A Review of Routing and Wavelength Assignment Algorithms and Some Research Challenges for Optical WDM Networks

by:

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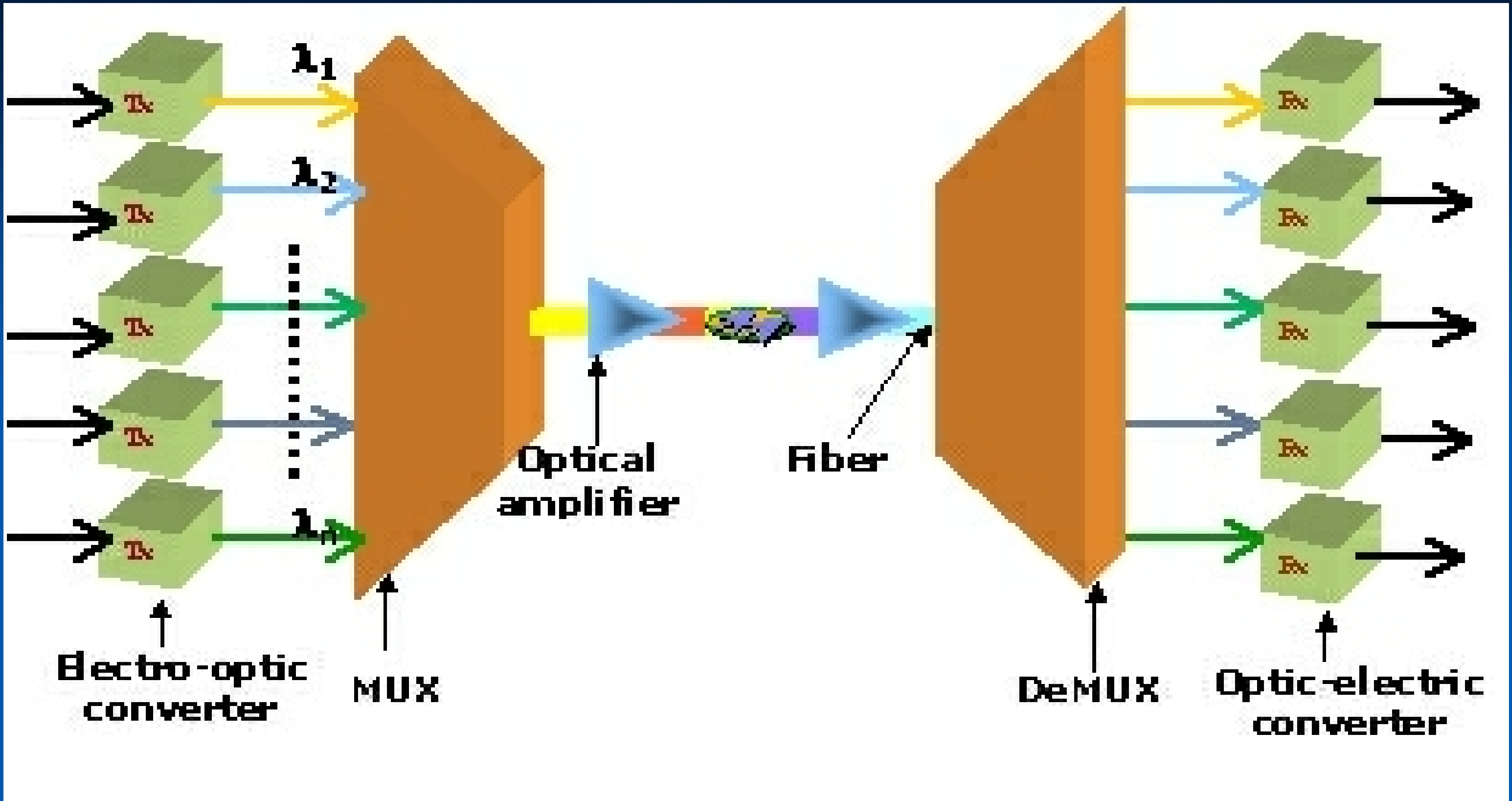
Presentation Breakdown

- Introduction
- Previous Research
  - Off-line Algos
  - On-line Algos
- Current Research
- Future Research Challenges
- Summary
- Conclusion

Introduction

- True power of Internet, WWW & emerging GRID computing can't be unleashed without high capacity optical networks
- WDM in optical networks is the most preferred technology today
  - IP over coarse WDM
  - IP over DWDM

WDM/DWDM

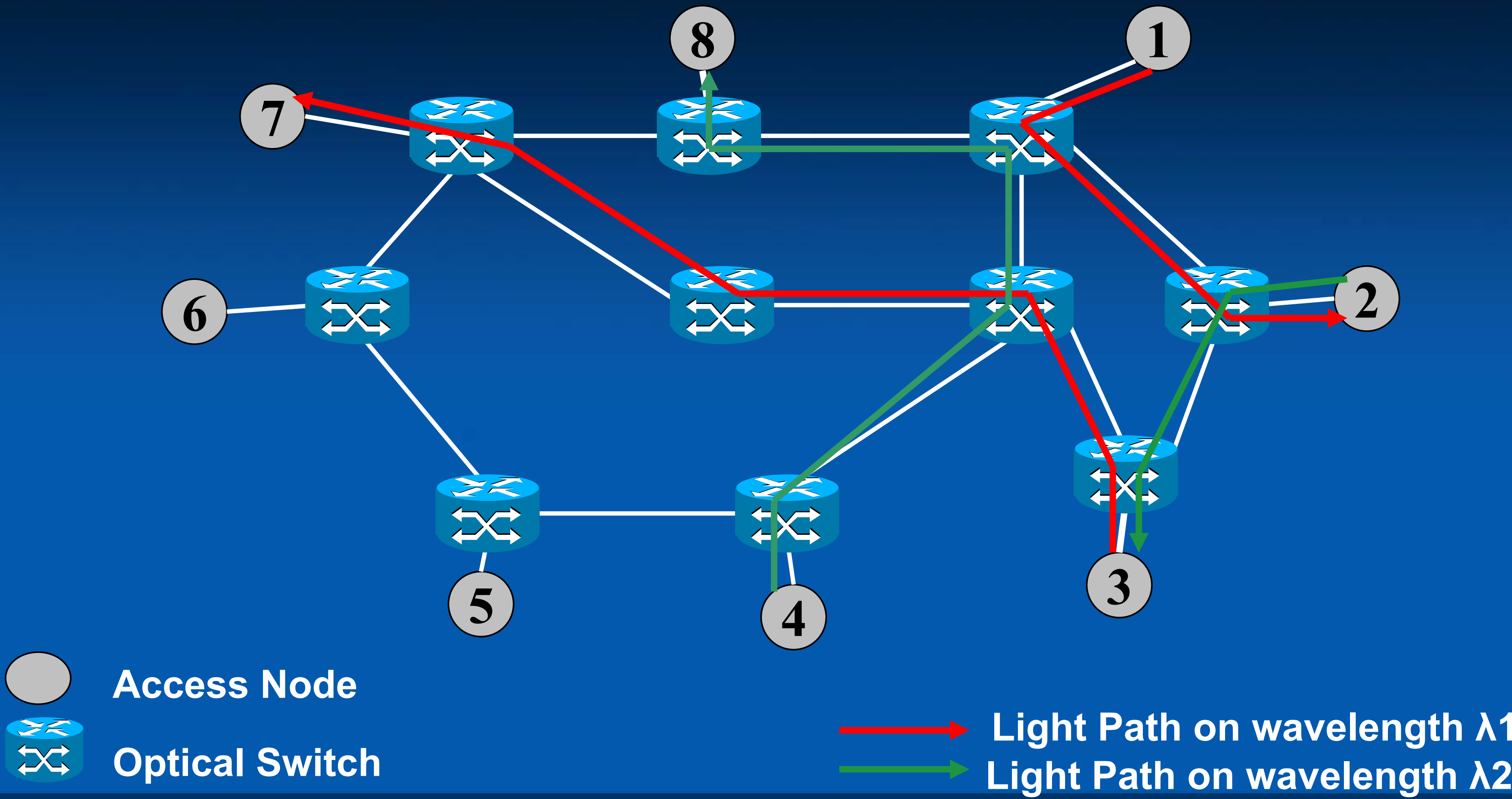


λ1
λ2
λn
Tx
Tx
Tx
Tx
Tx
Rx
Rx
Rx
Rx
Rx
Optical amplifier
Fiber
Electro-optic converter
MUX
DeMUX
Optic-electric converter

WDM/DWDM

- Sends multiple wavelengths on a single fiber in WDM networks
- Provides n times the bandwidth where n is the total no. of wavelengths available on the fiber
- A light path is an all optical path (no O-E-O conversion) from source to destination in wavelength routed networks

