# Heuristic Resource Provisioning for Dynamic Wavelength Services with Access Port Constraints

**Xiaolan J. Zhang, Steven S. Lumetta, Angela L. Chiu***

*Department of Electrical and Computer Engineering, University of Illinois at Urbana–Champaign*
**AT&T Labs Research*
*email: xzhang29@crhc.illinois.edu, lumetta@illinois.edu, chiu@research.att.com*

**Abstract:** This paper introduces a fast heuristic resource provisioning algorithm for dynamic wavelength services on agile reconfigurable ROADM networks on which customer connections are only constrained by access ports.



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## 1. Introduction

Network carriers have begun to support flexible on-demand connections at the optical layer for customers that require high data-rate private line services. One of the on-demand service models is called *dynamic wavelength service*. A customer owns or leases a few access ports in the network. The network allows them to connect between these ports in any way and to change the connections at any time. In this paper, we focus on providing dynamic wavelength services on agile reconfigurable ROADM networks. These networks support wavelength level on-demand connections at line rates 10Gbps to 40Gbps. Each connection can be created or released in a few minutes given that necessary network equipments are pre-installed and ready. In order to support any possible connection configuration between the customer's ports, the network must be pre-dimensioned with enough network resources. Previous work [1] has introduced the resource provisioning problem and a few optimization approaches. The complexity of the optimization problem grows exponentially in the number of customer's ports and network sizes. In this paper, we introduce a heuristic optimization algorithm that provides fast provisioning, which is especially useful for network carriers aiming at supporting many large customers on a national network.

The network model is represented by ROADMs as nodes and dense wavelength division multiplexer (DWDM) fiber pairs as links. Wavelength tunable optically transponders (OT) and 3R regenerators (REGEN) are installed at each ROADM's add/drop ports. The ROADM is fully reconfigurable, such that any wavelength from one DWDM input can be switched to other available DWDM port or add/drop port. OTs and REGENs are able to connect to any available add/drop ROADM port and any available wavelength channels. Customer network equipment accesses the reconfigurable network through OTs. An OT has a customer-side interface that connects to customer devices and a line-side interface (laser port) that connects to the ROADM network. A wavelength connection is setup between a pair of OTs installed at source and destination ROADM nodes. Intermediate ROADM nodes route the connection through optical bypass crossconnects, and are called "bypass" nodes. If the connection distance exceeds the maximal optical reachability for the network system, some intermediate nodes serve as "regen" nodes and crossconnect the connection through a 3R REGEN. The wavelength can change at the regen nodes.

Each customer owns or leases a set of OT ports to access the network. In practice, carriers may allow customers to share a poll of OTs via fiber cross-connect (FXC). But we only consider the non-shared case in this paper. They can choose to connect between their free OTs at different nodes in arbitrary ways. Every connection occupies one of the customer's OTs at each end of the connection until the connection is released. The routes are pre-provisioned and the network resources, such as REGENs and wavelengths, must be pre-installed so the customers can reconfigure their connections any time within a few minutes. A network can have many customers. But one customer is not allowed to connect to another customer's OT ports. In this paper, we only consider one customer at a time.

## 2. Heuristic Provisioning Algorithm

In a ROADM network of a set of nodes $\mathscr{N}$, the customer has a fixed number of OT ports at each node, denoted by $O_n$ where $n \in \mathscr{N}$. The customer is allowed to connect between nodes freely if spare ports are available. The maximal number OTs available to a customer is called a *port constraint*. A customer *demand* is defined to be a node to node bidirectional connection, which requires an OT port at each node. If there is more than one connection between a node pair, each connection is modelled as a distinct demand. A *demand matrix* for a customer is a set of demands that satisfy the port constraint of the customer. In this paper, we work with the set of reduced demand matrices. *Reduced demand* *matrix* set, denoted by $\mathscr{S}$, only contains demand matrices that the provisioning of demands in one set cannot be fully covered by the provisioning of demands in another set. A rigorous definition can be found in [1].

