EECS 864
Routing in Wavelength Conversion Networks

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Outline

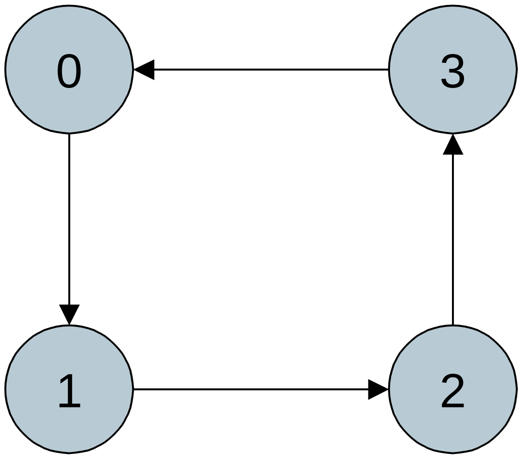
- Introduction to Wavelength Conversion
- Definition of Terms
- Layered Graph Representation of a Wavelength Converting Network
- Dijkstra's Algorithm for Finding Shortest Path
- Shortest Path Algorithm for a Wavelength Graph (SPAWG)
- Dijkstra's Algorithm: An Example
- References
- Homework

Introduction to Wavelength Conversion

- Wavelength conversion can improve network performance by relaxing the wavelength continuity constraint
- Wavelength conversion can be performed by O-E-O or by all-optical means
- All-optical means are in general faster than O-E-O methods. Common methods are four-wave mixing (FWM), semiconductor-optical amplifier gain saturation
- Placing converters in a network requires careful consideration since they are expensive
- Also, studies indicate network performance does not improve significantly beyond a certain number of converters
- Algorithms have been proposed for efficient routing in wavelength conversion networks

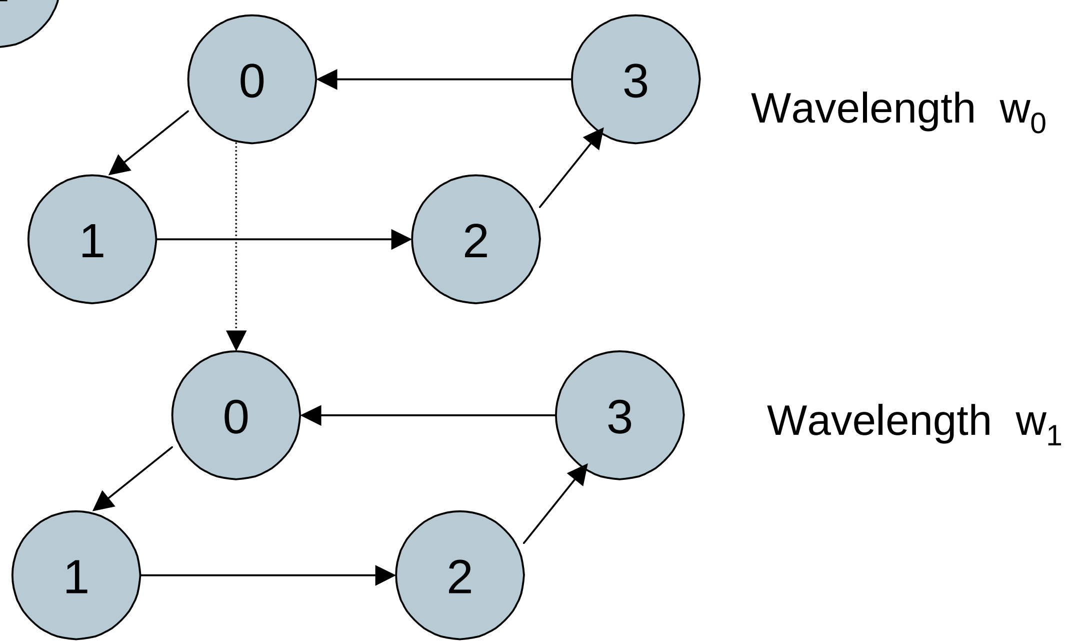
Introduction to Wavelength Conversion

- Example to illustrate use of wavelength conversion



Say, there are two wavelengths/fiber w_0 and w_1. The following routes need to be established: <0,2>, <1,3> and <2,1>. If <0,2> and <1,3> are established using w_0 and w_1 respectively, <2,1> cannot be established at all.

However, if node 0 has a wavelength converter, then <2,1> can also be established.