Example of Wavelength routed network



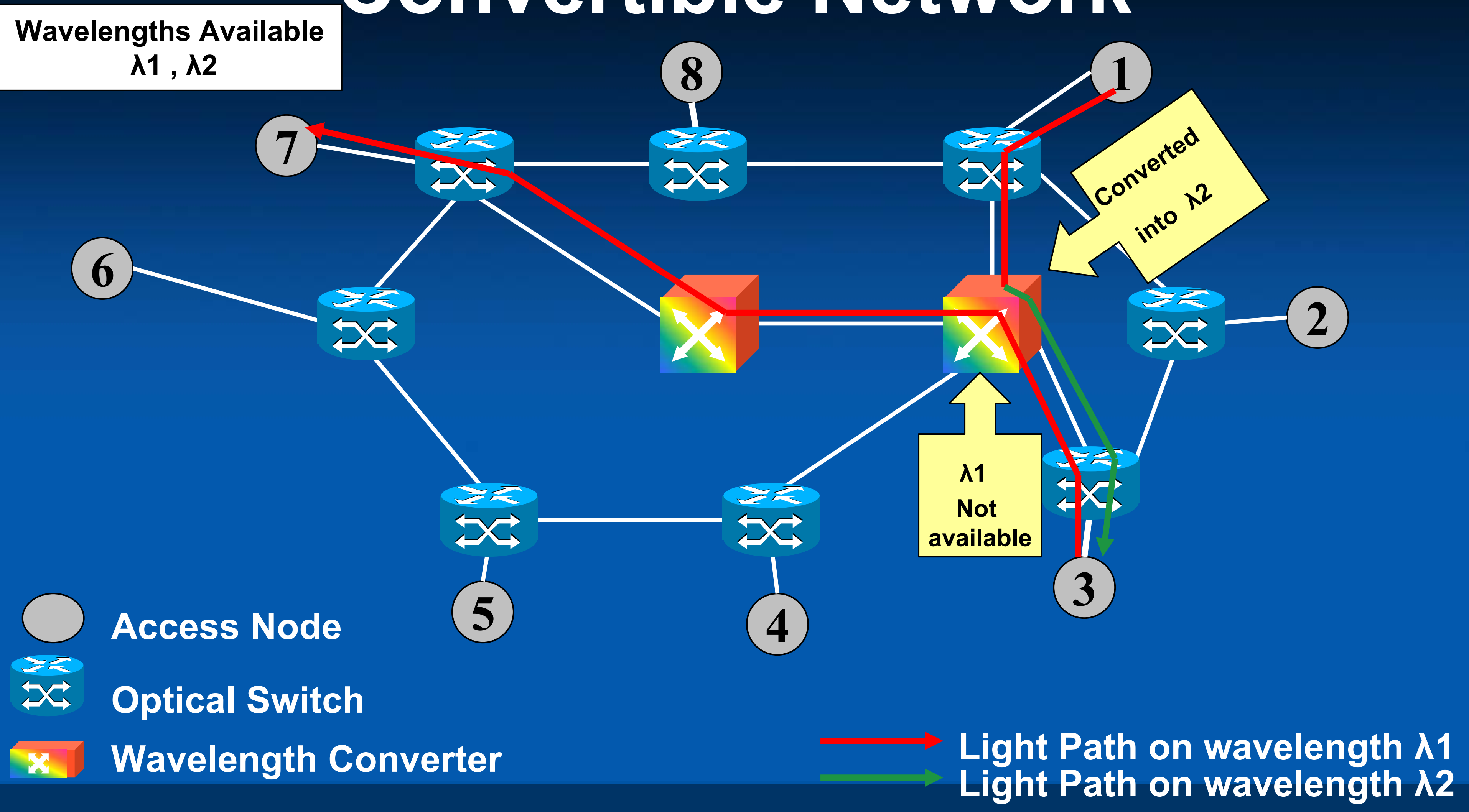
RWA Problem

- WDM networks have some peculiar challenges
  - RWA problem
- Routing and Wavelength Assignment (RWA) problem is defined as:
  - To select the best possible route from source to destination
  - To assign a wavelength to that route so that no two connections on the same link are assigned the same wavelength
  - Wavelength Continuity Constraint requires that a single light path must occupy the same wavelength on all of the links that it spans

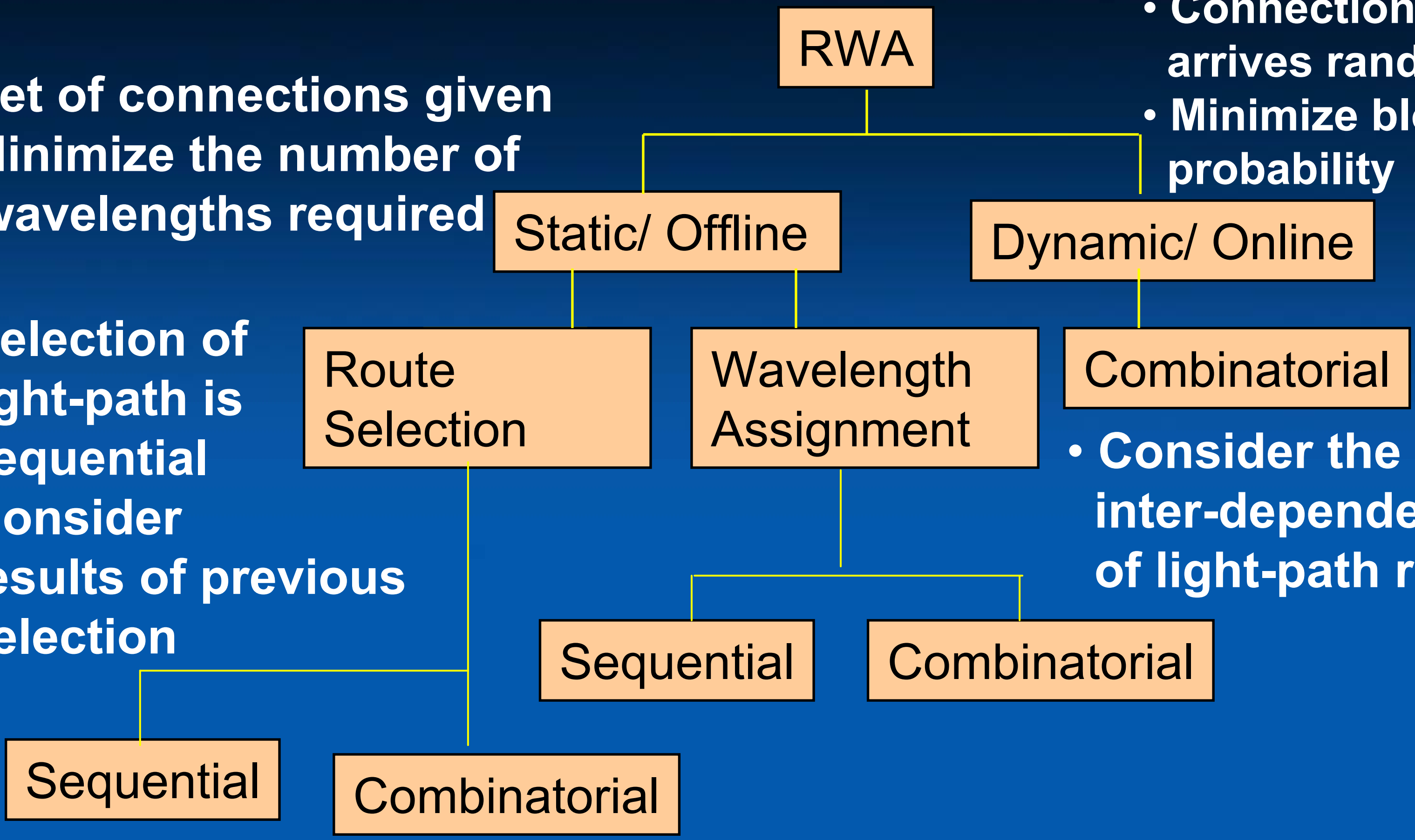
WDM Networks

- Wavelength Selective Network
  - No wavelength conversion
  - Wavelength Continuity Constraint (WCC) is strictly enforced
- Wavelength Convertible Network
  - Allows wavelength conversion on nodes
  - Wavelength Continuity Constraint (WCC) is relaxed either partially or fully
  - Wavelength converters – expensive piece of hardware

Example of Wavelength Convertible Network



Classification



- **Set of connections given**
- **Minimize the number of wavelengths required**

- **Connection request arrives randomly**
- **Minimize blocking probability**

- **Selection of light-path is sequential**
- **Consider results of previous selection**

- **Consider the inter-dependency of light-path routing**

Previous Research

Offline Algorithms

Online Algorithms

Goal for Offline Algorithms

- Minimize network resources
  - Number of wavelengths
  - Number of fibers

OR

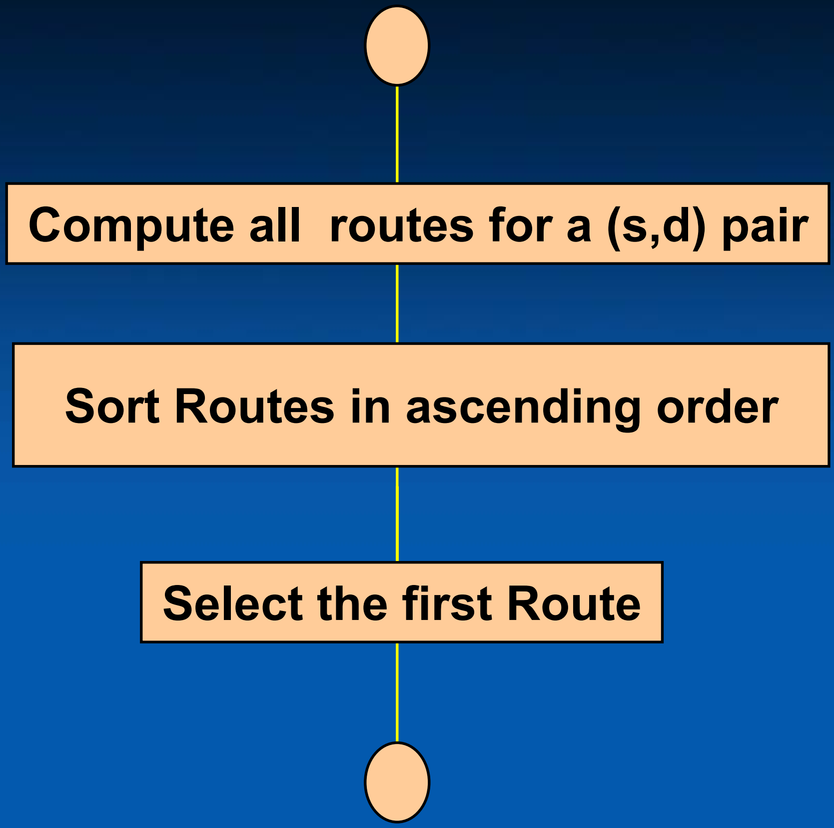
- Setup as many connections as possible for a given fixed number of wavelengths

