguish OBGP messages from other BGP messages a new type code has been introduced making the set of type codes as follows: OPEN, UPDATE, NOTIFICATION, KEEPALIVE, OBGP. In addition to the fixed-size header, the OBGP message contains the following fields:

4 bits	4 bits	4 bits	16 bits	Variable	Variable
Phase Id	Sub-code Id	Oper. Mode	Attributes Length	Attributes	Lambda RI

Fig. 2. OBGP Message Format.

Phase Id: This 4 bit field indicates the phase of the light path setup process. The possible phases which are described later on in the paper, are the following: a) Discovery, b) Reservation, c) Setup, d) Confirmation, e) Teardown, f) Error.

Sub-code Id: This 4 bit field is used by an OBGP message in the Confirmation or Error phase. For confirmation messages it allows to distinguish between Setup confirmation and Teardown confirmation messages. For error messages it allows to indicate in what phase the error occurred.

Operational Mode: This 4 bit field is used to indicate mode of operation of OBGP: two-phase or four-phase.

Attributes Length: This 16 bit unsigned integer indicates the total length of the Attributes field.

Attributes: The supported attributes for OBGP are the following:

AS_PATH: This is the AS Path from source to destination for which a light path is being setup. As an OBGP message travels from one router to the other along this path, this attribute does not change.

NEXT_HOP: The NEXT_HOP attribute defines the IP address of the border router that should be used as the next hop for the OBGP message.

CONN_ID: The CONN_ID attribute is used to identify light path connections. The connection identifier consists of a unique identifier plus the AS Path that corresponds to the specific light path.

Lambda RI: In the Discovery phase the Lambda Reachability Information (Lambda RI) contains a set of allowable wavelengths that can be used for the light path connection. In the Reservation phase the Lambda RI field contains only one wavelength, which has been selected for setting up the light path between source and destination.

C. OBGP Wavelength Table

Using the wavelength table the OBGP process can easily determine which wavelengths are available to be used for a light path setup. Each OBGP router stores wavelength availability and setup information in its wavelength table. Each wavelength entry in the table contains the following fields:

AS Number	Lambda Id	Connection Id	Preference Level	Setup Complete

Fig. 3. OBGP Wavelength Table Fields.

AS number: the AS number of the neighbor border router to which the specific wavelength connects.

Lambda Id: This consists of the wavelength number, source port number and destination port number.

Connection Id: This consists of an identifier plus the AS Path that corresponds to the light path. If this field is null, then it means that the wavelength is available, otherwise it indicates that the wavelength is unavailable and cannot be used for another connection. The numeric identifier plus the AS path create a unique connection id. The numeric identifier within the connection id is not unique by itself across the network. It is only unique with respect to the same Source and same AS Path from that source.

Preference Level: This field is included for future use, to allow for assigning different preference levels to specific wavelengths.

Setup Complete: This field indicates if the connection for the specific wavelength has actually been setup on the OXC. This can be either True or False.

D. OBGP Protocol

Figure 4 illustrates a basic network where node S wants to setup a light path to node D. Through regular BGP peering, node D has advertised its presence to the network and each node has AS path information and wavelength status information to reach node D. Suppose that for node S to get to node D, traffic must travel through X and Y. This is a path discovered through BGP and can be found in the BGP Routing Information Base. Each node in the path also has a wavelength table that stores the wavelength status information as described in the previous section.

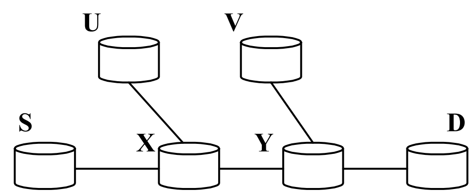


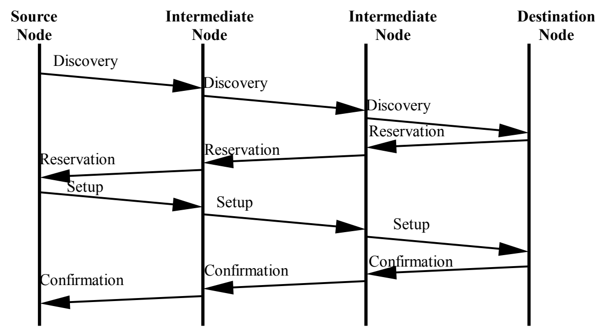
Fig. 4. Basic network where S requests light path to D.