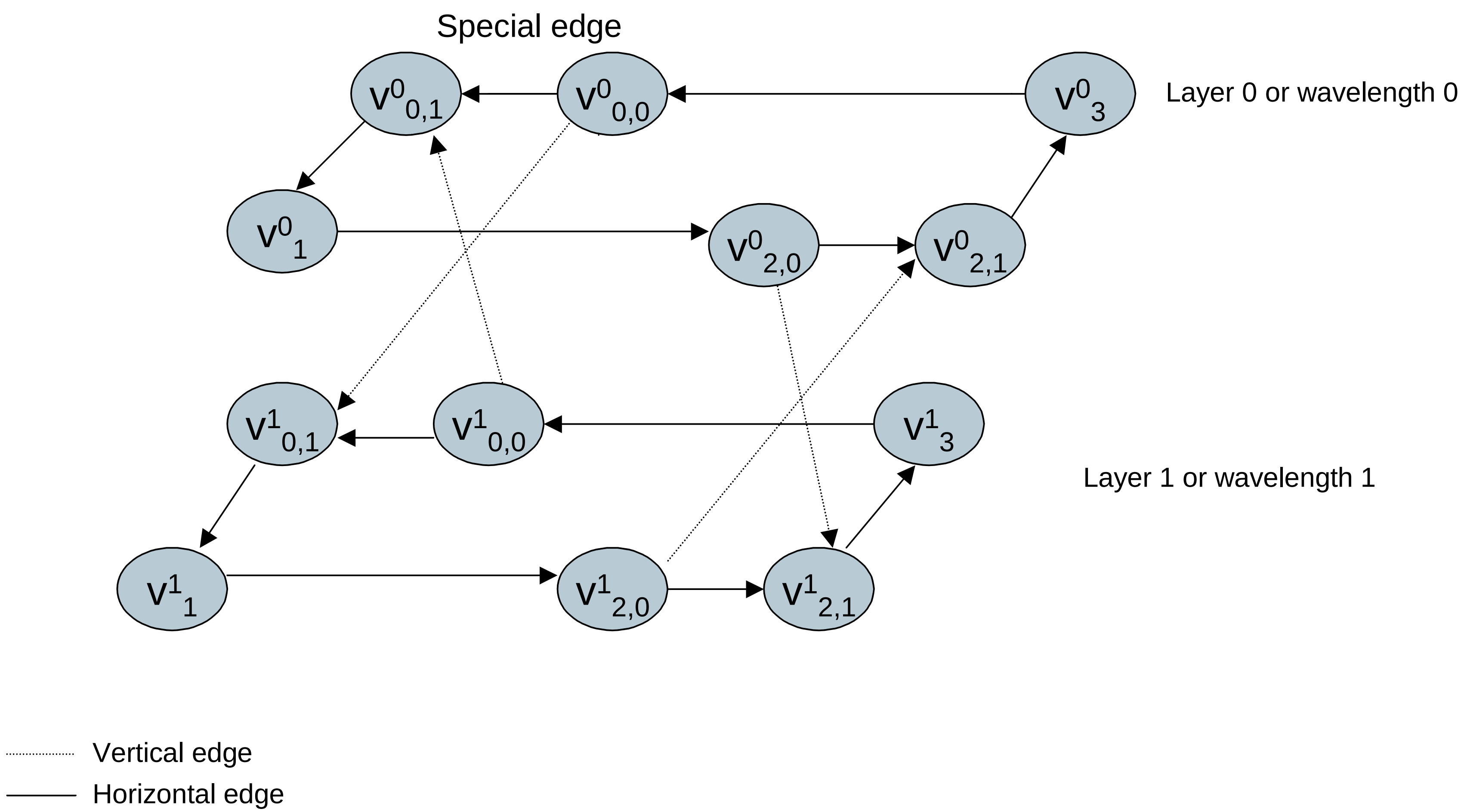
Definition of Terms

- Wavelength converting node: A node with a wavelength converter
- Wavelength selective node: A node without a wavelength converter
- Lightpath: A continuous transmission path between two nodes, without any converting node in between
- Semi-lightpath: A transmission path consisting of a sequence of lightpaths, with at least one converting node present in between
- Permanently labeled node: A node whose shortest path has been found and fixed
- Tentatively labeled node: A node whose shortest path has not been found yet

Layered Graph Representation of a Wavelength Converting Network

- A wavelength converting network can be represented as a layered graph
- A node is represented by a vertex in the graph, denoted as v^i_x : where, "i" is the wavelength and "x" is the node
- Each layer in the graph represents a unique wavelength
- A "directed edge" connects two vertices
- A wavelength converting node is represented using two vertices which are connected by a "special edge"
- A vertical edge connects two vertices in different layers in the graph
- A horizontal edge connects two vertices in the same layer
- A weighting function (usually a cost criterion) is added over each edge. The weight for a special edge is zero.