Offline Algorithms

Route Selection (Sequential)

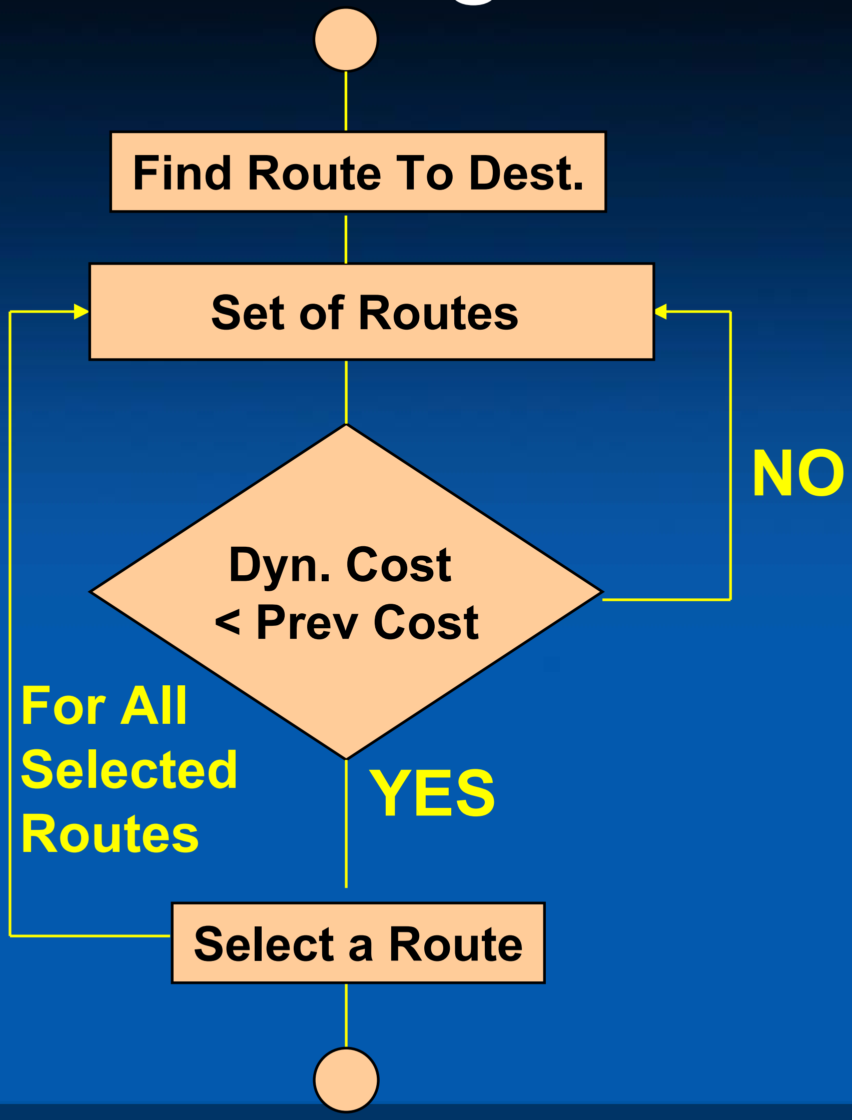
- Shortest Path
- Weighted Shortest Path
- K-shortest Path

Shortest Path



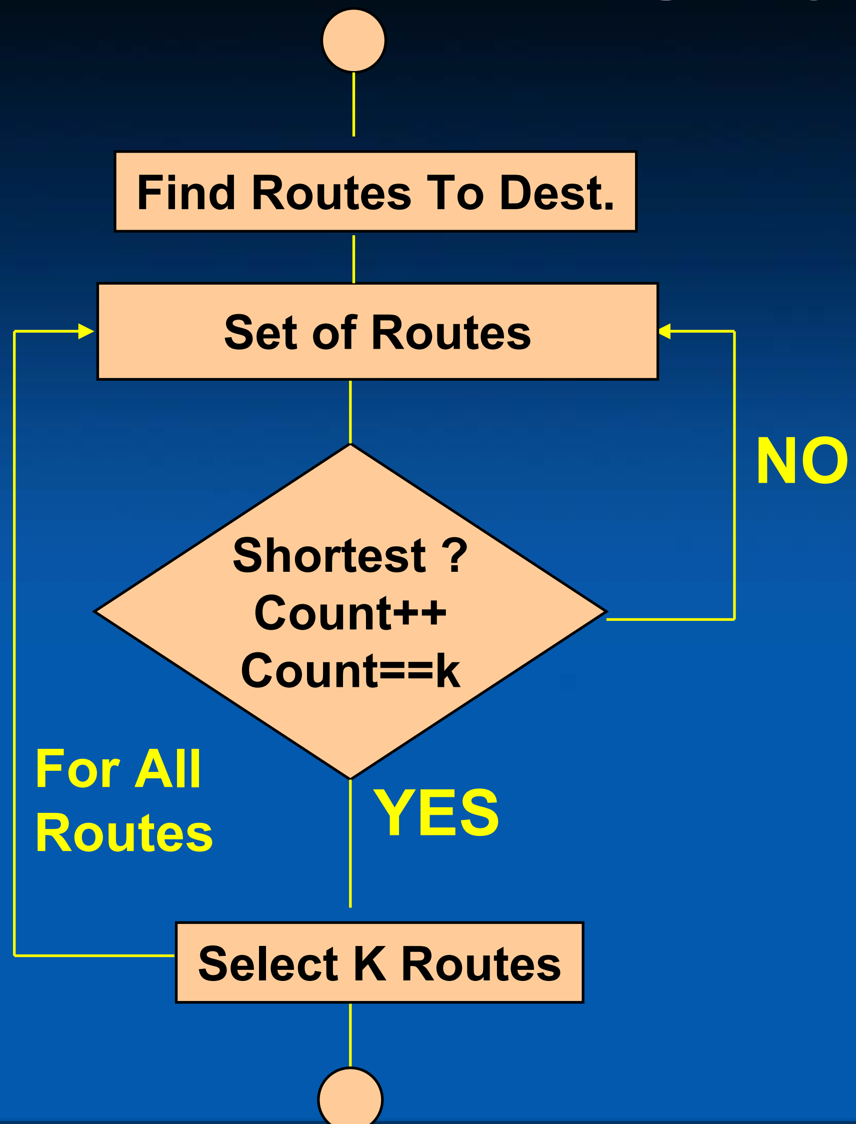
- Route between source & destination
- Cost is less than any other route
- Weights are static
- Generates one route

Weighted Shortest Path



- Shortest path algorithm
- Dynamically changing link cost associated with the number of routes established
- Requires Search Order
  - Largest Traffic First
  - Random

K - Shortest Path



- Shortest path algorithm
- More than one route i.e. k routes
- Flexibility in route selection
- Requires Selection Order
  - Routes are selected to obtain minimum cost
- Fault tolerant

Offline Algorithms

Route Selection (Combinatorial)

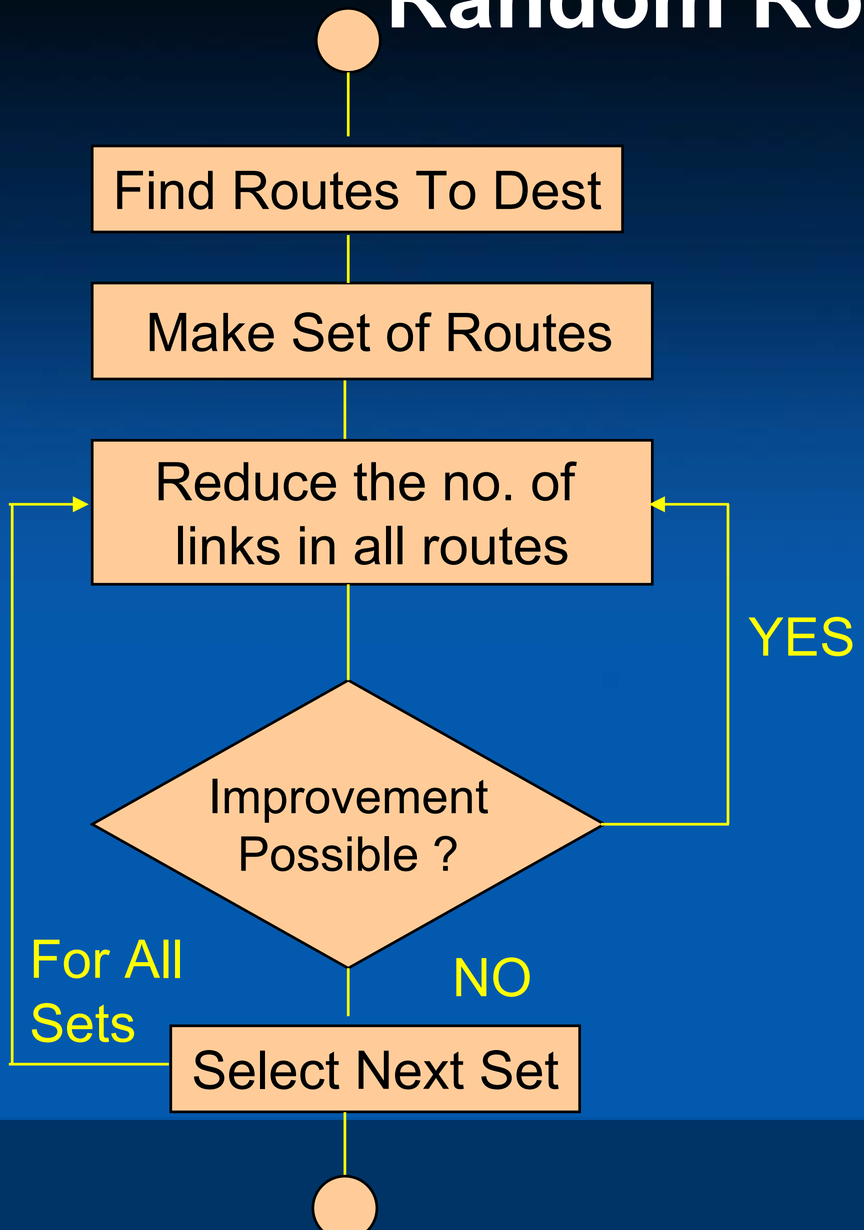
- Mixed Integer Program
- Random Rounding

Optimal Approach

–Mixed Integer Program[2]

- Modeled with the multi-commodity flow problem.
- Extremely difficult in terms of computational complexity.

