Design strategies for Survivable Grouped Routing Entity (GRE)-based Optical Networks

Hiroshi Hasegawa, Yuki Taniguchi, Ken-ichi Sato
Dept. of Electrical Engineering and Computer Science
Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan
{hasegawa, sato}@nuee.nagoya-u.ac.jp
y_tanigu@echo.nuee.nagoya-u.ac.jp

Amornrat Jirattigalachote, Paolo Monti, Lena Wosinska
School of Information and Communication Technology
Royal Institute of Technology KTH
Isafjordsgatan 22, Electrum 229, 164 40 Kista, Sweden
{amornrat, pmonti, wosinska}@kth.se

Abstract— **In bandwidth abundant optical networks, the Grouped Routing Entity (GRE) concept is a cost-efficient alternative used instead of waveband routing. It offers all the benefits of the waveband routing (i.e., reduced number of ports), without using expensive wavelength cross connects (WXCs) required in hierarchical optical networks. In fact in a GRE-based optical network wavelength channel add/drop operations are accomplished via Wavelength Selective Switches (WSS) or with optical couplers. The objective of this paper is to further investigate the benefits of GRE-based optical networks in a scenario where survivability is required. In this paper a dedicated protection scheme is proposed, where wavelength paths are efficiently routed using *mostly disjoint* working and backup GRE pipes (i.e., working and backup pipes are allowed to share some common nodes along their paths). Numerical experiments demonstrate that significant hardware scale reduction at the switching nodes can be obtained by using the proposed network design algorithm.**

Keywords— Grouped Routing Entity (GRE), coarse granular routing, dedicated protection, mostly disjoint path, survivable routing.

I. INTRODUCTION

Rearrangeable Optical Add-Drop Multiplexers (ROADMs) are currently widely deployed in wavelength routing optical transport networks. The network traffic is expected to increase every year by 30-40% [1], which suggests that in the next 15 years we might have to face a hundred times higher traffic volumes than today. To support this expected traffic growth, the fiber capacity will need to be ten times higher and, consequently, the nodal degree of ROADMs will have to be ten times bigger. However, based on the current technology, the degree of a ROADM is limited to a small number, usually eight. In this regard, alternative routing techniques, e.g., the ones based on optical path hierarchy were proposed in [2-6].

In hierarchical optical path networks, each node comprises two levels of switching (i.e., waveband cross connects (BXCs) and wavelength cross connects (WXCs)), each one with a different granularity. BXCs are used for routing waveband paths (i.e., bundles of wavelength paths), while WXCs are utilized for switching individual wavelength paths. In hierarchical optical networks, optical paths should be routed at the BXC level as much as possible to enhance the cost efficiency of the approach. In this context, performing grooming operations at WXC level plays a key role in improving the utilization of waveband paths [7]. This in turn increases the overall fiber utilization, a crucial factor in reducing the network cost. On the other hand, grooming at the WXC level requires: (*i*) extraction of wavelength paths from a waveband, (*ii*) switching of the individual wavelength paths, and (*iii*) re-grooming of these wavelength paths into one or more wavebands. It has been shown that high waveband utilization factors can be obtained already with small grooming degree values, e.g., 25 %, [7]. However, the hardware of WXCs does not scale as easily as the one of BXCs. This is mainly because WXCs are processing optical paths at a finer granularity.

To overcome this deficiency, a novel network architecture was proposed in [8] where switching nodes are able to offer coarse (i.e., waveband-like) granularity routing while the only functions performed at the wavelength granularity level are add/drop operations. Differently from hierarchical optical path networks, all the wavelength paths in each fiber are bundled into groups, i.e., *pipes* (instead of waveband paths), which are handled at nodes by the coarse granular switching operations mentioned above. However, the wavelength path level cross-connect function is not available, making wavelength level re-grooming not possible. In order to add/drop a single optical path to/from a pipe, at each node the basic node architecture utilizes either a 1x2 Wavelength Selective Switch (WSS) or an optical coupler at each input/output fiber.

