

WDM Planner: WDM Network Optimization Tool

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Abstract: WDM Planner is an open-source software for Wavelength Division Multiplexing (WDM) network optimization. It can determine the information such as the shortest paths between network nodes, the minimum amount of wavelength channels required to support the traffic demands, the maximum amount of traffic that the current network resources can support, and the minimum amount of additional wavelength channels required to support all traffic. It is a Graphical User Interface (GUI) based software. Accordingly, it can be conveniently used to help in actual planning of the WDM network resource allocation or to demonstrate the basic concepts in WDM network design for teaching and training purposes.

Keywords—WDM network design, optimization, open-source software

1. Introduction

WDM network design is a complicated task since there are several related parameters, constraints and variables. When designing a WDM network, the topics to be considered include traffic paths between network nodes, the amount of allocated wavelengths, the wavelength contention constraints, the resource utilization, and so on. Even with a small network, if these tasks are manually computed, it will take a long time and is also error-prone. Accordingly, a tool that can support network designers or operators in planning WDM networks would be useful.

We use experience from our research [1] [2] to develop an open-source software called “WDM Planner” [3] for solving basic optimization problems in WDM network design. We decide to make the tool available to the public as an open-source program because it would be beneficial to both professional and academic communities.

We focus on two categories of WDM network optimization problem: minimizing resource allocation and maximizing the supported traffic. In minimizing resource allocation, network resources (i.e., wavelength channels, fiber optic cables, etc.) are enough to support all of the traffic demands. A solution to this type of problem specifies how to allocate the minimum amount of resources to support the traffic demands. As for maximizing the supported traffic, network resources may or may not be enough to support all traffic demands. The solution for this type of problem specifies how to allocate network resources such that the maximum amount of traffic demands is supported.

In the current version, the program can determine basic solutions of a WDM network design [4] [5]: the traffic paths

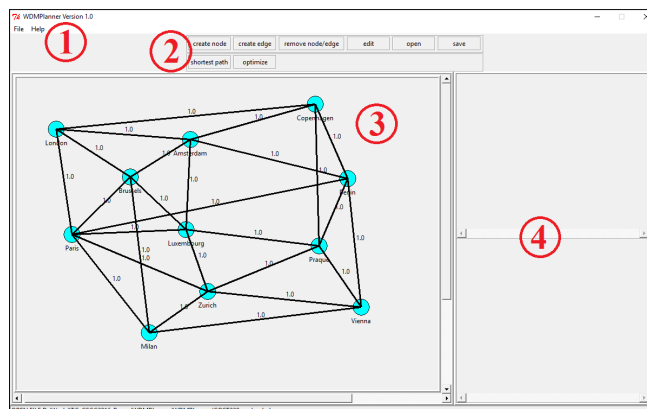


Figure 1. WDM Planner main window

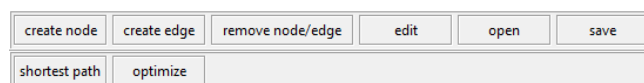


Figure 2. Command panel

between network nodes, the optimal wavelength allocation to support the traffic demands, the maximum number of traffic demands that the current network resources can support, and the additional wavelength channel requirements to support the traffic demands (i.e., in a situation when the current network resources are not enough, or there are future plans to expand the network).

Section 2 covers the basic information on WDM Planner. It begins by describing the program’s components and the user interface. Then, the traffic path finding algorithm and the information related to optimization are explained. The conclusion of our work is provided in Section 3 while the future plan can be found in Section 4.

2. WDM Planner

WDM Planner is written using the Python programming language. It works in conjunction with two other open-source tools: PuLP [6] and GNU Linear Programming Kit (GLPK) package [7].

WDM Planner accepts the input from the user such as network topology, link parameters, traffic demand matrix, and the type of problem to be solved. It uses the programs that are developed by our team to generate the objective function, constraints and variables for the Integer Linear Programming (ILP) problem. PuLP, which is a modeller, is then used to