Heuristic Approach
Random Rounding Algorithm[2]

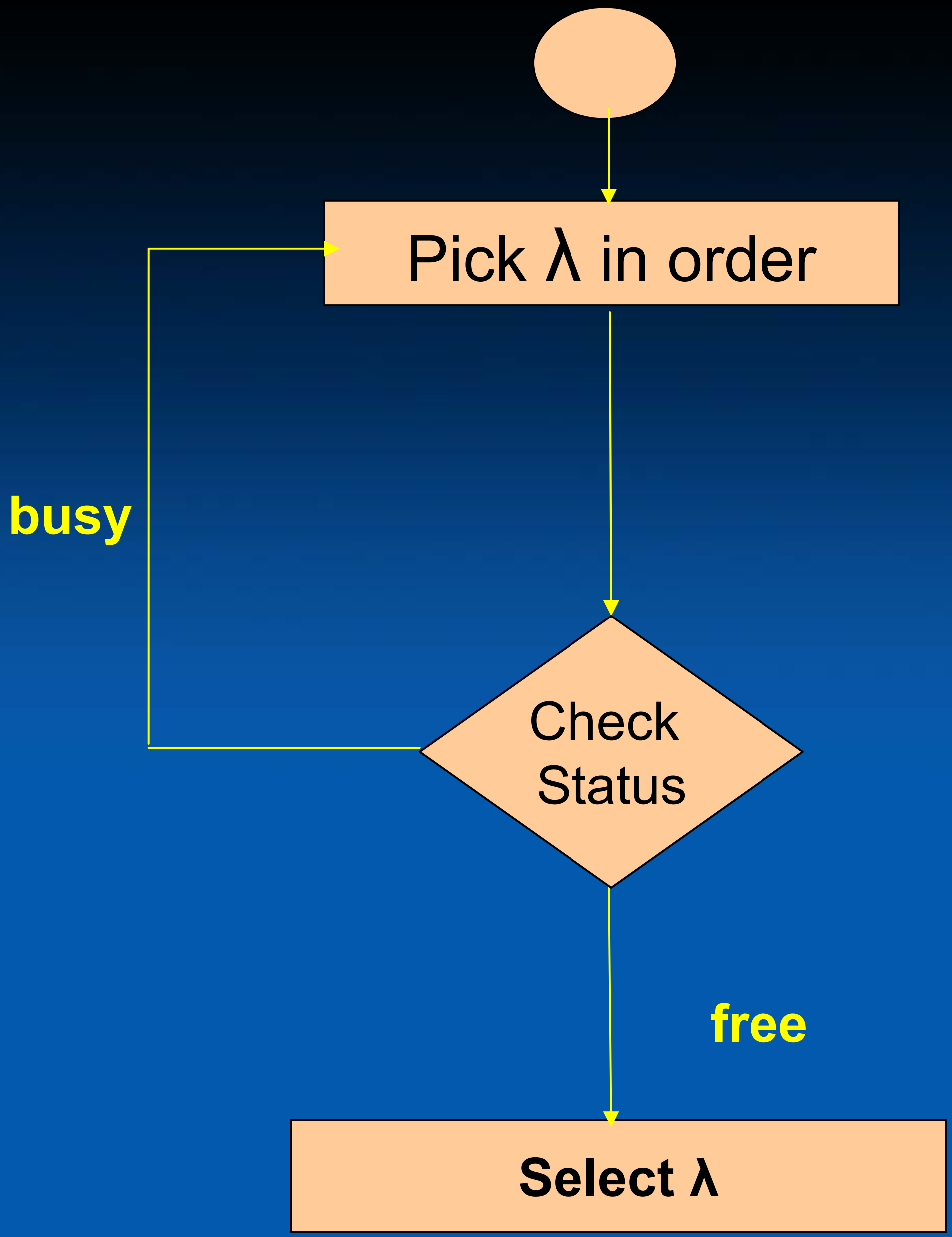


- Routing is performed repeatedly
- Links in routes are decreased
- Process continues till improvements are possible

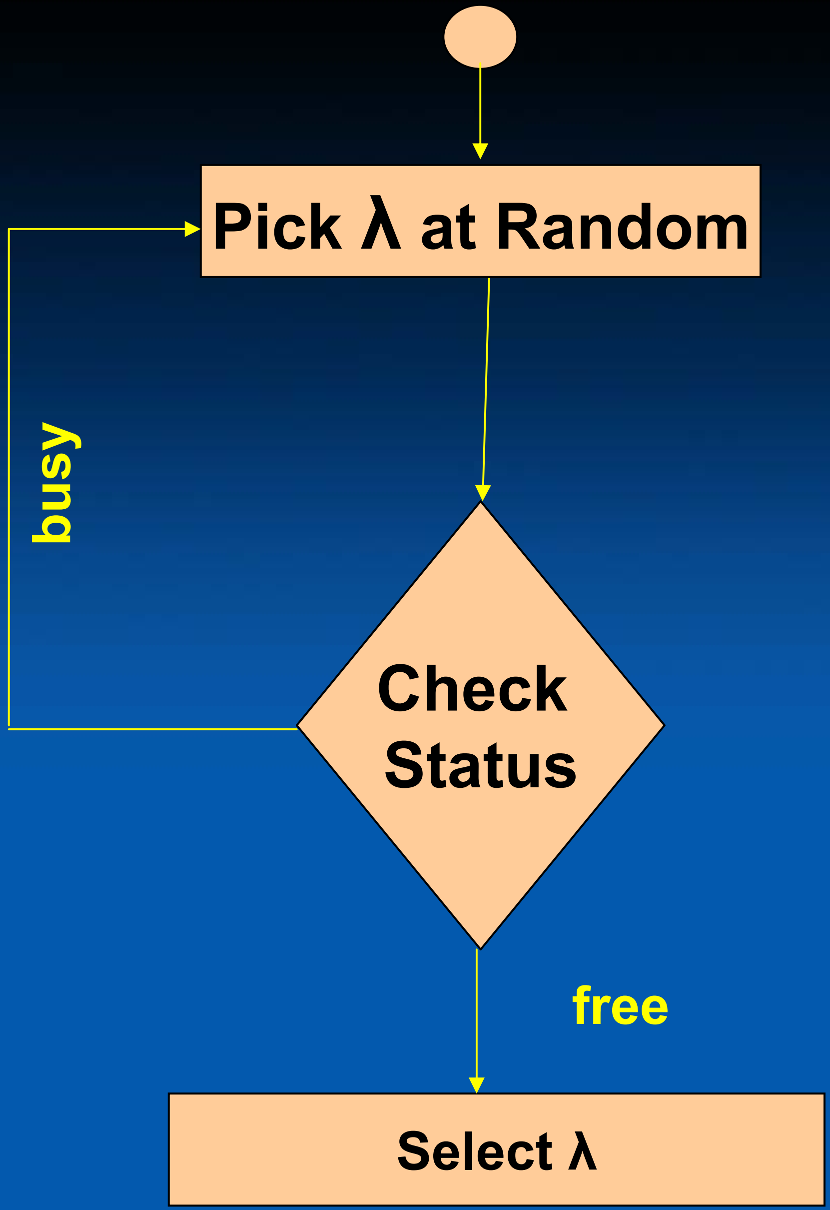
Wavelength Assignment (Sequential)

- First Fit
- Random
- Most-used
- Least-used
- Min-Product
- Least Loaded
- Max-Sum
- Relative Capacity Loss