Such a routing scheme is referred to as *grouped routing*, and the bundle of wavelength paths used for coarse granular switching is called *Grouped Routing Entity* (GRE). A GRE pipe is different from a waveband path in the sense that it does not possess path termination functions, i.e., the ones defined in ITU-T Rec. G.783 [9] for digital paths. As a consequence, a GRE pipe may form a closed loop. A GRE pipe can be seen as a virtual fiber with a capacity smaller than a physical fiber. Using GRE pipes, mesh-like networks will be virtually created on top of the existing fiber infrastructure (if there is enough traffic to fill a GRE pipe between two nodes). Conversely, if the traffic volume is small, GRE pipes can be used to create virtual ring networks. Numerical experiments in [8] show that by using this novel architecture cost-effective switching nodes with large throughput can be created. On the other hand, cost is not the only important aspect when considering bandwidth abundant networks. Even more essential than cost is efficient fault management, i.e., the ability to quickly recover from possible failures in order to guarantee that the traffic is not disrupted.

The objective of this work is to study GRE-based optical network architectures able to guarantee survivability while retaining their cost effectiveness. Although the design problem for protected hierarchical optical path network has already been studied in the literature [10-12], the peculiarity of GRE-based networks, i.e., their lack of wavelength re-grooming capability, calls for new survivable network design solutions. This paper proposes a dedicated protection mechanism for grouped routing optical networks where switching operations for backups are done at the GRE granularity level. The simplest way to realize dedicated protection is to provide two disjoint GRE pipes between the source and the destination nodes of each wavelength path group, i.e., one accommodating the working wavelength path and one reserved for the backup wavelength path. Note that all switching operations are done at the GRE granularity level, including the necessary signaling for the backups. However, these GRE pipe-pairs can only accommodate wavelength paths connecting the end points of the pipes, and they may become underutilized if the number of wavelength paths to be routed between the two end nodes is not sufficiently high. To avoid this drawback, the paper proposes to use pairs of *mostly disjoint pipes*, where a backup GRE pipe can share intermediate nodes with its corresponding working pipe. Following this rationale it is possible to accommodate wavelength paths between any of the intermediate nodes shared along the route of the GRE pipes. This, in turn, enhances the GRE pipe utilization. In the paper a simple network design heuristic based on the mostly disjoint pipes concept is presented. Numerical experiments demonstrate that a significant cost reduction can be obtained compared to conventional (i.e., single layer) dedicated path protection based optical networks, as well as compared to GRE-based optical networks that do not allow for sharing of any intermediate node along the working and the backup pipes.

The rest of this paper is organized as follows. Section II first gives an overview of a GRE-based optical network architecture, and then it presents the concept behind a dedicated GRE protection scheme that uses mostly disjoint paths. In Section III, the proposed design algorithm for protected GRE-based optical networks is described. Some numerical results are analyzed in Section IV and, finally, Section V provides a few concluding remarks.

II. PRELIMINARIES

This section first provides additional details about the concept of a GRE-based optical network architecture, including the explanations of the pipe/path structure and the node capability. This information is essential for describing the GRE-based network design problem that will be introduced later in the paper. In addition this section presents an example of the implementation of a number of components to highlight the hardware simplification that a GRE-based optical network architecture is able to achieve. The idea of dedicated GRE protection is then introduced, along with a design strategy based on the mostly disjoint paths concept.

A. Grouped Routing Optical Networks

Grouped routing optical networks [8] utilize coarse granularity routing (i.e., multiple wavelength paths grouped in the same switched entity) and allow add/drop operations at the wavelength path level. The wavelengths in a fiber are divided logically into several groups, where each group is defined as a coarse granular routing entity, i.e., a pipe. Throughout this paper, we denote the number of wavelengths in a fiber as W and we assume that wavelengths are divided into W/B groups where each group consists of B wavelengths. Moreover, each group is assigned an ID, called *GRE-index*, which is an integer ranging from 1 to W/B. Grouped routing is comparable to a situation where nodes are concatenated by GRE pipes whose bandwidth equals to a bundle of multiple wavelength paths (see Fig.1).

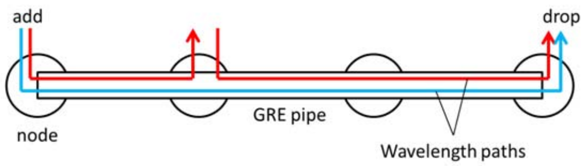


Fig.1 Grouped Routing Entity pipe (GRE pipe).