Layered Graph representation of a Wavelength Converting Network



Dijkstra's Algorithm for Finding Shortest Path

- The Dijkstra's algorithm can be summarized as follows:

  Say we want to traverse from a source node "s" to a destination node "d"

- Initially the source node alone is permanently labeled
- The minimum of all distances from "s" to every other node is found and the minimum distant node (say "y") is permanently labeled
- Next, the distance values of the remaining nodes (other than "s" and "y") are updated:

  $$dist(x) = min[\, dist(x), dist(y)+wt(y,x)]$$

- "wt(y,x)" is a weighting function (usually a cost criterion)
- The above steps are repeated till the node "d" becomes permanently labeled

Shortest Path Algorithm for a Wavelength Graph (SPAWG)

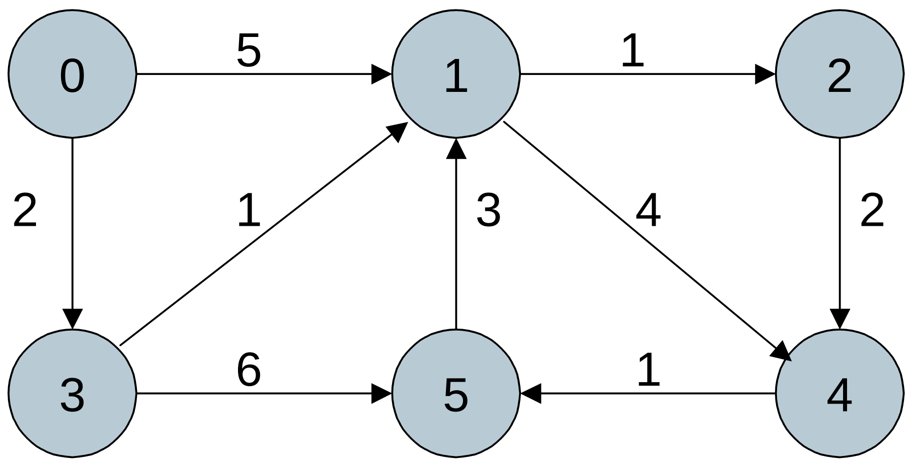
- The SPAWG requires lesser number of iterations than Dijkstra's algorithm
- To start with, the layered graph is represented as a matrix.
- A row in the matrix corresponds to a wavelength (i.e. a layer). Thus, total number of rows in the matrix equals the total number of wavelengths
- A column represents a node in the network. If N_1 is the number of wavelength selective nodes in the network and N_2 is the number of wavelength converting nodes, then the number of columns in the matrix is (N_1+2N_2).

Shortest Path Algorithm for a Wavelength Graph (SPAWG)

- The algorithm to find the shortest paths from “s” to every other node proceeds as follows: (assume “d” is the destination node in each case)

- Form a set R_i which is the the set of minimum distances from “s” to all tentatively labeled nodes in row “i”
- Similarly, form a set C_j (set of minimum distances from “s” to all tentatively labeled nodes in column “j”)
- In order to select “d”, start by examining the set of distances in R_i and C_j (note the difference from Dijkstra’s algorithm). Find the row or column which contains the absolute minimum distance value “m”
- Using “m”, search for the node in the specific row or column and (permanently) label that node as “d”
- Update the distance values for all nodes adjacent to “d” (same way as in Dijkstra’s algorithm)
- Update the set of R_i and C_j
- Proceed with the search till all nodes are permanently labeled

Dijkstra’s Algorithm: An Example



Need to find the shortest path from node 0 to node 5 using Dijkstra’s algorithm :

- To start with, node 0 alone is permanently labeled.
- All other nodes are tentatively labeled using the distances from node 0

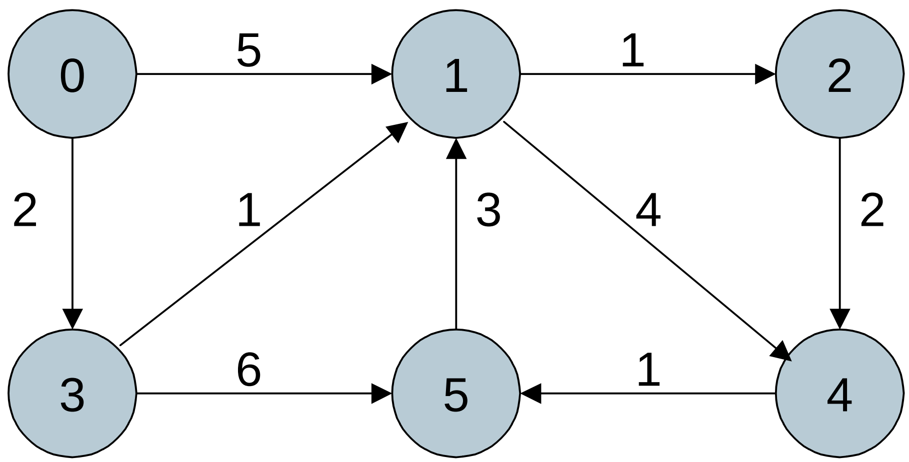
    dist(1)=5, dist(3)=2, dist(2)=dist(4)=dist(5)= ¥

