Wavelength Assignment Algorithms

Mohammad Hadi

mohammad.hadi@sharif.edu

@MohammadHadiDastgerdi

Spring 2022

Overview

Wavelength Continuity

Wavelength Continuity in Optical Bypass-Enabled Networks

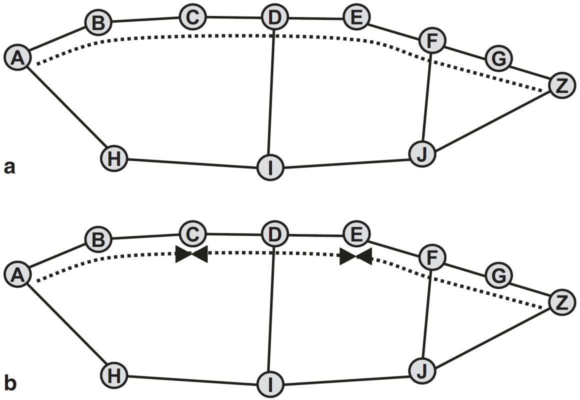

Figure: a It is necessary to find a wavelength that is continuously free along each of the links of the path between Nodes A and Z. b If regeneration occurs at Nodes C and E, different wavelengths can be assigned to the three resulting sub-connections provided that there is no architectural limitations for regeneration (fixed-tuned transponders, patch-cabled transponders). Note that optical reach, traffic grooming, and protection can affect regeneration process and wavelength continuity.

Multistep and One-step Routing and Wavelength Assignment

Multistep RWA

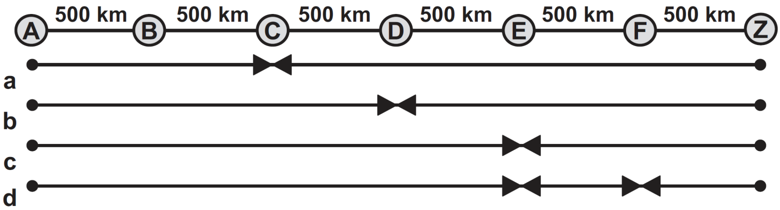

Figure: In multistep routing and wavelength assignment (RWA), (1) a route is selected for a connection, (2) the connection is broken into sub-connections, if necessary, and (3) each of the sub-connections is assigned a wavelength. If the wavelength assignment fails, some of the steps are repeated to alleviate wavelength contention. The wavelength contention could be resolved by changing regeneration sites, moving demands from heavily loaded links, dynamic routing for problematic requests, adding more regenerations, or deploying new network elements or optical fibers. When a demand is added to a network that is not heavily loaded, the multistep RWA should have little problem finding a feasible RWA. However, under heavy load, using a one-step RWA can provide a small improvement in performance.

Multistep RWA

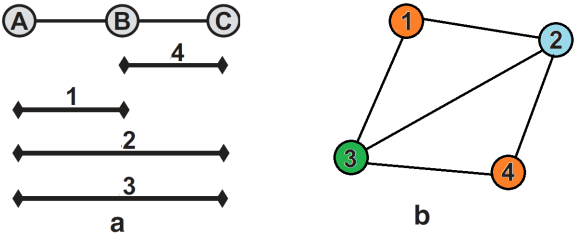

Figure: The wavelength assignment stage of the multistep RWA is analogous to graph coloring on a conflict graph. In a conflict graph, the vertices represent sub-connections and the colors represent wavelengths; two vertices are connected if the sub-connections have at least one link in common. There are heuristic approach for graph coloring. The minimum number of required colors (chromatic number) for graph coloring is upper bounded by the maximum vertex order plus one and is lower bounded by the size of the largest graph clique (fully connected sub-graph)

One-step RWA using Topology Pruning

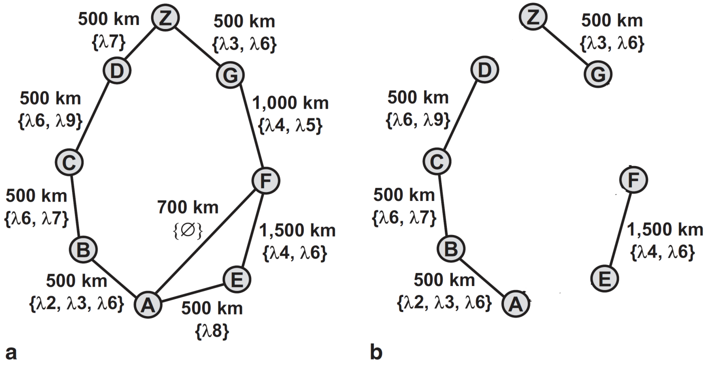

Figure: In one-step approach, RWA is treated as a single problem to ensure feasibility from the start. As an elementary one-step algorithm, topology pruning starts with a particular wavelength and reduces the network topology to only those links on which this wavelength is available. The routing algorithm is run on this pruned topology. If the RWA fails, the pruning is repeated for another selected wavelength. The orders of the wavelength selection affects the optimal operation of the network.