As mentioned earlier, it might happen that a GRE pipe does not have any end points. It means that it does not have the so-called "path" functions (defined in ITU-T Rec. G.783 for digital paths [9]), and it can potentially form a closed loop. A GRE pipe works as a "highway" where wavelength paths can be added/dropped at any node provided the wavelength resource is not in use when a new wavelength path is added.

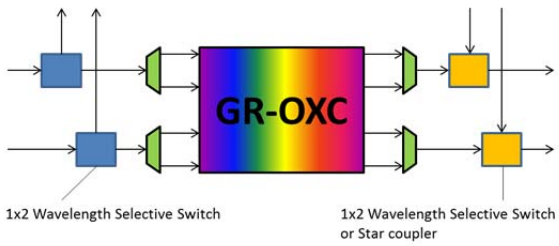


Fig.2 OXC node architecture for grouped path routing with wavelength granular add/drop.

Figure 2 shows an example of a node architecture that realizes grouped routing. The add/drop interface part uses 1x2 WSSs to add and to drop wavelength paths. In the drop part, specific wavelength paths are dropped, terminated, and passed to the electrical layer. In order to provide colorless/directionless/contentionless (C/D/C) capabilities, a large scale matrix switch can be placed for example at the add/drop part to distribute a wavelength path to any electrical system. Another option to provide C/D/C capabilities is to use tunable filters.

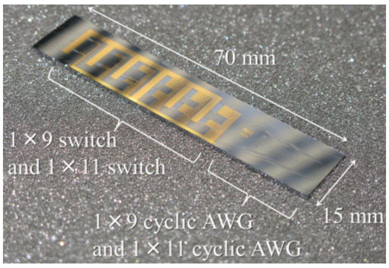


Fig. 3 Our monolithically implemented tunable filter [13].

We have recently developed an ultra-compact tunable filter for efficient C/D/C operations [13]. This tunable filter is monolithically implemented on a 70mm*15mm Planar Lightwave Circuit (PLC) chip (Fig. 3). This component is also used in conventional single layer optical path cross-connects, and for this reason it is not discussed hereafter. In the add part, a WSS or a star coupler is assigned to each output fiber and it is used to add wavelength paths to GREs. The switching part (i.e., the GR-OXC) routes optical paths at the GRE granularity. A GR-OXC can be implemented using matrix switches [14] or WBSSs (WaveBand Selective Switches) [15]. Indeed, we recently developed a compact WBSS with monolithic fabrication using PLC technology. A 1x10 WBSS (Fig. 4) has been fabricated on an 82mm*53mm PLC chip [15].

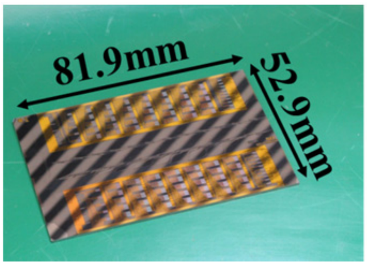


Fig. 4 Our monolithically implemented 1x10 waveband selective switch with extra ports for grooming and termination [15].

By concatenating theses chips, a compact 100x100 WBXC (i.e., a two-stage WBSS) can be developed. This node size is not feasible with current single layer ROADM/OXC technologies. In Sec IV, we evaluate the switch scale reduction attained by the proposed network. Note that for the sake of simplicity we only consider the number of ports of the matrix-switch-based cross-connect, since the cost ratio of WSS/WBSS is not clear at present.

B. Protection in Grouped Routing Optical Networks

This paper considers dedicated protection in order to guarantee fast recovery and minimum service disruption against a single element failure. In grouped routing optical networks, two dedicated protection options are available. One is *wavelength-path level protection*, i.e., each working path (routed on its own GRE pipe) has a backup path provisioned over a separate SRLG (Shared Risk Link Group)-disjoint GRE pipe (Fig. 5). The other option is *GRE-pipe level protection*, i.e., a SRLG-disjoint backup GRE pipe is provisioned for each working GRE pipe. Each pair of working and backup wavelength paths are then accommodated over their respective GRE pipes (Fig. 6). GRE-pipe level protection simplifies the switching and signaling operation upon failure, while wavelength-path level protection is able to achieve lower facility cost. This is because wavelength-path level protection strategies can lead to a more efficient use of the GRE pipe capacity by avoiding separate GRE pipes specifically allocated for working or backup purposes (i.e., as it is the case of GRE-pipe level protection). However, in order to have fast recovery upon a failure, in this paper we target GRE-pipe level protection schemes and we develop a simple heuristic design algorithm for it.