First Fit



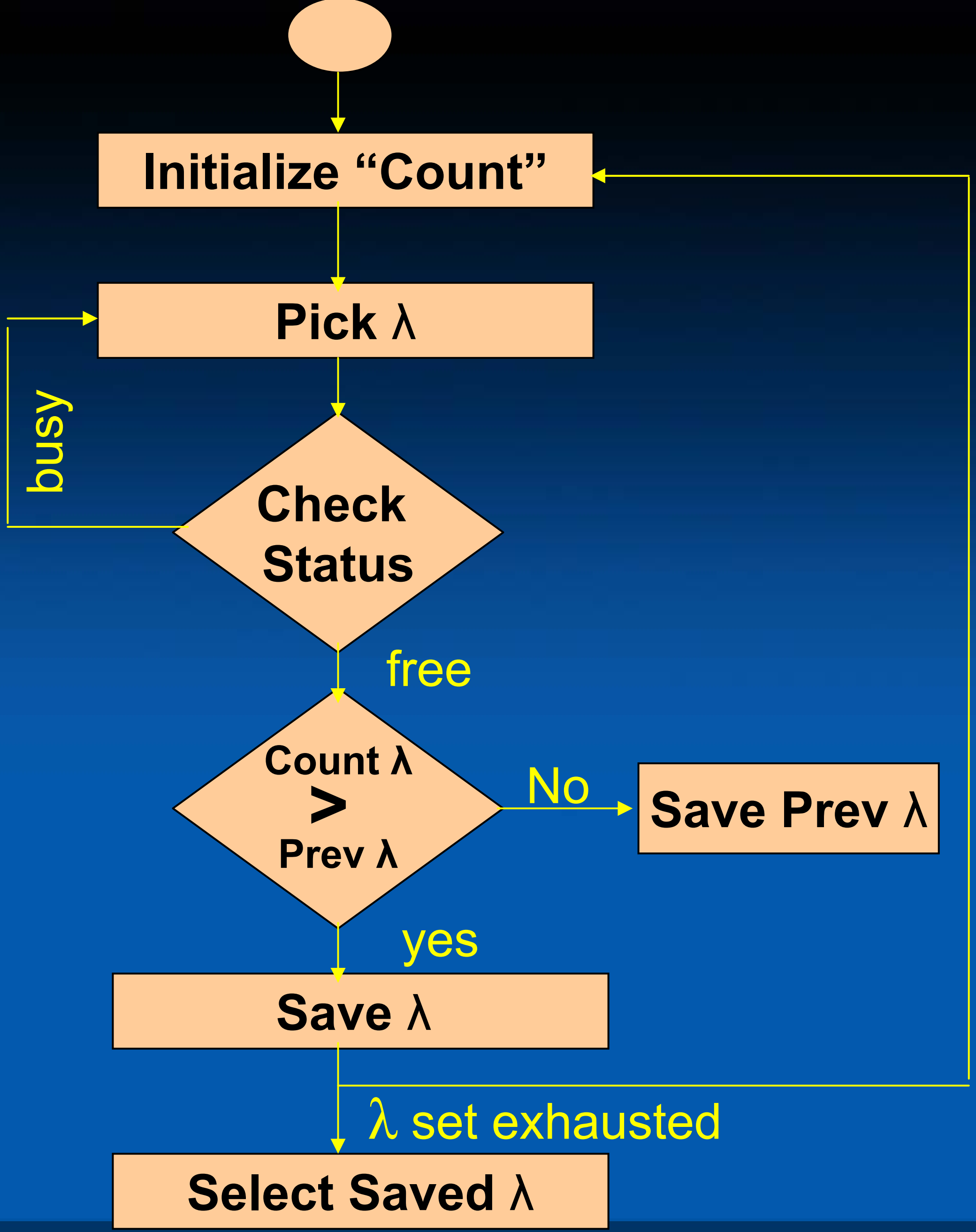
- First available wavelength is chosen
- No global information is needed
- Performs better in terms of Blocking Probability and fairness [4]



Random

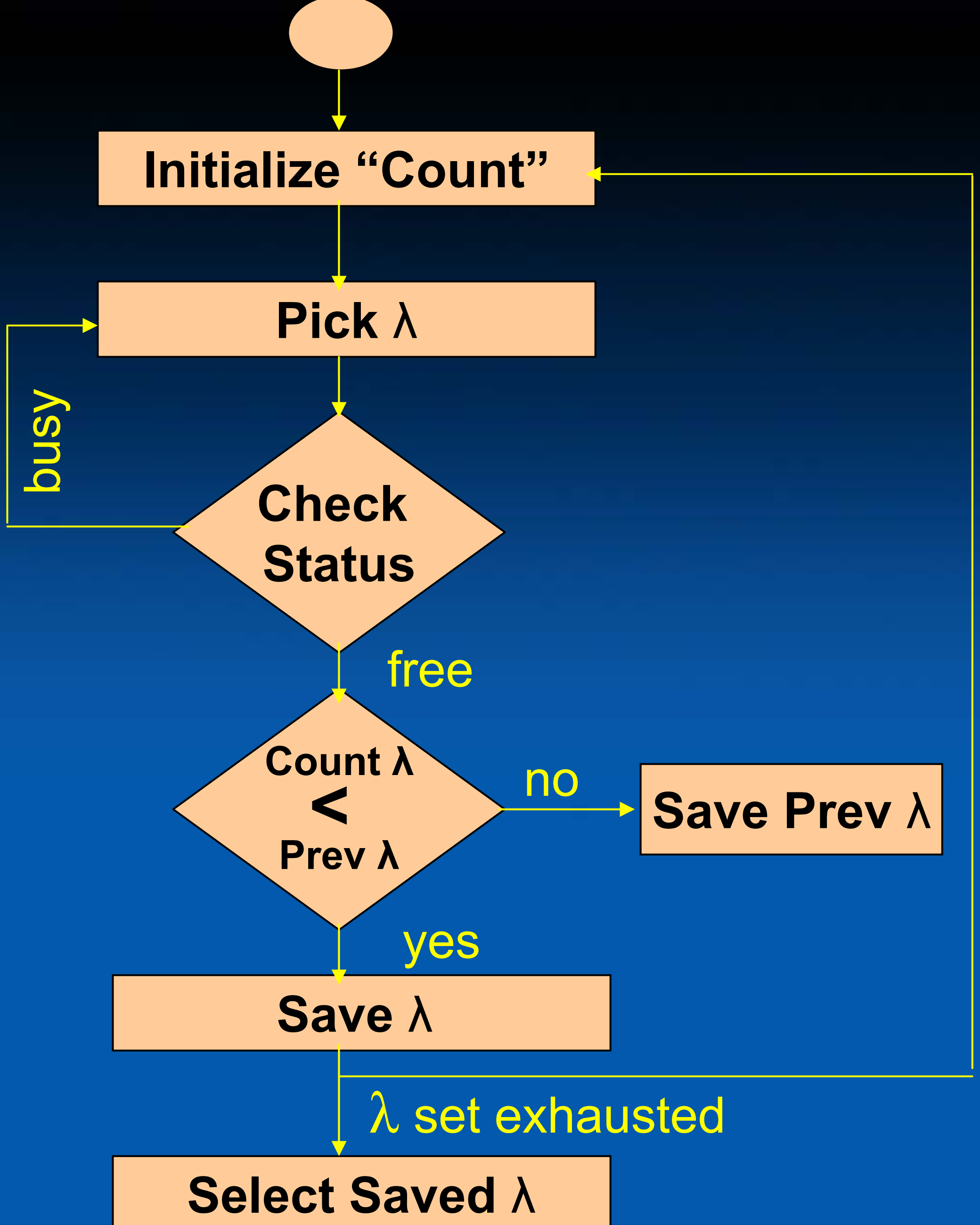
- Wavelength is chosen at random
- No global information needed
- Performs worse than First Fit

Most-used



- Selects most-used wavelength in the network
- Requires network-wide wavelength usage information
- Packs connections into fewer wavelengths
- Slightly better than First Fit algorithm
- Overheads [4]
  - Storage
  - Communication
  - Computation

Least-used



- Selects least-used wavelength in the network
- Requires network-wide wavelength usage information
- Performs worse than random
- Overheads [4]
  - Storage
  - Communication
  - Computation

Multi-Fiber Algorithms

- Min-Product [4]
  - Pack wavelengths into fibers - minimize the number of fibers required
  - Chooses the lowest numbered wavelength
- Least-Loaded [4]
  - Selects the wavelength with the largest residual capacity on the most-loaded link along a route
  - When used in single-fiber networks, it chooses the lowest-indexed wavelength with residual capacity 1
  - It gives best performance in multi fiber case under high load

Multi-fiber Algorithms

- Max-Sum [4]
  - Considers all possible lightpaths and attempts to minimize the total capacity loss on all lightpaths
  - Also applicable in single-fiber networks
  - It work well when the load is high in both single and multiple fiber case
- Relative Capacity Loss [4]
  - Based on Max-Sum
  - Considers all possible lightpaths and attempts to minimize the relative capacity loss on all lightpaths

Offline Algorithms

Wavelength Assignment (Combinatorial)

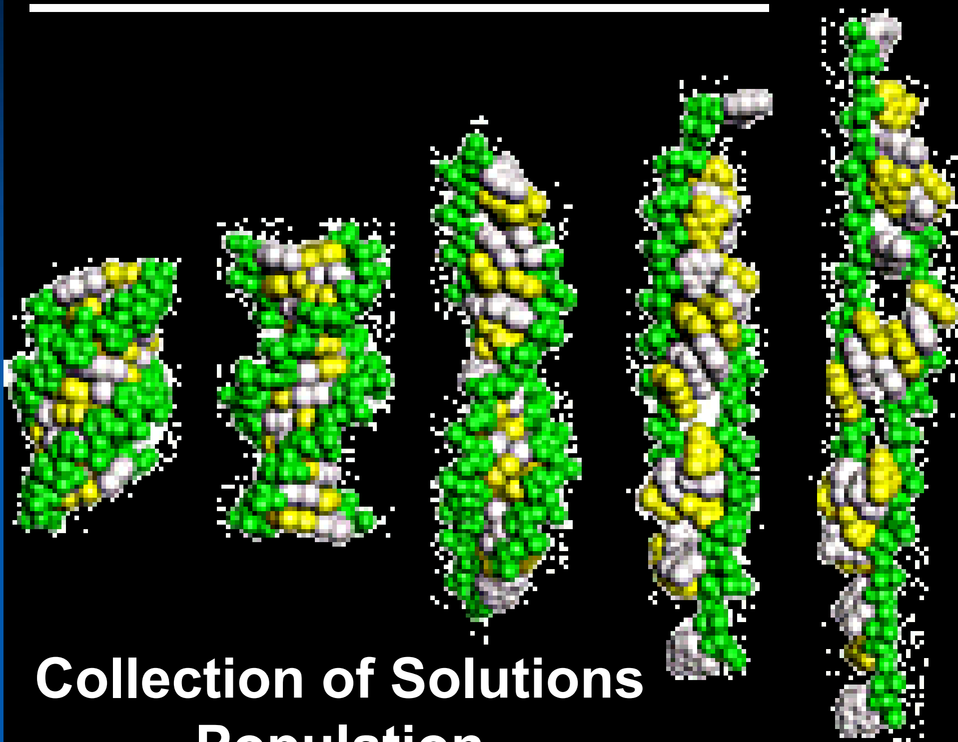
- Exhaustive Search
- Genetic
- Simulated Annealing
- TABU

Optimal Approach
Exhaustive Search[2]

- In graph coloring problem, graph is constructed such that each lightpath in the system is represented by a node in graph.
- There is an undirected edge between two nodes in graph if the corresponding lightpaths pass through a common physical fiber link.
- Color the nodes of graph such that no two adjacent nodes have the same color
- Generates best coloring results
- Cannot handle considerably large graphs
- Computationally intensive

