# Discrete optimization for optical networks

Alexey Ivanov

Research Engineer

Mathematical Modeling & Optimization Algorithm Competence Center

www.huawei.com

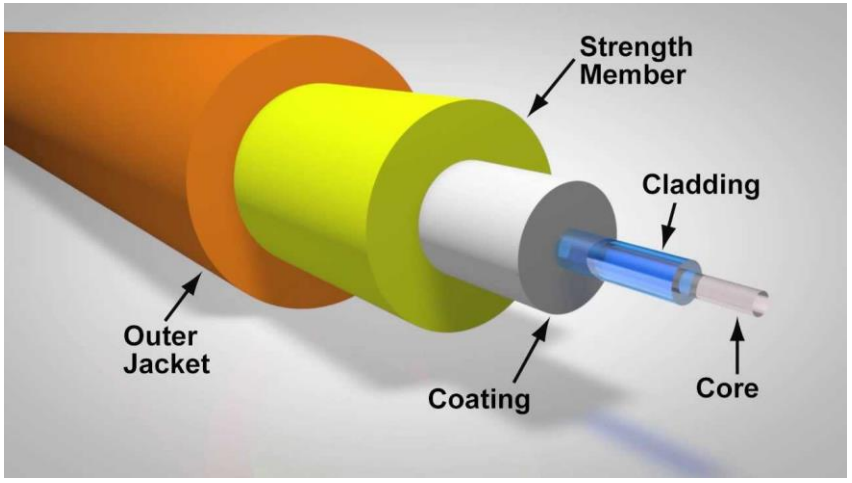


HUAWEI

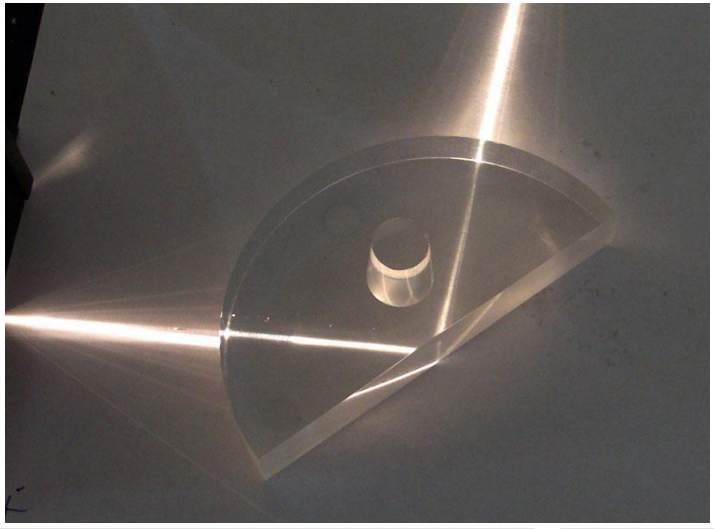
# Contents

# Optic fibers

- Signal is transferred by light path inside optic fiber

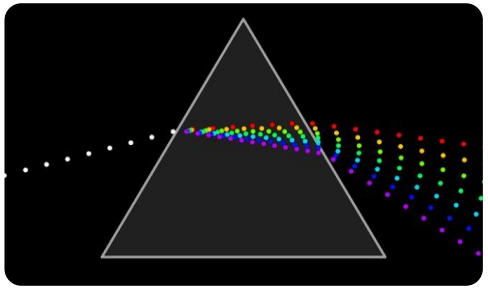


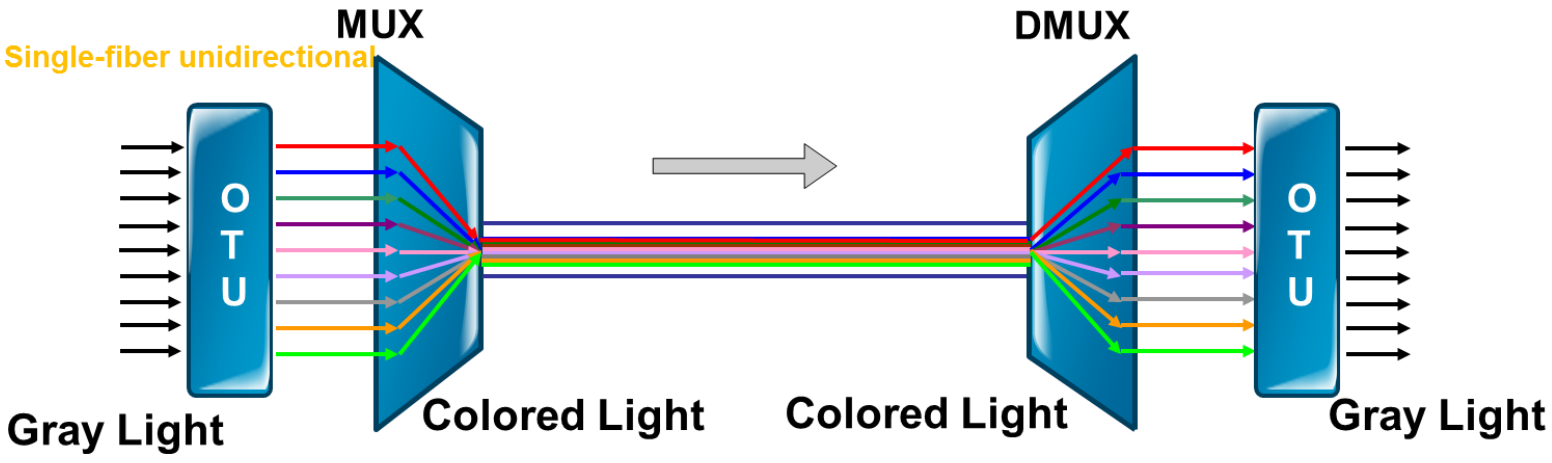

- Light path spreads along fiber because of total internal reflection which happens due to different indices of refraction



# Wavelength Divison Multiplexing (WDM)

- At present, one optic fiber can carry several signals
- This is achieved by multiplexing of these signal to one light path and then de-multiplexing of this light path into corresponding spectrum
- This function is performed by reconfigurable optical add-drop multiplexer (ROADM)





# Mathematical model

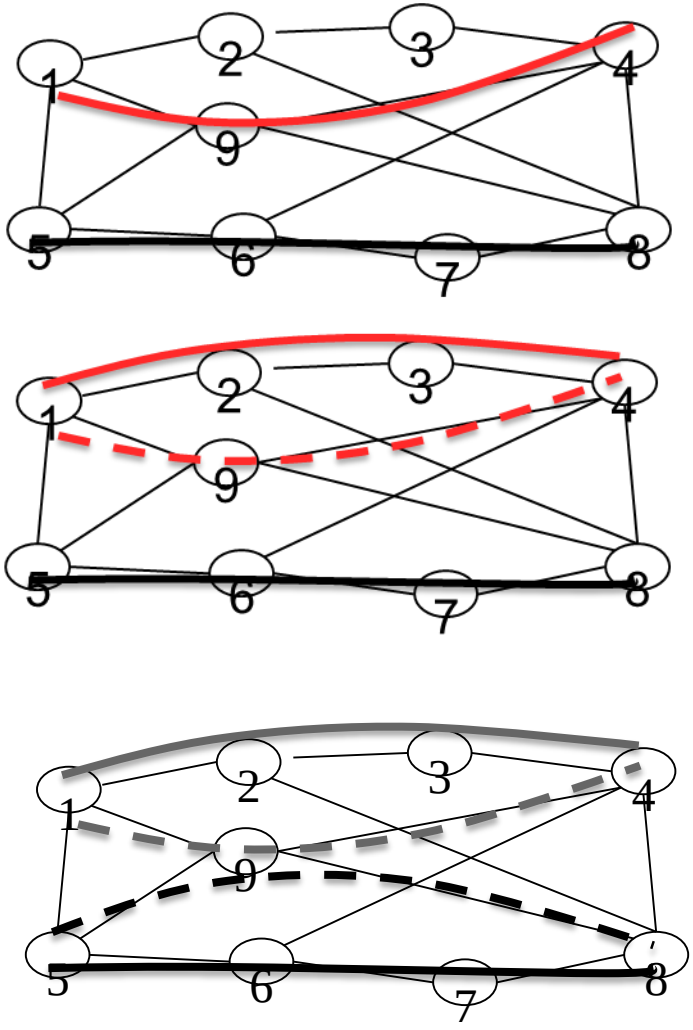
- Graph $G = (\{\text{multiplexers}\}, \{\text{optical cables}\})$
- Attributes of nodes:
  - Can have regenerator
  - Can apply forward-error-correction
  - Local dimension
- Attributes of edges:
  - Physical length
  - Number of amplifiers
  - Set of free colors
  - OSNR Margin
- Demands = set of triples (source, target node, protection type)
- Routing = set of colored paths satisfying given demands

# Amplification, regeneration, recoloring

- Since a signal attenuates spreading along a fiber link we have to use optical amplifiers
- After several amplifications the quality of signal which is measured by Optical Signal to Noise Ratio (OSNR) becomes worse, so we need use an error correction
- Also in order to route the maximal number of demands we have to change a color of paths at some nodes
- Regenerators are used for these purposes. Since usage of them are expensive we want to minimize their number.