C. Design of Grouped Routing Optical Networks with Dedicated GRE-Pipe Level Protection

In this paper, we consider the static network design problem for GRE-based optical networks with dedicated GRE-pipe level protection. The objective of the proposed algorithm is to minimize a linear function accounting for the number of switch ports and fibers (i.e., a measure of the network facility cost) for a set of given wavelength path connections to be provisioned with dedicated protection.

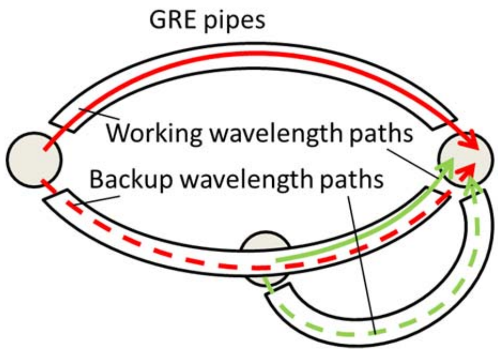


Fig.5 An example of dedicated protection at the wavelength-path granularity level.

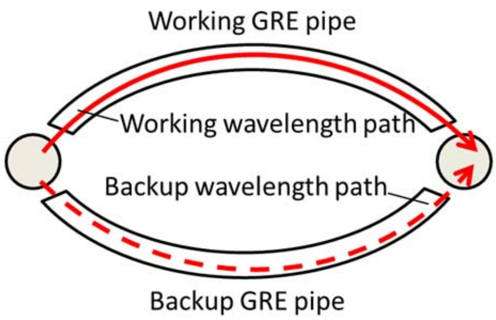


Fig.6 An example of dedicated protection at the GRE-pipe granularity level.

The simplest GRE-pipe level protection scheme is the one shown in Fig. 6, where a pair of working and backup GRE pipes connects a source node and a destination node. Note that only wavelength paths from the same source and the same destination nodes can be accommodated into this GRE pipe-pair. We call this GRE pipe-pair *end-to-end*. The drawback of end-to-end GRE pipe-pairs is that their utilization is not high if the number of demands is low compared to the GRE pipe capacity.

In order to increase the utilization of GRE pipe-pairs we propose to open each end-to-end GRE pipe to allow the working and the backup GRE pipes to share a limited number of intermediate nodes. Note that link failures are much more frequent than node failures [16]. For this reason, sharing intermediate nodes will not significantly degrade the survivability performance of the proposed scheme.

Fig. 7 shows an example of a working and backup GRE pipe-pair sharing one intermediate node. Differently from conventional hierarchical optical paths, we can add or drop wavelength paths to/from GRE pipes without terminating them. The GRE pipes in the figure can carry working and backup wavelength path-pairs simultaneously connecting nodes A and B, nodes B and C, and nodes A and C. In the example in the figure, if the number of wavelength paths to be established between a pair of nodes is on average the same for all node-pairs, then we can double the utilization ratio of GRE pipes.

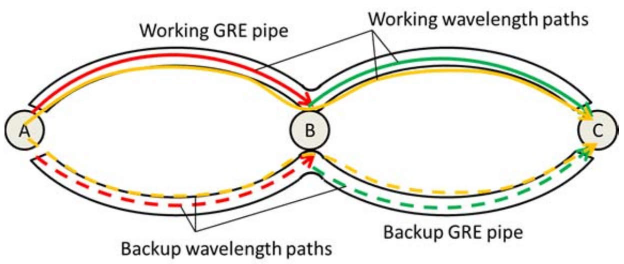


Fig.7 A pair of working and backup GRE pipes sharing an intermediate node.