Heuristic Approach
Genetic Algorithm[2]

Survival of the fittest

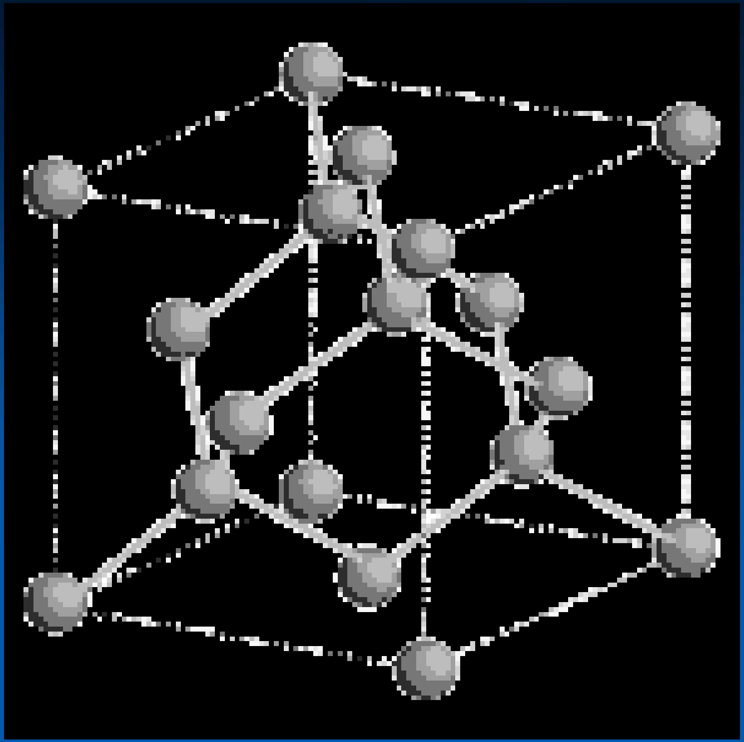


Collection of Solutions
Population
Randomly Created

- Solution - *string of genes*
- Moving from one generation to other, fitness of each gene is recorded
- Genes with higher fitness level produce offspring
- Genetically inherit the best characteristics of its parents

Heuristic Approach

Simulated Annealing Algorithm[2]

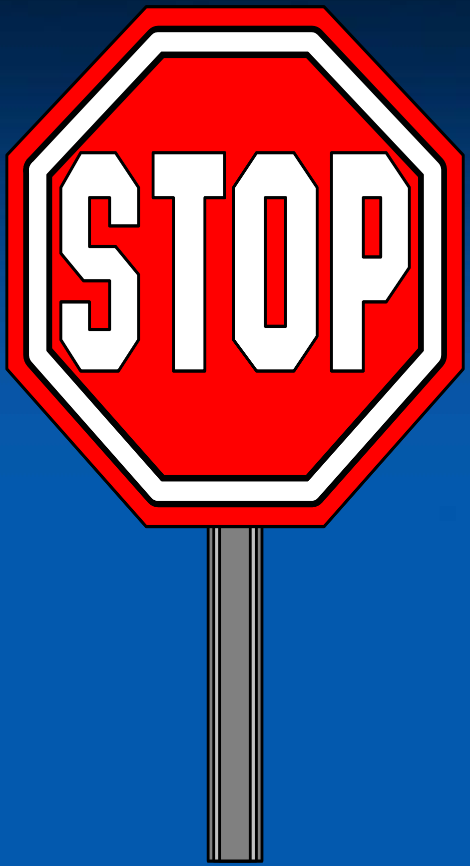


- Crystal - state of minimum energy
- Sub optimal and optimal solutions are found by iterative improvements
- Avoid traps at local minima
- Random search which accepts changes that decrease as well as increase the objective function

An Analogy

Metal cools and freezes into a minimum energy crystalline structure and search for an optimum solution

Heuristic Approach
TABU Algorithm[2]



- Extensive search - to find all possible and feasible solutions
- Iterative in nature
- Avoid the loops and achieve globally optimal solutions, some steps are restricted i.e. forbidden - TABU
- Sub optimal solutions are improved, refined - reaching an optimal solution

Goal for Online Algorithms

- Objective is to minimize blocking probability

OR

- Maximize the number of connections established

Online Algorithms

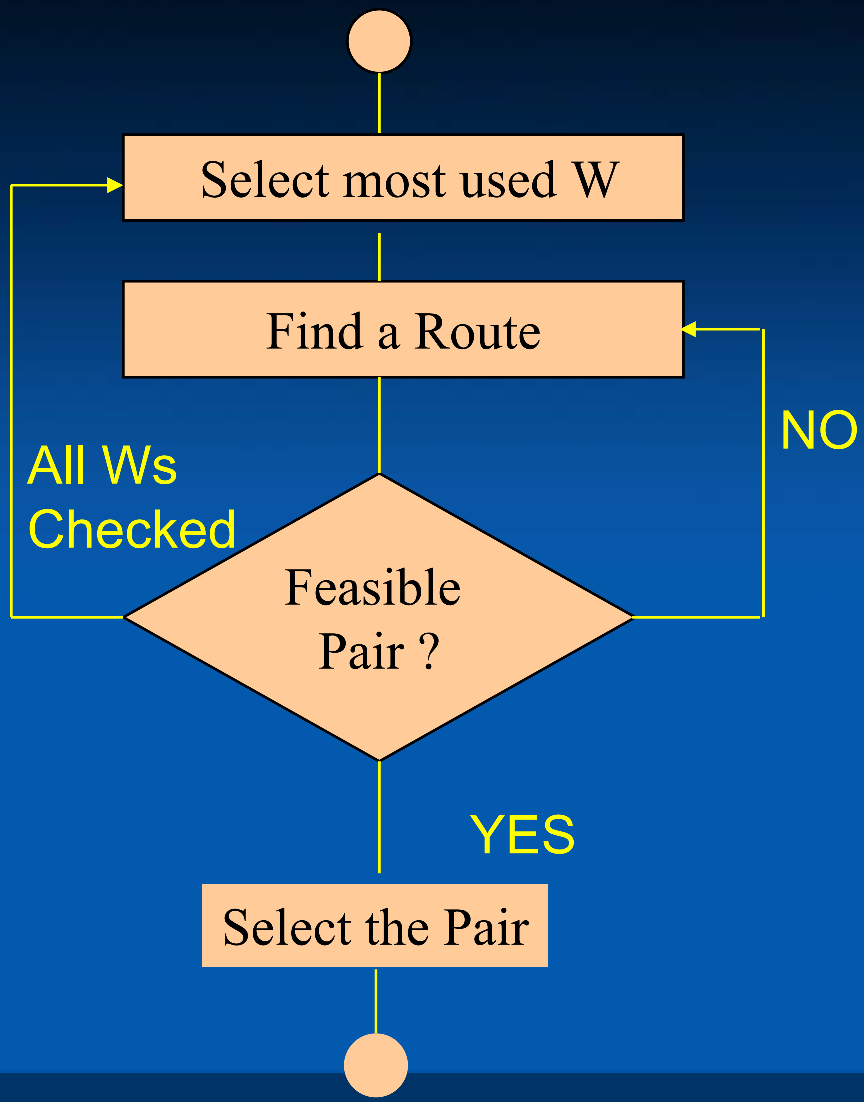
Combinatorial Approach

- Adaptive Unconstrained Routing

On-Line Approach

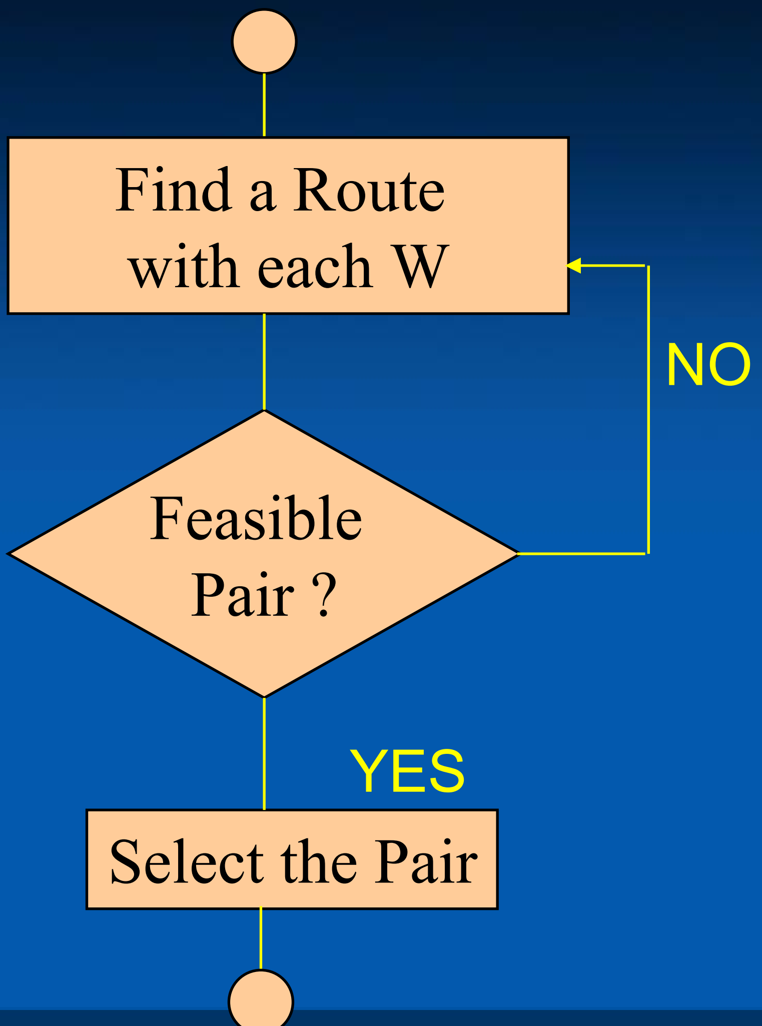
- Connections Requests arrive dynamically
- Combinatorial Algorithms
  - Optimal Approach
    - Not proposed as of yet
  - Heuristic Approach
    - Adaptive Unconstrained Routing