-The shortest path among the tentative nodes is to node 3. Thus, node 3 is permanently labeled

- Distances to adjacent nodes are updated (if needed) :

    dist(1)=3 (via nodes 0-3-1)
    dist(5)=8 (via nodes 0-3-5)
    dist(2)=dist(4)= ¥

Dijkstra's Algorithm: An Example



-Next, among the remaining tentative nodes, node 1 has the shortest distance. It is permanently labeled

-The distances to adjacent nodes are updated (if needed) as:

dist(2)=4 (via nodes 0-3-1-2)

dist(4)=7 (via nodes 0-3-1-4)

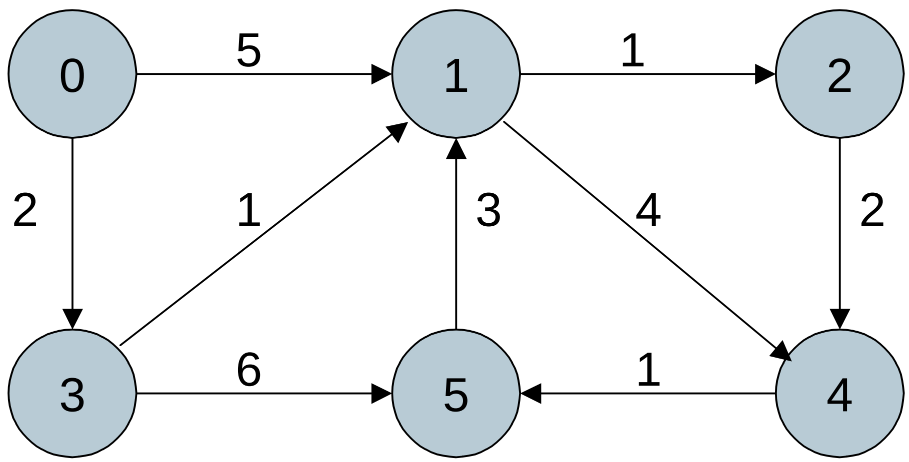
dist(5)=8 (not changed since last update)

-Next, node 2 is permanently labeled and the updates (if needed) are:

dist(4)=6 (via nodes 0-3-1-2-4)

dist(5)=8 (not changed since last update)

Dijkstra's Algorithm: An Example



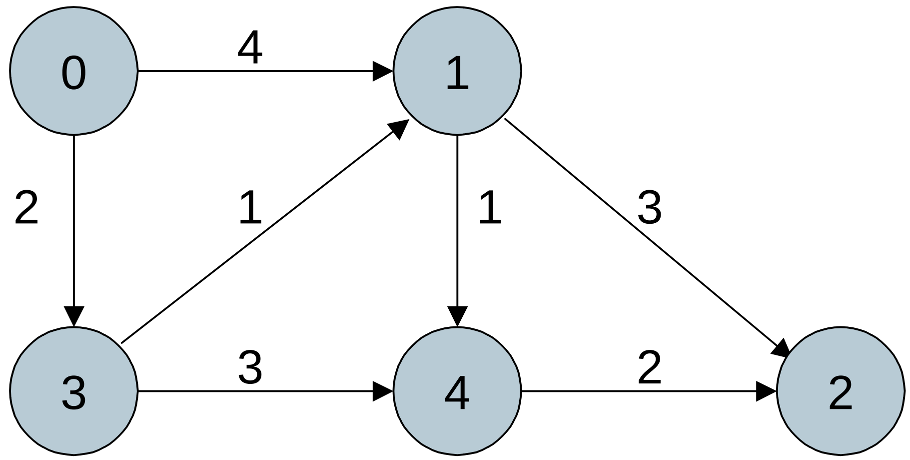
-Next, node 4 is permanently labeled and updates are:
dist(5)=7 (via nodes 0-3-1-2-4-5)
-Now, node 5 is permanently labeled and the algorithm ends since the destination is reached

References

1) C.Siva Ram Murthy and Mohan Gurusamy, *“WDM Optical networks: Concepts, Design and Algorithms,”* Prentice Hall, Upper Saddle River, New Jersey, 2002
2) I.Chlamtac, A.Farago and T.Zhang, *“Lightpath (Wavelength) Routing in Large WDM Networks,”* pp. 909-913, IEEE Journal on Selected Areas in Communications, vol. 14, no. 5, June 1996

Homework

1) For the network shown below, find the shortest path between nodes 0 and 2 using Dijkstra's algorithm



2) In the network above, assume nodes 0 and 4 are wavelength converting. Draw the layered graph representation for the above network if there are two wavelengths per fiber.