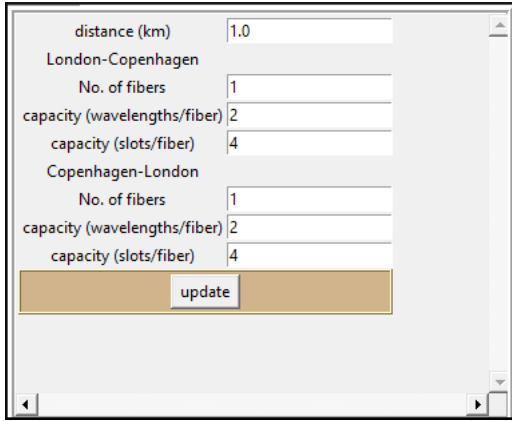


Figure 3. Link parameters

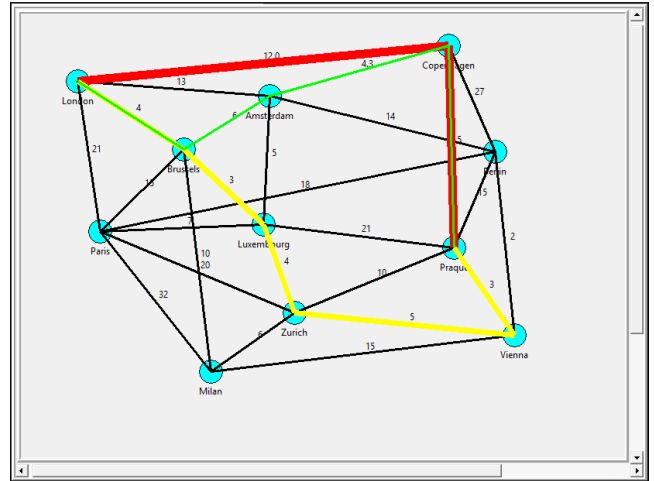


Figure 4. The paths between two network nodes

call the ILP solver. In our program, we use GLPK as an ILP solver. Once an optimal solution is found by GLPK (i.e., the problem is feasible), the related information is shown on the screen.

2.1 User Interface

The program's main window is shown in figure 1. It has the following components.

1. *Menu bar*: The basic commands for controlling the general aspect of the program can be found in the menu bar. It contains functions such as creating a new network topology, loading a saved network topology, exiting the program, loading the demo file, and so on.
2. *Command panel*: The command panel is shown in detail in figure 2. It is for controlling the main functions of the program such as node and link creation/modification, open/save the network topology, finding the paths between network nodes and solving an optimization problem.
3. *Network topology panel*: This panel is for displaying the network topology. It also shows the graphical information such as the traffic paths between network nodes and the link utilization.
4. *Information panel*: This panel is for displaying the information related to the computational such as optimization method, simulation results, and so on.

2.2 Shortest Path Calculations

It is beneficial to have more than one traffic path between network nodes. One reason is to distribute traffic between different paths in a case that links on any single path do not have enough resources to support the traffic. Another reason is to provide backup paths in case of link or node failures. A Shared Risk Link Group (SRLG) is a group of links that share a common resource (e.g., fiber optic cable) [4]. A failure in the shared resource can affect all links in the group. Accordingly, to avoid a total traffic disruption, the links in the traffic paths should be diversified.

In our program, to determine the possible traffic paths between nodes, we use the k-shortest path algorithm [8] which is based on the Dijkstra shortest path algorithm. We choose

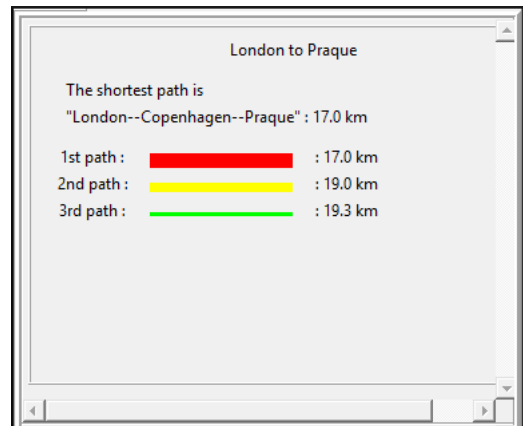


Figure 5. The calculated distances of the paths

this algorithm due to its simplicity in implementation and fast computation time. Currently, we consider all the links to be bidirectional and use only the physical distances as the link costs. The distance of a link along with other link parameters can be modified by the user through the "Edit" function as shown in figure 3.

In theory, the algorithm can determine up to k alternative paths (i.e., if exist) between network nodes. However, increasing the number of alternative paths leads to an increase in computation time that GLPK takes to solve the ILP problem. Accordingly, we set the number of alternative paths to three. As shown in figure 4 and figure 5, up to three different paths in which each source-destination pair have at least one link not in the same SRLG can be calculated by the program.

In the future, we plan to add more link parameters such as attenuation, dispersion, link utilization, etc.