Adaptive Unconstrained Routing



- **AUR-Pack Algorithm[2]**
  - Sort wavelengths according to their use
  - Dynamically search routes
  - Check all feasible pairs
  - Selects the most appropriate
  - There is no need to store possible routes

Adaptive Unconstrained Routing



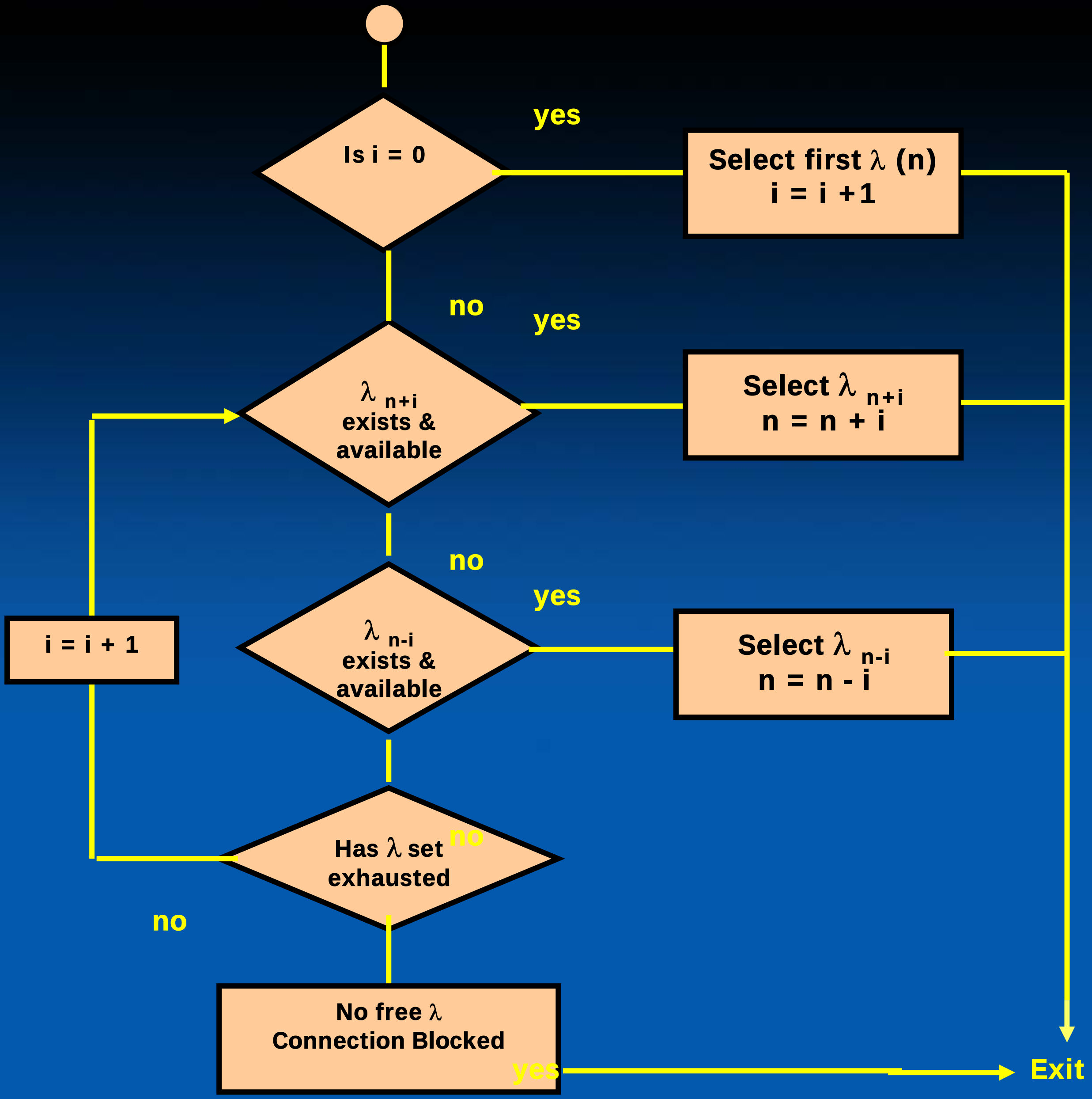
- **AUR-Exhaustive[2]**
  - Search for route based on current state of the network
  - Find route with each wavelength
  - Choose the shortest
  - There is no need to store possible routes

Current Research

- Closest Wavelength Tuning (CWT)
- Enhanced Weighted Least Congested Routing (EWLCR)

Closest Wavelength Tuning Algorithm

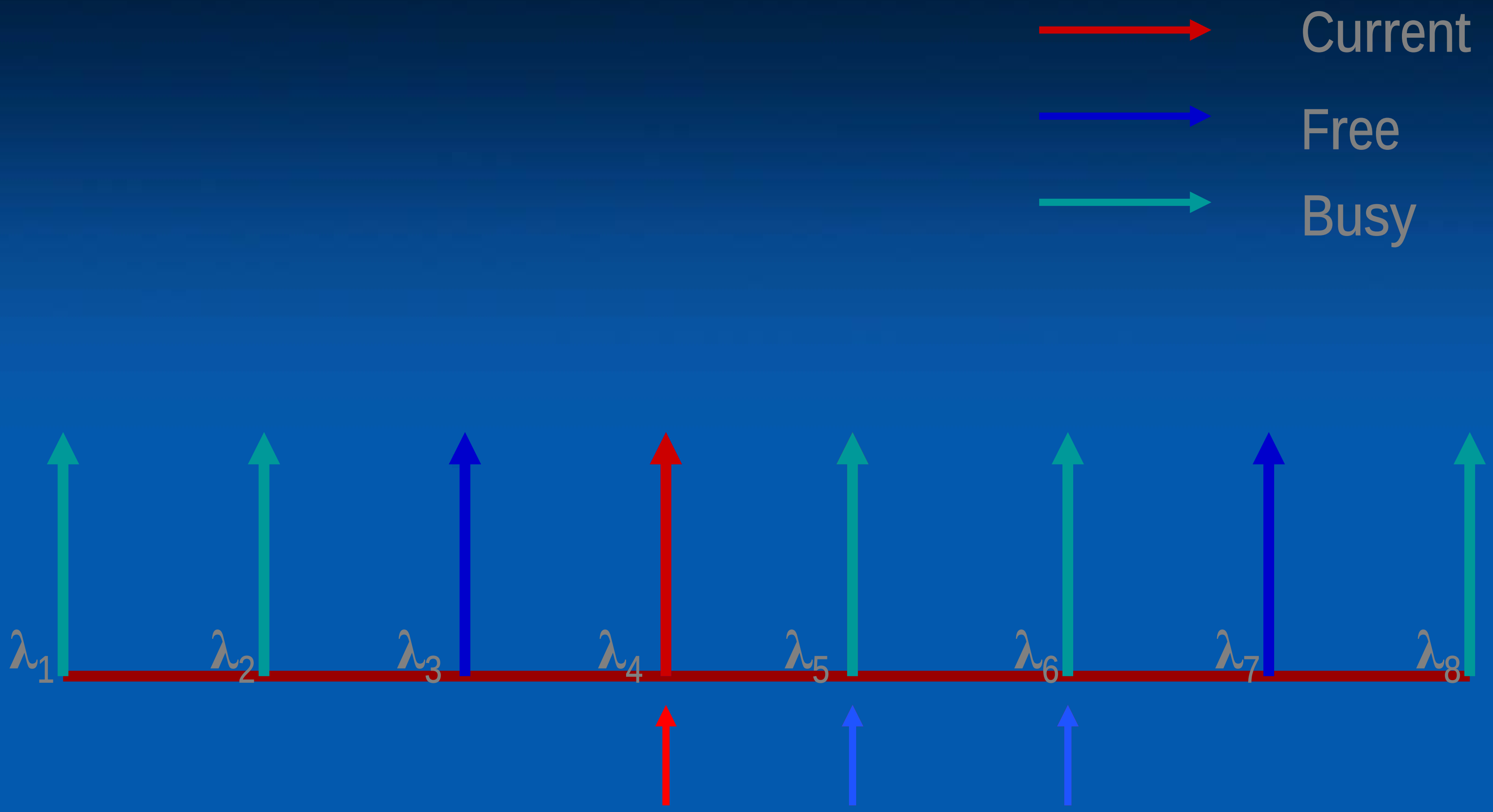
- Keep in view practical constraint of wide tuning.
- For continuous wavelength tuning scenarios
  - Laser can be tuned to any λ from the whole set of available λs
- Offline algorithm



Salient Features

- Cost-effective Sequential WA algorithm
- Picks closest wavelength to the current wavelength