Each OBGP node must be aware of its position within the AS Path in order to process correctly the OBGP messages. There are three types of OBGP nodes present in any optical network: Source, Intermediate, and Destination. A node's classification will change according to its relative position in the light path segment that is being reserved. If a node is listed at the head of a light path reservation segment it is the Source, if it is at the tail, it is the Destination. Otherwise, the node is considered to be an intermediate node in the path segment. In the case of the network of figure 4 where S request light path to D, S is the Source node, X and Y are Intermediate nodes and D is the destination node.

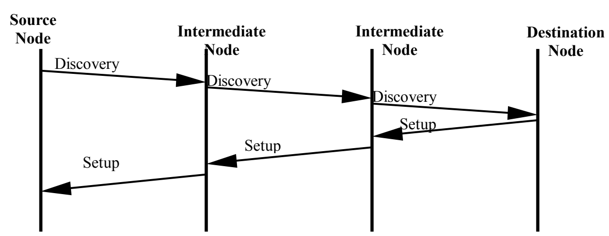
The OBGP protocol can either operate in as a two-phase or a four-phase setup mode. In the four-phase setup mode, all resources have to be reserved first before the Setup of the actual OXCs can take place. This ensures that during the Setup phase, resources are available. On the other hand in the two-phase mode, Setup takes place immediately after having determined if there is a wavelength available to use.

If there are many wavelengths available, then most likely there will be few setup failures due to competition scenarios. In this case a two-phase approach might be more efficient and faster approach. In the case though where there are many users trying to setup light path connections over the same path or sections of the same path, many competition failures may occur. In this case the four-phase approach can be more efficient since the competition will be detected in the reservation phase while trying to reserve the resources. Thus no time is wasted making the actual connection on the OXC, which can be costly. Also, no time has to be spent to destroy any connections on the OXCs.

In the four-phase mode of OBGP, the phases are: 1) Discovery, 2) Reservation, 3) Setup, and 4) Confirmation. In the two-phase mode the phases are: 1) Discovery and 2) Setup. In the two-phase approach there is no need of an explicit confirmation message since the Setup message that eventually reaches the Source serves as a confirmation. The two modes of operations are also illustrated in figure 5. These phases will also be described in more detail in the next sections.



a) 4 Phase Setup



b) 2 Phase Setup

Fig. 5. Figure Four Phase vs. Two Phase OBGP.

1) *Discovery Phase:* Node S in Figure 4 initiates the light path setup request by sending a Discovery OBGP message to node X. A Discovery OBGP message is an OBGP message with its Phase Id field set to Discovery. S also fills the Lambda RI field of the Discovery OBGP message with all available wavelengths that connect to node X. The AS Path and the connection id are stored in the attributes field of the message.

When node X receives the Discovery OBGP message it extracts the wavelengths from the Lambda RI field. It then checks its wavelength table to determine which of the received wavelengths can be used to reach the next node in the AS path, which is node Y in this case. In this stage node X will possibly eliminate a few wavelengths. Only a subset of the original wavelengths will be sent to the next node in the AS Path (node Y) via a Discovery OBGP message. Node Y in turn will perform the same elimination process as node X and then will pass the Discovery OBGP message with the new subset of Lambda RI to the destination node D.

When the destination node receives the Discovery OBGP message, it contains all common wavelengths that can be used from source to destination for the light path setup. It is now up to the destination node D to decide which wavelength to use. For simplicity in this approach, the destination selects the first available wavelength in the list. At this point the Discovery Phase has completed.

The above algorithm applies to the case where the wavelength continuity constraint is required. In the case where the OXC have wavelength conversion capabilities then there is no need to perform elimination rather all available wavelengths can be passed to the next node. In the wavelength continuity constraint case the Lambda RI list of the Discovery message gets smaller and smaller as it approaches the destination. In the case though where there are wavelength converters, this list can actually get bigger as it approaches the destination.