One-step RWA using Reachability Graph Transformation

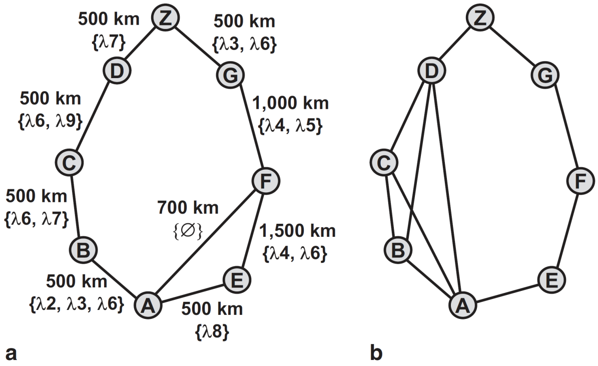

Figure: a The true network topology where it is assumed that the optical reach is 2000 km. The wavelengths listed next to each link are the wavelengths that are assumed to be free on the link. b The reachability graph, where a link is added between a node pair if there is a regeneration-free path between the nodes with at least one available wavelength along the path. To obtain the reachability graph, KSP algorithm along with a check for free wavelength on each path can be used. Once the reachability graph is formed, a minimum-hop SP algorithm is run for the demand, where each hop corresponds to a sub-connection. The path produced may include a link that is common to more than one sub-connection comprising the path. This issue can be addressed using heuristic approaches. In the long-term planning, the available regeneration equipment at a node is not a factor while a more complex graph transformation may be needed with real-time planning.

One-step RWA using Optimization Techniques

1. Global integer linear programming (ILP)-based RWA
2. Relaxed linear programming (LP)-based RWA
3. Limited candidate path ILP-based RWA
4. Per-connection ILP-based RWA
5. ILP-based ring RWA

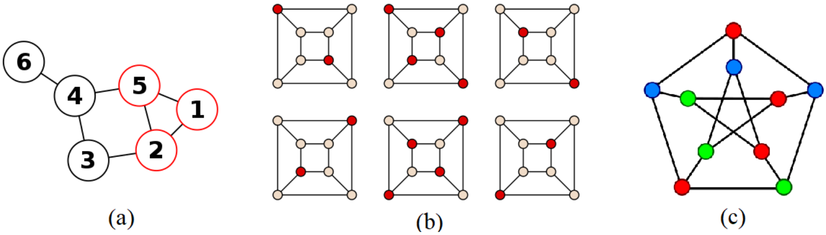

Figure: a Maximum clique problem b Maximal independent set c Graph coloring problem

1. Maximum clique-based RWA
2. Maximal independent set-based RWA
3. Graph coloring-based RWA

Wavelength Assignment Strategies

Wavelength Assignment Strategies

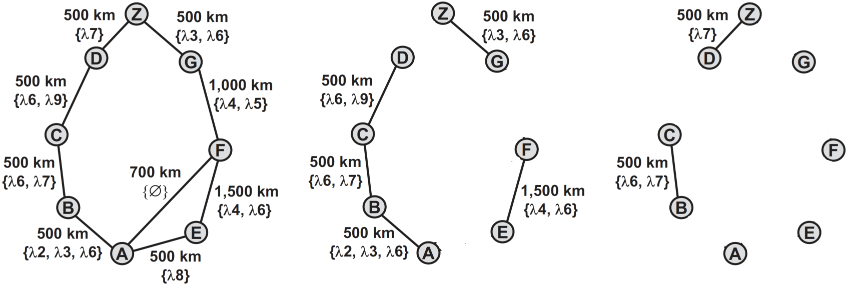

Figure: The wavelength assignment strategy determines the order in which wavelengths are considered when assigning a wavelength to each of the subconnections. The strategy affects both one-step and multi-step RWA. First-Fit, Most-Used, and Relative Capacity Loss (RCL) are the famous wavelength assignment strategies.

First-fit Strategies

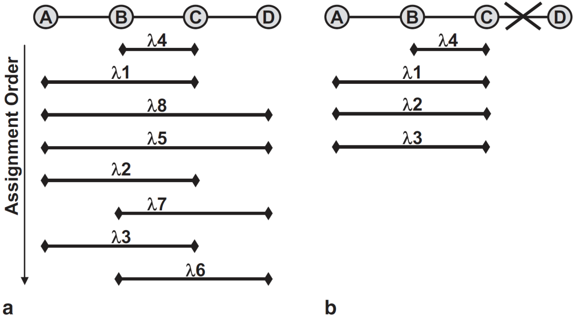

Figure: a Eight connections are added one-at-a-time using first-fit strategy, according to the order $\lambda_4, \lambda_1, \lambda_8, \lambda_5, \lambda_2, \lambda_7, \lambda_3, \lambda_6$. b After Link CD fails, only four connections remain. The wavelength orders are not important as a long-term constraint due to network churn.