# Protection of paths

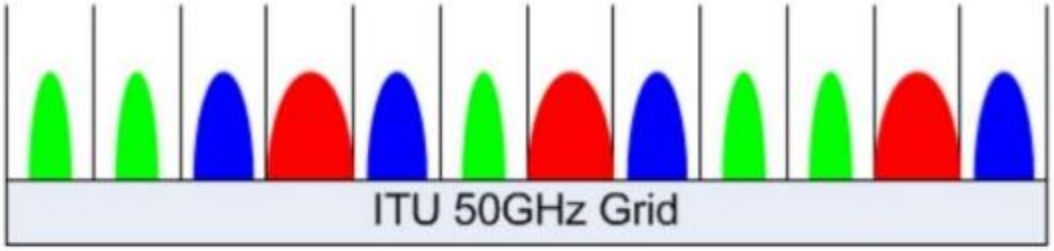
- In practice, a routed path can become failed due to various reasons, so some demands require to have protected paths as well as working
- There are several types of protections which differs by amount of required protected paths, sharing of edges among protected paths and so on



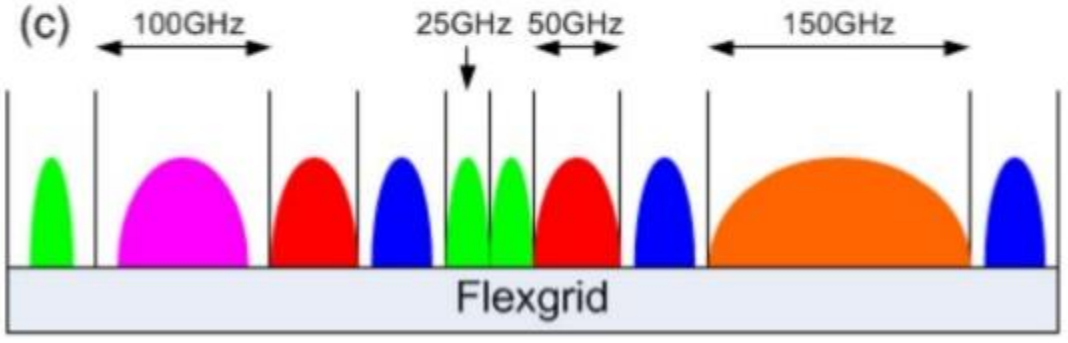
# Additional constraints

- In practice we always have a limited budget, so we have to consider upper bounds on the number of regenerators, the total length of routing and so on.
- Also we can require for routing to satisfy some additional constraints which can be defined by user
  - Passing through given nodes or links
  - Using specified colors for some demands
  - Disjointness of some groups of paths
  - Using the same path for some subset of demands
- Moreover, there are situation when some (old) connections are already established and routing of new demands should account them.

# Fix/flex-grid




- Fix-grid
  - For every fiber link the whole interval of wavelengths is divided into fixed number of subintervals (for example, 80)
  - Every path takes exactly one interval (color) on each used link




- Flex-grid
  - Every path can take more than one intervals along each used links
  - However, these intervals should be subsequent

# Optimization problem

- For given set of demands find out the routing which satisfies given constraints and optimizes one of the following objectives:
  - Number of routed demands
  - Number of regenerators
  - Total physical length
  - Total number of used colors
  - Variance of the number of used colors
  - Total OSNR
- In the case when some of these objectives are incomparable we want to approximate corresponding Pareto frontier