By increasing the number of intermediate nodes that can be shared, the fiber utilization can be further improved. However, sharing more nodes adds extra routing constraints for the route of the GRE pipes, forcing them to go through a predefined number of intermediate nodes when connecting a given source-destination pair. More routing constraints also translate into extra fibers having to be deployed on those links where there is not enough spare capacity. This may happen despite the fact that it would have been possible to establish different GRE pipes (i.e., using some spare fiber capacity on other links on a different route) between the same source and destination nodes. Note that the length of the shortest route directly connecting node A and node C in Fig. 7 is equal to or shorter than the sum of the routes connecting nodes A and B, and nodes B and C. This means that the total length of SRLG-disjoint GRE pipes connecting node A and node C is generally smaller than that of the pair of GRE pipes sharing intermediate node B. Furthermore, from a practical point of view the number of traversable/sharable nodes is characterized by the considered network topology (e.g., the number of nodes and the nodal degrees), and by the transparent transmission reach of each wavelength path. Therefore, the number of sharable intermediate nodes between a pair of working and backup GRE pipes should be set to a small number, e.g., one or two.

The routing and wavelength assignment (RWA) problem for the static design of conventional single layer optical path networks is known to be NP-complete [17] (i.e., there are no known heuristics running in polynomial time able to optimally solve the static RWA problem). Moreover, with the introduction of grouped routing the static RWA problem becomes even more difficult, and impossible to be solved in an optimal way simultaneously. This extra complexity comes from the need to include (for each GRE pipe) information about the route, the location of (possible) intermediate nodes, the GR-index, not to mention the problem of how to accommodate wavelength paths into GRE pipes. Therefore, in the next section, we propose a design algorithm that establishes (sequentially, instead of simultaneously) pairs of working and backup GRE pipes taking as input a given set of wavelength path demands that have to be established.

Note that a dedicated protection scheme for hierarchical optical path networks was already presented in a previous work [12], where each working and backup wavelength path-pair is accommodated into a series of concatenated working and backup waveband-pairs. In case of a failure, working wavelength paths are switched to their backups at the waveband granularity level. Similarly, the dedicated protection scheme presented in this section also switches at the GRE-pipe granularity level, i.e., it uses coarse granularity. However, in contrast to hierarchical optical path networks, grouped routing optical networks with GRE-pipe level protection do not need any wavelength level grooming operations to bridge the GRE pipe-pairs. Consequently, a significant advantage of GRE level protection is hardware scale reduction at the cross-connects, as already discussed previously. On the other hand, in order to improve the utilization ratio of GRE pipes it becomes very important to carefully choose the location of the intermediate nodes to be shared between working and backup GRE pipes.

III. A Design Algorithm for Protected GRE-Based Optical Networks

The objective of protected GRE-based optical network design is to find suitable working and backup GRE pipe routing onto which accommodate the given set of wavelength path demands. We propose an algorithm that sequentially establishes pairs of working and backup GRE pipes so that the wavelength path demands are accommodated while minimizing the overall network infrastructure cost. In order to achieve high GRE pipe utilization, a limited number of nodes can be shared between the pairs of working and backup GRE pipes, as explained in Sec. II. The algorithm is described below.

Design Algorithm for Protected Grouped Routing Optical Networks that Allows Intermediate Node Sharing between Working and Backup GRE Pipes

Step 1. Select an upper bound $b(\geq 0)$ for the number of nodes that can be shared between a working and a backup GRE pipe. Fix two thresholds, $0 < \sigma_1$, and $\sigma_2 < B$. Both of them will be explained in the following steps. For each source and destination node-pair (s,d), find a set of candidate routes R(s,d) for the working path by using the k-shortest path algorithm [18]. For each candidate route in R(s,d), all links belonging to the path under consideration are temporarily removed, and the k-shortest path algorithm is run again to find a set of candidate backup routes for the examined working path. The set of candidate working and backup route pairs is then saved in P(s,d). Go to Step 2.

Step 2. In descending order of their shortest path distance, for each node-pair check the number of wavelength path demands to be established between them. If this number is larger than σ_1, establish a working and a backup GRE pipe. The route for each pipe (chosen within P(s,d)) and the GRE index are selected so that the number of newly deployed fibers necessary to accommodate these GRE pipes is minimized. Repeat this procedure until the number of wavelength path demands that are not accommodated yet is larger than σ_1. Go to Step 3.