We use $\mathscr{E}$ to denote the set of physical DWDM links. Each physical link $e$ associates with a distance $l_e$ in miles. Let $W$ be the set of wavelength channels available on a link. Let $R$ be the set of REGENs available on a node. We define a *resource graph* be a set of link-wavelength tuples $(e,w)$ and node-REGEN tuples $(n,r)$ installed in the network. A route $p$ includes a set of link-wavelength tuples denoting the route and wavelength assignment, and a set of node-REGEN tuples denoting the regenerating site. Each link-wavelength tuple associated a per-mile cost rate $cost_{e,w}$. Each REGEN has a per-equipment cost $cost_{n,r}$. The cost of a route is computed by $\sum_{(e,w)\in p} l_e cost_{e,w} + \sum_{(n,r)\in p} cost_{n,r}$. Let $\mathsf{CC}$ be the default cost for wavelength channel per mile. Let $\mathsf{RC}$ be the default cost for a REGEN.

Initialize empty resource graph $G \leftarrow \emptyset$;
**foreach** *reduced demand matrix* $D \in \mathscr{S}$ **do**
  Initialize residual resource graph with full capacity $RG \leftarrow \cup_{\forall e\in E, w\in W}(e,w) \cup_{\forall r\in R_n, n\in N} r$;
  **foreach** $(e,w) \in RG$ **do**
    **if** $(e,w) \in G$ **then**
      $cost_{e,w} \leftarrow 0$;
    **else**
      $cost_{e,w} \leftarrow l_e \times \mathsf{CC}$;
  **foreach** $(n,r) \in RG$ **do**
    **if** $(n,r) \in G$ **then**
      $cost_{n,r} \leftarrow 0$;
    **else**
      $cost_{n,r} \leftarrow \mathsf{RC}$;
  **foreach** *demand* $d \in D$ **do**
    Find the least cost path available on the residual graph $p \in RG$;
    $RG \leftarrow RG \setminus p$;
    demand route $A(d) \leftarrow p$;
  Get used resource graph $UG \leftarrow RG^c$;
  Combine resource graphs $G \leftarrow G \cup UG$;

Fig. 1: Heuristic Provisioning Algorithm.

Our heuristic provisioning algorithm is described in Figure 1. The basic idea is to greedily allocate the resources of all demands that maximally reuses the resources that have been already allocated. Note that the demands of different demand matrices can share resources but the demands of the same demand matrix can not. We allocate each demand matrix one by one in an arbitrary order. In the beginning, there is no resource allocated. So the routes allocated for the demands in the first demand matrix are their least cost paths using default cost for wavelength channels and REGENs. After the first demand matrix, we have a network that some resources have been already provisioned. Starting with the second demand matrix, the resources that have been provisioned previously are marked with zero cost. Then, the route for each newly allocated demand attempts to maximally reuse the wavelength and REGENs that are used by other provisioned demand matrices. For the demands of the same demand matrix, they need to pick non-overlap paths to avoid resource sharing. This is done by assuming maximally available resources on the residual network at the beginning of each demand matrix. After a route is picked for a demand, the resources used by the route is removed from the residual network and so forth. The resources used by the demand matrix is then combined with the currently provisioned graph. We use "union" operation so the resources that have been there previously are not doubly counted. During routing, if there are multiple available wavelength channels of the same cost, the first-fit wavelength assignment algorithm is used. We have the provisioned network after all demand matrices have been allocated. The algorithm is linear in network sizes for a given number of demands. Although we aware that the possible number of demands still can grow exponentially in the number of ports, the complexity of the algorithm has been greatly reduced by eliminating the combinatorial optimization part.

## 3. Simulation Results

CORONET is created by Telcordia-AT&T team to mimic a typical large international core network [2]. We use the U.S. contiguous part of CORONET that consists of 75 nodes and 99 links. Each node maps to a U.S. city. Figure 2 shows the network topology with links marked with distance in miles. We assume an 40Gbps system with an optical reach of 932 miles (the maximal distance that optical signal can travel without a REGEN). Each fiber contains 80 wavelength channels. Based on the current vendor's price, we use 150 for the default cost of a REGEN and 0.07 for the default cost for each wavelength channel per mile. Three cities are picked as base cities for a customer. They are marked in the figure with red (Chicago), blue (New York City), and green (San Diego).