2) *Reservation Phase:* The Reservation phase is specific to the four-phase mode of operation of OBGP. In this phase resources are reserved in order to ensure their availability in the Setup phase. Once the destination node D selects the wavelength to be used, it finds this wavelength in its wavelength table and sets the Connection Id field to the Connection Id that was passed in the Attributes field of the Discovery OBGP message. After completing the reservation at node D, D needs to inform all other nodes in the AS Path of the selected wavelength so they can also update their wavelength tables. To do this D sends a Reservation OBGP message to the previous node in the AS Path (node Y). A Reservation OBGP message is an OBGP message with its Phase Id field set to Reservation. The AS Path and the connection id are stored in the attributes field of the message.

When node Y receives the Reservation OBGP message it updates its wavelength table the same way node D did. It then sends the Reservation OBGP message to the previous node in the AS Path (node X). This is repeated until all intermediate nodes have received the Reservation message and have updated their tables. Eventually, the source node S receives the Reservation OBGP message. The source node also has to update its wavelength table. At this point the Reservation phase has completed.

3) *Setup Phase:* In the four-phase mode the Setup phase takes place after resources have been reserved and the Reservation has completed. At this point all nodes along the AS Path have reserved a wavelength in their wavelength tables for the light path setup, but they have not actually made any hardware connections on the OXC. This is done in the Setup Phase. The source node S initiates the Setup Phase by sending a Setup OBGP message to the next node in the AS Path (node X). A setup OBGP message is an OBGP message with its phase field set to Setup.

In general when a node receives a Setup OBGP message, it makes the appropriate OXC connections and once this is complete it updates its wavelength table to indicate that Setup is complete. Eventually the Setup OBGP message is received at the destination node D and the Setup Phase is complete.

In the case of the two-phase mode the Setup phase takes place immediately after the Discovery phase. During the Setup phase in the two-phase mode, the OXC connections are setup, and the wavelength table is updated at the same time to indicate that the specific wavelength is being used. In contrast to the four-mode operation the Setup phase proceeds from the Destination node to the Source node as shown in the diagram on the right in figure 5. Since the Setup phase is complete when the Setup OBGP message reaches the Source node, there is no need to send a separate confirmation message. The

Setup message also serves as the confirmation of a successful setup.

4) *Confirmation Phase:* In the four-phase mode after the Setup Phase is complete, the source node is not aware of this. Until it receives some kind of notification, the source node can't start sending data over the optical light path. For this reason, the destination node D needs to send a Confirmation OBGP message back to the source along the AS path. A Confirmation OBGP message is an OBGP message with its phase field set to Confirmation. In this case since this is a confirmation for a Setup request, the subcode field of the message is set to Setup. This is used in order to distinguish between Setup and Teardown Confirmation messages. Once the source node receives the Confirmation message this phase is complete and the source can start using the light path (in the case of a Setup Confirmation).

5) Teardown Phase: Teardown as opposed to setup is always a two-phase process since there is no competition in this case. Only the source node can request to teardown a light path. In order to achieve this the source node S, sends a Teardown OBGP message to the next node in the AS Path for the connection to be torn down. This information can be looked up in the wavelength table. When a node receives a Teardown OBGP message it first releases the hardware resources and then updates the wavelength table to indicate that the wavelength is available. Then it passes on the Teardown OBGP message to the next node in the AS Path. When the Teardown message is received at the destination node, the Teardown Phase is complete. The destination node then sends a Confirmation OBGP message with sub-code field set to Teardown back to the Source. This notifies the sources that the light path teardown was successful.

6) *Error Phase:* Whenever an error is detected, an OBGP Error message is sent back to the Source node. An Error OBGP message is an OBGP message with its phase set to Error and the sub-code field is set to the phase where the error was detected. The source node in a light path segment is considered to be the master and is the one that decides what action to be taken in the various error conditions. For example if the Source is notified that error occurred in the Setup phase, then it should immediately send a Teardown message to release the resources. Figure 6 illustrates the flow of messages in the case of an error in different phases of the four-phase approach.