Step 3. For each node-pair (in descending order of their shortest path distance) check the number of wavelength path demands to be established between them. If the number is not zero, for all candidate routes in R(s,d), select up to b intermediate nodes and try to maximize the ensemble average of the utilization ratio of the GRE pipes of each candidate route. If the maximum average utilization ratio of the GRE pipes is larger than σ_2, establish a working and a backup GRE pipe on the route with a GRE index that minimizes the number of newly established fibers. Accommodate the wavelength path demands in the GRE pipe-pair. Repeat this procedure until all node pairs are processed. Go to Step 4.

Step 4. For each node-pair (in descending order of their shortest path distance) check the number of wavelength path demands to be established between them. If the number is not zero, establish a pair of GRE pipes on a route and with a GRE index such that the number of newly established fibers is minimized. After this procedure is applied to all node pairs, terminate.

IV. NUMERICAL EXPERIMENTS

In this section, we evaluate the performance of the proposed grouped routing scheme for optical networks with dedicated protection. Not only GRE-pipe level protection simplifies recovery but also the hardware cost, especially at cross-connects, is significantly reduced.

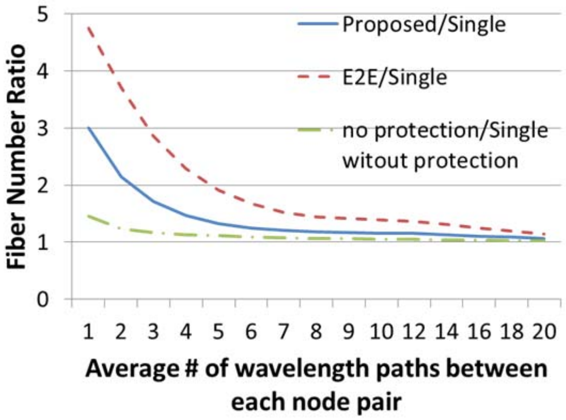
Two regular mesh network topologies (i.e., 7x7 and 9x9) are used as reference networks. It is assumed that wavelength conversion is not available. Furthermore, for simplicity, the length of all links is set at 500km to allow for a transparent transmission reach over several hops. The number of wavelengths in a fiber (W) is set to 80 and the GRE pipe size (B) is assumed to be 10. In order to measure the infrastructure cost, we used the cost model explained in the Appendix section. Moreover, we assume randomly and uniformly distributed traffic demands represented as the average number of wavelength path requests between each node pair. We set b to 1 and thresholds σ_1, σ_2 are set to B and $B/2$, respectively. Up to 5 candidate routes are saved in R(s,d).

In order to demonstrate the effectiveness of the proposed protection scheme, two reference schemes are used as benchmark. The first scheme, referred to as "single", utilizes a conventional single layer optical path architecture with wavelength level dedicated protection, i.e., it accommodates the given wavelength path demands one by one so as to minimize the number of newly added fibers. The second scheme, referred to as "E2E", uses the grouped routing architecture concept where all GRE pipes are established one by one in an end-to-end manner. Routes are selected so as to minimize the number of newly added fibers. For both benchmarking approaches, routes are selected from set P(s,d) to avoid excessively long detours.