# Single-objective optimization

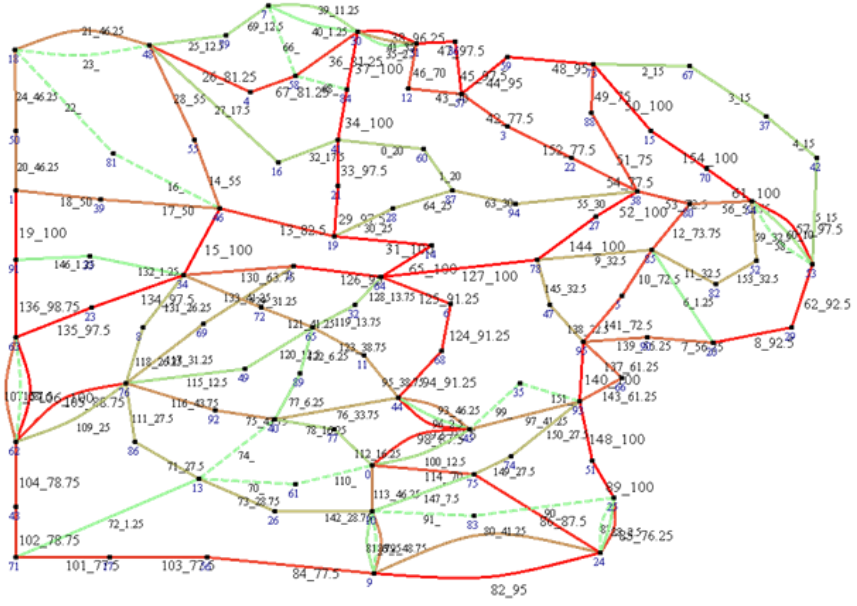
- In some cases the problem is equivalent to the graph coloring problem or multi-commodity flow problem, so it is NP-complete
- By this reason, we need different heuristic algorithms which are effective for the cases which we can determine in advance
- Some approaches for finding paths:
  - Fixed path routing (it is a simplest algorithm)
  - Fixed alternate routing (+ Yen K shortest paths)
  - Adaptive routing (+ rerouting of conflicted paths)
- Wavelength assignment can be performed after process of finding all paths or during this process

# Multi-objective optimization

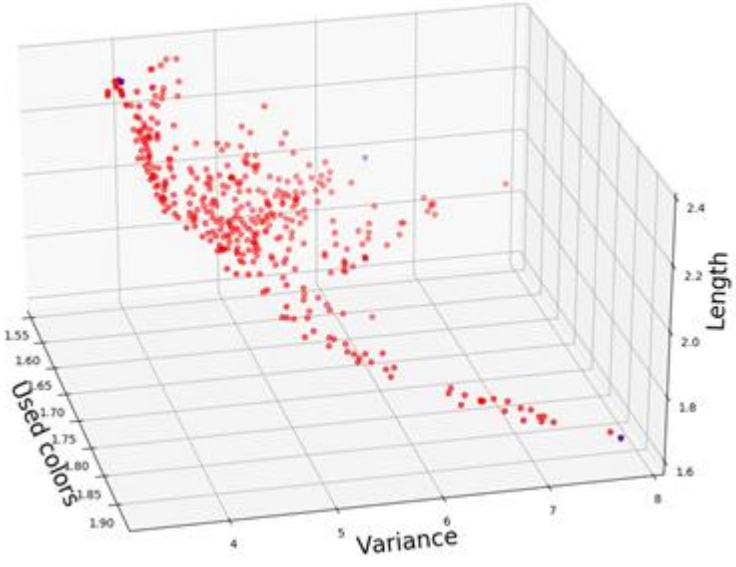
- Due to the discreteness of solution space and complexity of finding one solution it is hard to find fully deterministic algorithm of discovering Pareto frontier
- Instead of this the various evolutionary algorithms like genetic algorithms can be applied
- They are based on generation in some way an initial set (population) of different solutions, and then applying recombination operations (mutations, crossover) several times
- Pros: simplicity, generation of new solutions using already obtained ones, ability to use as superstructure over any single-objective solver
- Cons: high amount of iterations, lack of the strong stop criteria, difficulty to support good diversity of Pareto approximation

# Parallel computations

Speed of performance can be significantly increased by using parallel computations. During each iteration one could choose list of pairs of chromosomes and do crossover for each pair independently. Similarly, with the mutation operations.



96 nodes, 153 links
200 demands



# References


1. I. Szczesniak, B. Wozna-Szczesniak, Adapted and constrained Dijkstra for elastic optical networks, *2016 International Conference on Optical Network Design and Modeling (ONDM).*
2. K. Deb, A. Pratap, S. Agarwal, T. Meyarivan, A fast and elitist multiobjective genetic algorithm: NSGA-II, *IEEE Transactions on Evolutionary Computation*, vol. 6, no. 2, pp. 182-197, 2002.
3. K. Deb, H. Jain, An evolutionary many-objective optimization algorithm using reference-point based nondominated sorting approach. Part I: Solving problems with box constraints, *IEEE Transactions on Evolutionary Computation*, vol. 18, no. 4, pp. 577-601, 2014.

# Thank you!!!