There are several sources of error. Some of the most important ones are the following:

- No available wavelength for setting up a light path. This will be detected in the Discovery phase if for example all common wavelengths are eliminated.
- Various competition cases where two light path setup requests both discover that a certain wavelength is available but then one of them reserves it first. The other one assuming that it is still available, attempts to reserve it and an error occurs. These errors are detected in the Reservation Phase for the four-phase mode and the Setup phase for the two-phase mode.
- Errors related to hardware failures on the OXCs. These types of errors will most likely be detected in the Setup Phase, when trying to make a connection on the OXC.

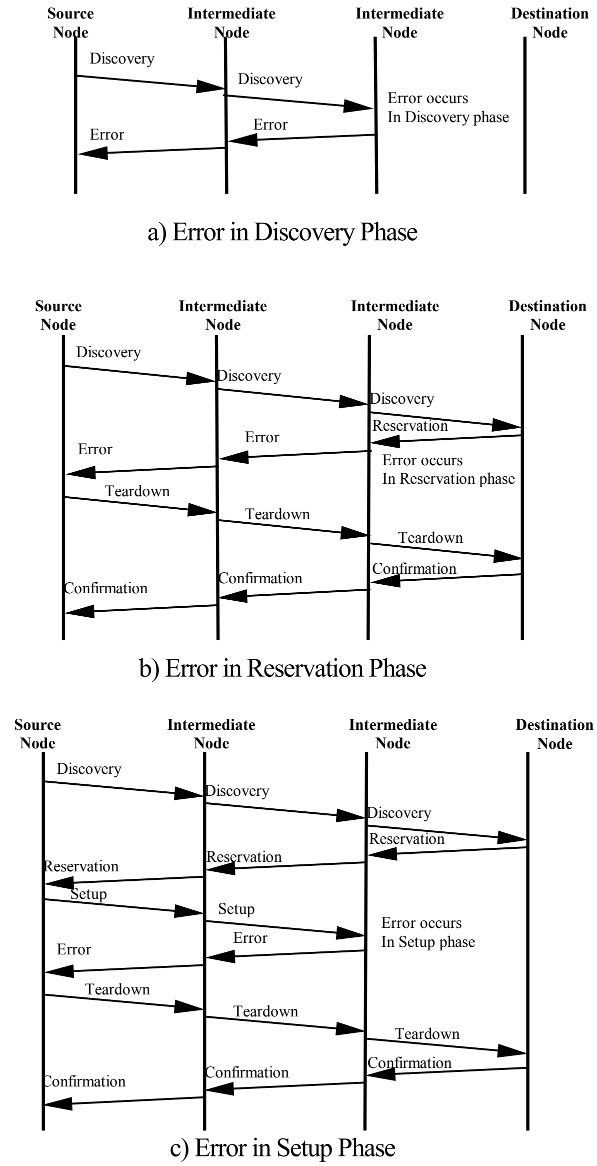


Fig. 6. Error Scenarios.

III. TESTING OBGP

OBGP has been implemented using OPNET network simulation software. There are several reasons for using a network simulation package such as OPNET rather than implementing the protocol in hardware. The main reason is that OPNET provides a flexible development environment. In addition, protocols such as BGP are clearly defined in OPNET using state based methods. The test network was designed to cover the major points of the OBGP algorithm.

The OPNET test network used for this simulation is depicted in Figure 7, and includes only the control plane. This was sufficient to test the OBGP algorithm. The network as shown in the figure consists of six gateway routers. These routers are BGP and OBGP enabled. The network through AS 1000, AS 2000, AS 3000 and AS 4000 is the core of the OBGP where a light path is to be setup. Periphery nodes at AS 2000, and AS 3000 have been added to test the OBGP algorithm. To simulate a light path reservation request from

AS1000 to the destination AS4000, a request was simulated. The light path reservation was made to AS4000, which spanned two intermediate nodes, AS2000 and AS3000.