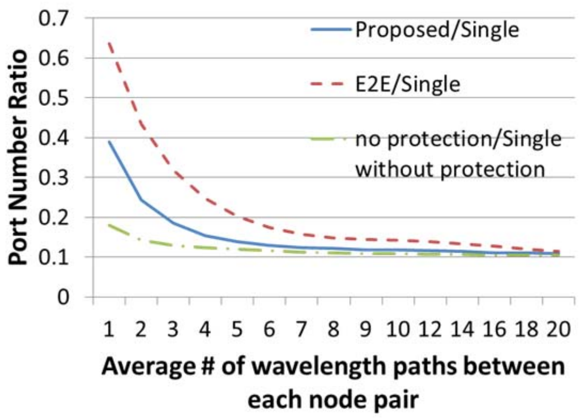
Figures 8 and 9 show the results of the proposed scheme tested on the 7x7 and the 9x9 topologies, respectively. Note that the results are normalized to the ones obtained by the single layer approach. Almost the same trends are observed for both topologies. Indeed, the normalized port count for the proposed design method rapidly drops and approaches $0.1 = 1/B$, which is the lower bound. On the other hand, due to the introduction of coarse granular routing at nodes, the number of fibers increases, especially when the traffic intensity is low. However, the normalized number of fibers obtained by our proposed algorithm is still much less than that of E2E (Fig. 8 (b)). Moreover, for the 7x7 regular mesh network the difference on the normalized number of fibers between our scheme and the single layer approach becomes 0.2 when the average number of wavelength paths between each node pair is 8, and becomes 0.1 when the average number is 16. Due to the significant port count reduction at nodes, the proposed method achieves lower network cost than both "single" and E2E algorithms. The parameter values in the network cost function change with the network scenario, i.e., link length, existence of already laid fiber cables, etc. Already 1000 fiber cables (23mm diameter) have been introduced in Japan [19]. Often in metro areas, a certain number of fiber cables are laid in conduits or tunnels in parallel. In such a case, node cost reduction is the most prominent factor in reducing the total investment cost. A slight increase in fiber count is entirely reasonable. Therefore, the grouped routing optical network architecture can be considered as the most effective solution for application to metro areas where node cost dominates.

Figure 8 also shows the ratio of performance results between grouped routing optical networks without protection [8] and single layer optical path networks without protection. The normalized results for networks with dedicated protection are higher than those for networks without protection. The reason for this difference is the following. For GRE-based optical networks without protection, GRE pipes can accommodate any wavelength paths whose source and destination nodes lie on the routes of the pipes. On the other hand, for grouped routing optical networks with dedicated GRE-pipe level protection, GRE pipes can only accommodate wavelength paths whose source and destination nodes are the end points of GRE pipe pair (or eventually one of the intermediate shared nodes along the path). However, the normalized results of the network with dedicated protection become similar to those of the unprotected cases as the amount of demand increases. Thus, the proposed protected grouped optical path networks would also be cost-effective, compared to the unprotected cases.

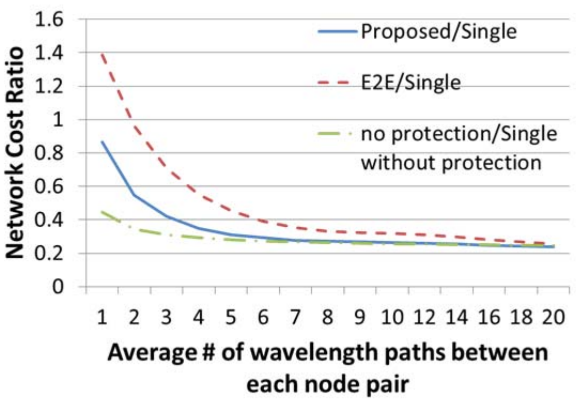
It is worth mentioning that our proposed design scheme is a simple heuristic which sequentially establishes pairs of working and backup GRE pipes. Throughout the experiments, we found that most of wavelength paths are established in Step 2 and Step 3, and the ratio of wavelength paths established in these two steps to all wavelength paths increases as the traffic intensity increases. This implies that almost all GRE pipes are well utilized and the inefficiency caused by sparsely utilized GRE pipes established at Step 4 is limited. Further improvement in the utilization of GRE pipes and fibers will be considered in our future work.