Most-used Strategies

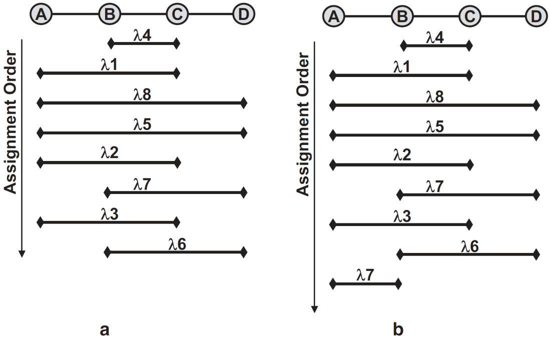

Figure: a Eight connections are added one-at-a-time using most-used strategy, according to the an initial order $\lambda_4, \lambda_1, \lambda_8, \lambda_5, \lambda_2, \lambda_7, \lambda_3, \lambda_6$. b A new connection is added using most-use strategy. In most-use strategy, the wavelength are sorted according to their usage and then, the first-fit strategy is applied to the sorted wavelengths.

Relative Capacity Loss

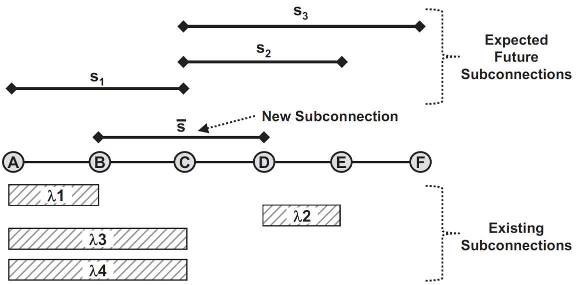

Figure: Setup to illustrate RCL wavelength assignment where the shaded boxes indicate the links on which a wavelength from 4 available wavelengths has already been assigned. λ_1 is selected for $\bar{s}$ because this assignment is less harmful to the expected future sub-connections.

- Number of available wavelengths: $N_1 = 1, N_2 = 3, N_3 = 3$
- Harm metric for λ_1: $C_1 = \frac{0}{N_1} + \frac{1}{N_2} + \frac{1}{N_3} = \frac{2}{3}$
- Harm metric for λ_2: $C_2 = \frac{1}{N_1} + \frac{0}{N_2} + \frac{0}{N_3} = 1$
- Harm metric for λ_3 and λ_4: $C_3 = \infty, C_4 = \infty$

Sub-connection Ordering

Sub-connection Ordering

Several sub-connections for wavelength assignment may be ordered based on

- Link load: the load of the links traversed by the sub-connections
- Sub-connection hop: the number of hops in the sub-connections
- Sub-connection load: the product of link loads of the links constituting the sub-connections
- Sub-connection wavelength availability: the number of available wavelengths that could possibly be assigned to the sub-connections

Bidirectional Wavelength Assignment

Bidirectional Wavelength Assignment

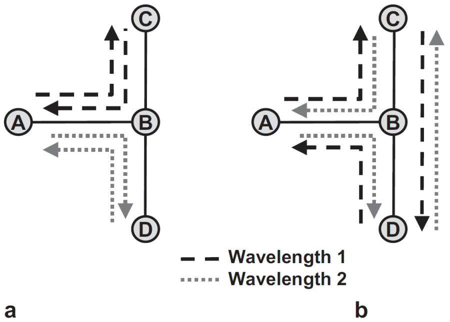

Figure: Assume that there are only two wavelengths supported on a fiber in this small network. a The wavelength assignments for connections AC and AD are both bidirectionally symmetric. If a connection between C and D is added, that connection must undergo wavelength conversion at Node B in order to avoid wavelength conflicts with the existing connections. b Different wavelengths are assigned to the two directions of connections AC and AD. The connection between C and D can be added without any wavelength conversion, as shown.

Miscellaneous Topics

Wavelengths of Different Optical Reach

Optical reach may differ for various wavelength because of

- Different fiber types
- Wavelength-dependent dispersion
- Wavelength-dependent nonlinearity
- Wavelength-dependent network elements
- Nonflat amplification gain and noise figure

Nonlinear Impairments Due to Adjacent Wavelengths

Nonlinear impairments can be managed using

- Power management
- Guard band allocation
- SNR margin
- Precise calculation of optical reach
- Modulation format selection
- Line rate adjustment
- Spectrum partitioning
- Long-haul and short-haul transmission management

The End