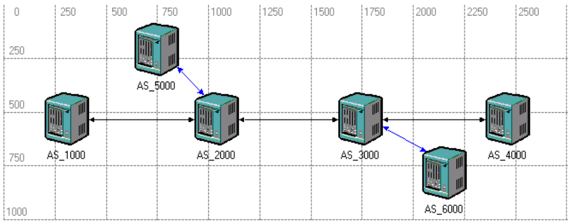


Fig. 7. Test Network and sequence of events for OBGP Light-path Reservation.

IV. Future Research

Our OBGP proposal has been shown as a valid way of reserving and creating end-to-end light paths from source to destination in an interdomain optical network. Yet, there is still further research that must be explored to ensure that OBGP will work with all scenarios.

Firstly, more work must be done on how to support scenarios, where there is a combination of OXCs with wavelength conversion capabilities and OXCs without wavelength conversion capabilities.

In the Discovery Phase the Destination node makes a decision as to which wavelength to use for the lightest setup. For this paper the destination node simply chooses the first wavelength in the list of available wavelengths to be used. Further research should be done to figure out if this is an optimal wavelength selection algorithm and compare to other possible algorithms such as random selection, etc.

Our OBGP proposal supports two modes of operation two-phase and four-phase setup. Further research should be done to determine in which cases should each mode be used, and how both of these modes perform in various networks.

Network reliability is a very important issue, which OBGP must consider. By creating several diversely routed paths from source to destination, the end-to-end connection from source to destination can be protected under failure of a link. The current approach of OBGP uses the AS Path list to determine the destination. Since BGP stores only one path to a destination, further research must be conducted to allow OBGP to set up alternate paths.

V. Conclusions

This paper has outlined a method of extending BGP to support light path setup and management across an optical network. The development of OBGP has been discussed by reviewing current BGP behavior and design requirements for OBGP. An implementation of our OBGP proposal using simulation tools has been presented, along with initial test results.

The main goal of developing and simulating OBGP was to extend the BGP protocol to provide added functionality for light path setup. This goal has been met by demonstrating how OBGP can be used to set up light paths in a simulation network. These initial demonstrations prove that our proposed scheme for OBGP is a viable mechanism and is worthy of future study. The modifications made so far to BGP include the storage of wavelength information in the wavelength table at each node, and the new OBGP message type. Some behavior changes have been made to BGP. However OBGP is still compatible with BGP. We feel that overall changes are small and acceptable. A seamless migration from BGP to OBGP is possible.

The explosion of the Internet will demand new and innovative solutions for the IP/Optical convergence. The development and implementation of OBGP has demonstrated an example of this convergence. Continued research into OBGP is expected, as further studies will revise the details of the protocol.

References

[1] G. Bernstein, et al., “Some comments on GMPLS and optical technologies”, *Network Working Group*, November 2000.

[2] B. Rajagopalan, et al., “IP over Optical Networks: Architectural Aspects”, *IEEE Communications Magazine*, September 2000.

[3] B. St.Arnaud, et al., “*Optical BGP Networks Discussion Paper”*, Revised Draft, July, 2000.

[4] Y. Rekhter, et al., “A border gateway protocol 4 (BGP-4)”, *IETF Request for Comments 1771*, March 1995.

[5] J. Yates, M. Rumswewicz, J.P.R. Lacey, “Wavelength converters in dynamically-reconfigurable WDM networks”, *IEEE Communication Surveys*, 1999.

[6] H. Zang, et al., “A review of routing and wavelength assignment approaches for wavelength-routed optical WDM networks”, *SPIE Optical Networks Magazine*, January 2000.

[7] T. Bates, et al., “Multiprotocol extensions for BGP-4”, *IETF Request for Comments 2858*, June 2000.

[8] R. Chandra, et al., “Capabilities advertisement with BGP-4”, *IETF Request for Comments 2842*, May 2000.

[9] M. Francisco, et al, “Interdomain routing in optical networks”, in Opticomm 2001, J. Bannister, J. Senior and J. Touch, Eds., *Proceedings of SPIE Vol.4599*, pp. 120-129 August 2001.