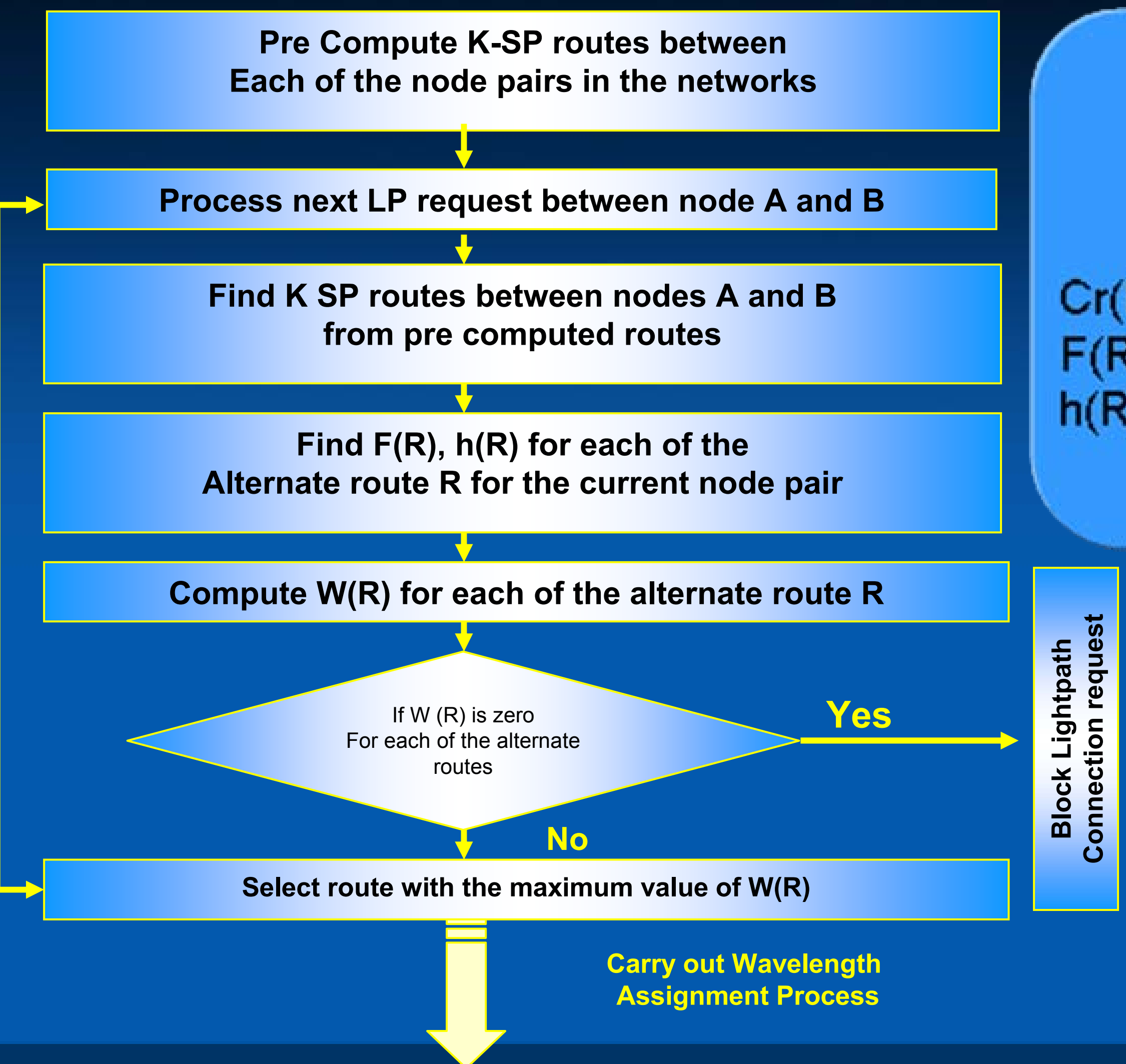
Working of CWT



Motivation - EWLCR

- Most current routing algorithms are designed for networks with no wavelength conversion capability (SPR,FAR,LLR) and do not work well for networks with sparse or full wavelength conversion[5]
- Reason for this mediocre performance is absence of joint consideration of all the performance parameters for making a routing decision
- Current routing algorithms must be re evaluated to devise an efficient solution for wavelength convertible networks [6][7]

Routing Algorithm - EWLCR



$$W(R) = \frac{F(R)^{1.5}}{\sqrt{h(R)} * Cr(R)^2}$$

Cr(R) = Criticality Weight of route R
F(R) = no of free wavelengths in route R
h(R) = number of hops in route R

Some Conclusions

- EWLCR shows noticeable blocking performance improvement over existing algorithms in sparse and full wavelength conversion scenarios
- Relative Blocking Reduction is dependent on the network topology, wavelength conversion scenario and network load
  - 10% - 23% (NSF Net)
  - 11% - 21% (Mesh Tourus Network)
  - 21% - 25% (Ring Network)
- Communicational overhead is no more than LLR and WLCR (only free wavelength distribution information is need to be exchanged between the nodes)

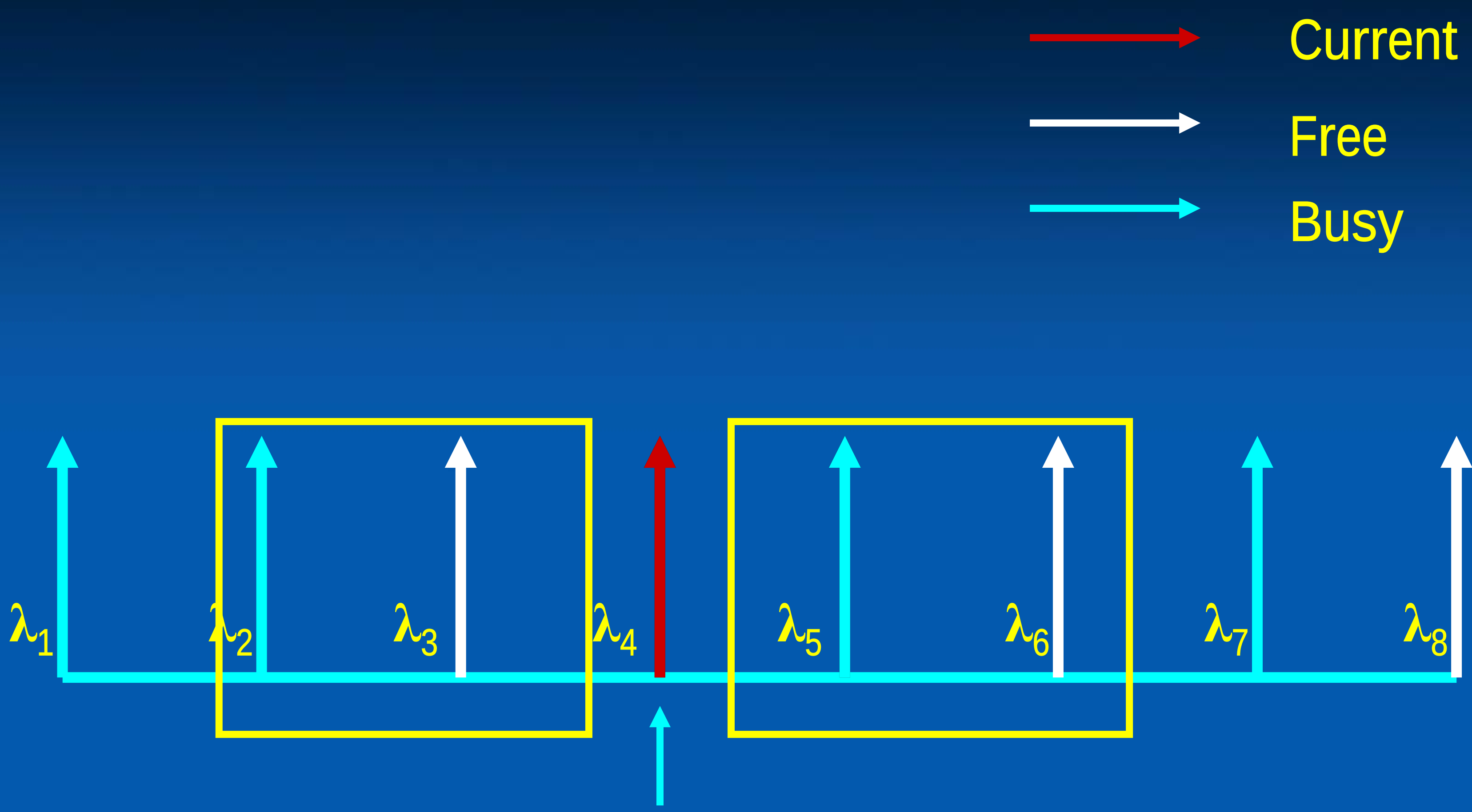
- Communicational overhead is no more than LLR and WLCR (only free wavelength distribution information is need to be exchanged between the nodes)

Future Research Challenges

Some Future Research Challenges

- Combinatorial solutions are computationally intensive
- The dynamic optimal RWA algorithms are yet to be discovered
- RWA algorithm keeping in view the practical constraints of tunable light sources
- Explore hybrid approach to combine benefits of various existing solutions

Hybrid Approach



Some Future Research Challenges

- Performance evaluation of the EWLCR under other wavelength assignment schemes (Most Used, Random Fit etc.)
- Performance evaluation using more sophisticated converter placement algorithms such as WMSL, MBPF in case of sparse conversion environment

Summary

Offline RWA Algorithms

- Route Selection
  - Sequential Approach
    - Shortest Path
    - Weighted Shortest Path
    - K-Shortest Path
  - Combinatorial Approach
    - Optimal
      - Mixed Integer Program
    - Heuristic
      - Random Rounding Algorithm

- Wavelength Assignment
  - Sequential Approach
    - First-Fit - Random
    - Most Used - Least Used
    - Min-Product - Least Loaded
    - Max-Sum - Relative Capacity Loss
  - Combinatorial Approach
    - Optimal
      - Exhaustive Search
    - Heuristic
      - Genetic Algorithm
      - Simulated Annealing Algorithm
      - TABU Algorithm

Online RWA Algorithms

- Combinatorial Approach
  - Heuristics
    - Adaptive Unconstrained Routing
      - AUR-Pack Algorithm
      - AUR-Exhaustive Algorithm

Current Research

- Closest Wavelength Tuning (CWT) algorithm
- Enhanced Weighted Least Congested Routing (EWLCR)

Future Research Challenges

- Hybrid Approach
- EWLCR extensions
- Complex Adaptive System

Conclusion

- Maximum benefits of WRN can be reaped by effectively solving the RWA problem
- Sequential Approaches for both search and selection are simple and efficient - usually used
- More work needs to be done on combinatorial approaches to improve their computation speed
- Identified some promising future research directions

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