(a) Normalized number of ports

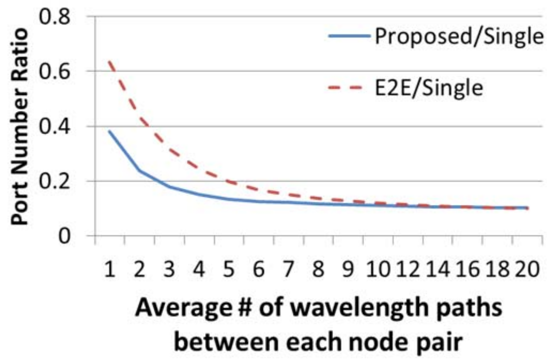


(b) Normalized number of fibers

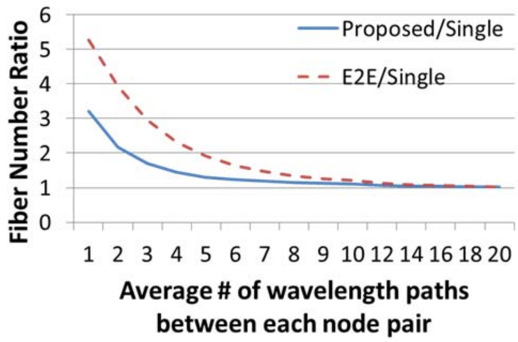


(c) Normalized network cost

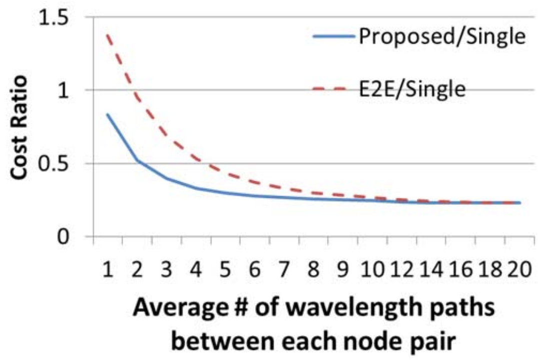
Fig. 8 Results for the 7x7 regular mesh network.



(a) Normalized number of ports



(b) Normalized number of fibers



(c) Normalized network cost

Fig. 9 Results for the 9x9 regular mesh network.

V. CONCLUSION

We proposed a dedicated protection scheme for GRE-based optical networks that provides coarse granular optical switching and wavelength granularity add/drop. With our proposed approach, significant hardware scale reduction at nodes can be obtained. Moreover, the proposed architecture can be considered as a useful alternative for creating reliable and cost effective optical networks.

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TABLE I PARAMETERS FOR COST EVALUATION

Given Parameters		
C_{B_NNI}	GR-OXC NNI (network node interface) port cost per GR-pipe	1
C_{B_UNI}	GR-OXC UNI (user network interface) port cost per GR-pipe	1.2
C_{BXC}	GR-OXC base cost	4
C_{W_NNI}	WXC NNI port cost per wavelength	1
C_{W_UNI}	WXC UNI port cost per wavelength	1.2
C_{WXC}	WXC base cost	4
C_F	Optical fiber cost per km	0.012
C_{AMP}	Amplifier cost	2.04
D_{AMP}	Amplifier span	60
W	Maximum number of wavelength per GR-pipe	
B	Maximum number of GR-pipes per fiber	
K	Number of nodes in network	
D_{ij}	Distance between node i and node j; D_{ij} =0 for node pair that is not physically adjacent to each other	
Variables		
F_{ij}	Number of fibers between node i and node j	
B_NNI_i	Number of GR-OXC NNI ports at node i	
B_UNI_i	Number of GR-OXC UNI ports at node i	
W_NNI_i	Number of WXC NNI ports at node i	
W_UNI_i	Number of WXC UNI ports at node i	

Appendix

The network cost is given by the sum of the node cost (GR-OXCs and WXCs) and the link cost (optical fibers and amplifiers). The node/link costs are expressed by combining the parameters and variables given in Table I as explained next. The cost function also includes a constant that represents the costs of the control systems and other overheads. Specific cost values used for the calculations are given in [4].

Node cost: BXCs and WXCs

$$C_{\text{node}} := \sum_{i=1}^{K} (C_{\text{B\_NNI}} \times \text{B\_NNI}_i + C_{\text{B\_UNI}} \times \text{B\_UNI}_i + C_{\text{BXC}} + C_{\text{W\_NNI}} \times \text{W\_NNI}_i + C_{\text{W\_UNI}} \times \text{W\_UNI}_i + C_{\text{WXC}})$$

Link cost: optical fibers and amplifiers

$$C_{\text{link}} := \sum_{i=1}^{K} \sum_{j=1}^{K} \left(C_{\text{fiber}}(i,j) \times F_{ij} \right)$$

where

$$C_{\text{fiber}}(i,j) := C_{\text{F}} \times D_{ij} + C_{\text{AMP}} \times \left\lfloor \frac{D_{ij}}{D_{\text{AMP}}} \right\rfloor$$