We compare the performance of our heuristic algorithm (HEU) with the optimized result (OPT) using a four-node demand constraints $O_r = 2$, $O_b = 3$, $O_g = 24$, $O_x = 1, x \in \mathscr{N}$. The fourth node is an arbitrary node in the network. If $x$ is the same node as the red, blue or green one, there are still 3 nodes except for one having an additional port. Each optimized result is obtained by running two-stage genetic algorithm with fixed routes [1] with 3000 generations and 80 population per generation (approximately for 1.5 hour). The HEU result can be obtained within a second. The comparison is shown in Figure 3-5. All the nodes are sorted in the increasing order of the lower bound for each test case. The results for red, blue and green nodes are annotated. On average, HEU incurs an overhead of 11% of the optimal approach.

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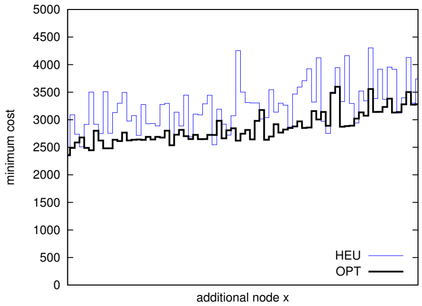


Fig. 3: Comparison of results for $O_r = 2, O_b = 3, O_g = 2, O_x = 1$.

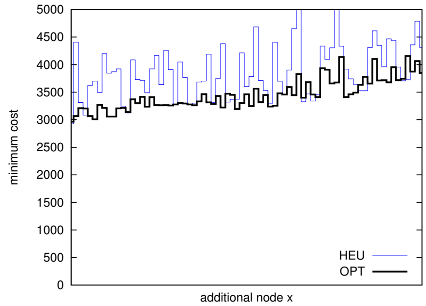


Fig. 4: Comparison of results for $O_r = 2, O_b = 2, O_g = 3, O_x = 1$.

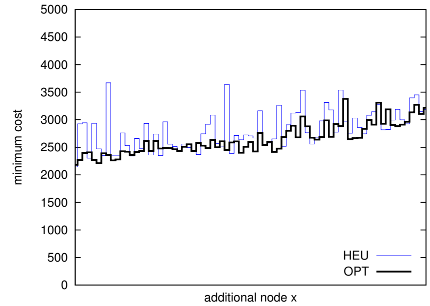


Fig. 5: Comparison of results for $O_r = 3, O_b = 2, O_g = 2, O_x = 1$.

## 4. Conclusion

We proposed a heuristic algorithm for provisioning the network resources for dynamic wavelength services, which is a highly complex resource optimization problem. On a carrier-grade ROADM network for a set of possible customer demands, our heuristic algorithm on average achieves 11% overhead with about 0.02% of the runtime of the optimized approach. Our algorithm reduces the provisioning cost for network carriers who want to expand their on-demand dynamic wavelength services to a large number of customers on a national scale backbone network.

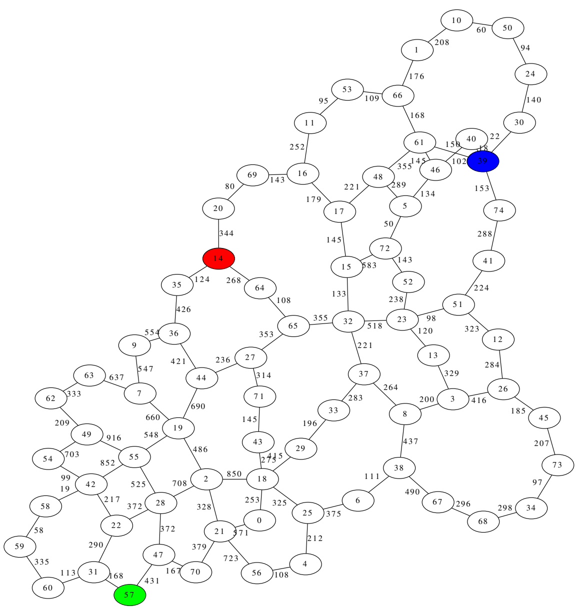

Fig. 2: US CORONET with marked cities: red (Chicago), blue (New York City), and green (San Diego). Links are labeled with distance in miles.

## References

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