2.3 WDM Network Optimization

The main feature of WDM Planner is to solve WDM network design problems using optimization techniques. A network design problem is formulated as an ILP problem based on inputs from the user. These inputs are network topology, link

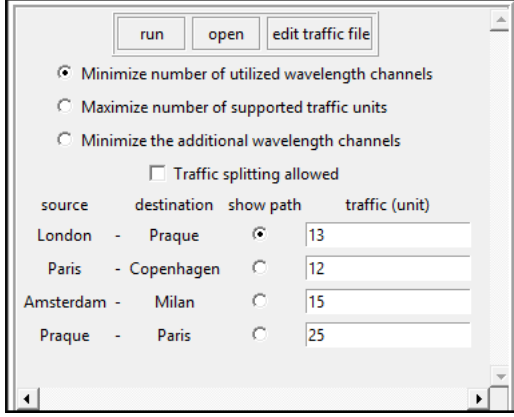


Figure 6. Options for optimization

parameters, traffic demands and the objective function.

A network topology is made up of nodes that are connected by links. The nodes can be the endpoints of the traffic demands or intermediate points along the traffic paths. We do not include the optical bypass capability to the nodes. Accordingly, the nodes switch traffic using the “O-E-O” (Optical-Electrical-Optical) paradigm.

The links in the network topology are characterized by four parameters: distance, number of fibers in the link, number of wavelength channels in a fiber, and number of Time Division Multiple Access (TDMA) timeslots in a wavelength channel. These parameters can be set as shown in figure 3.

The traffic demands are considered to be bidirectional and represented in terms of TDMA timeslots. They are stored in a separated text file. The format of a traffic demand is “Source, Destination, Demand,”. An example of the contents in a traffic demand file are as follows.

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London,Praque,13,
Paris,Copenhagen,12,
Amsterdam,Milan,15,
Praque,Paris,25,
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Based on the objective function, there are three types of problem that WDM Planner can solve. They can be selected from the information panel as shown in figure 6.

- *Minimize the number of utilized wavelength channels, as given in equation (1):* The objective is to support all traffic demands while minimizing the total number of allocated wavelength channels. If a solution cannot be found, the screen shows the message “INFEASIBLE”. This opens an option to determine the additional wavelength channels that are required to support all traffic demands.
- *Maximize the number of supported traffic demands, as given in equation (2):* The network resources may or may not be enough to support all traffic demands. However, the objective of this function is to support as many traffic demands as possible using the available resources.
- *Minimize the additional wavelength channels, as given in equation (3):* If there are not enough resources to support all

traffic demands, this function can be used. It determines how many additional wavelength channels are needed to support all traffic demands.

The explanations of the notations, the decision variables, the objective function and the constraints of the ILP formulation are as follows.

Network notations:

\mathcal{S}	set of source-destination pairs with non-zero traffic
\mathcal{E}	set of directed physical links
F	number of fibers in a link (in fiber)
T	number of TDMA timeslots in a wavelength channel (in timeslot)
W	number of wavelength channels in a fiber (in channel)

Traffic notation:

$t^{(s,d)}$	traffic demand (in timeslot unit) of source-destination pair (s,d) , where $t^{(s,d)} \in \mathbb{Z}^+$
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Path notations:

$\mathcal{K}^{(s,d)}$	set of candidate paths for source-destination pair (s,d)
$\mathcal{K}_{(m,n)}^{(s,d)}$	set of candidate paths for source-destination pair (s,d) that use physical link (m,n)

Variables:

$b_k^{(s,d)}$	bandwidth allocated to path k (in timeslot unit) for source-destination pair (s,d) , where $b_k^{(s,d)} \in \mathbb{Z}^+$
$v_k^{(s,d)}$	Indicator that specifies whether or not $b_k^{(s,d)}$ is positive, where $v_k^{(s,d)} \in \{0, 1\}$
$c_{(m,n)}$	number of wavelength channels used in physical link (m,n) , where $c_{(m,n)} \in \mathbb{Z}^+$
$d_{(m,n)}$	number of additional wavelength channels that are required in physical link (m,n) , where $d_{(m,n)} \in \mathbb{Z}^+$

Objective function:

$$\text{Minimize: } \sum_{(m,n) \in \mathcal{E}} c_{(m,n)} \quad (1)$$

$$\text{or Maximize: } \sum_{(s,d) \in \mathcal{S}} \sum_{k \in \mathcal{K}^{(s,d)}} b_k^{(s,d)} \quad (2)$$

$$\text{or Minimize: } \sum_{(m,n) \in \mathcal{E}} d_{(m,n)} \quad (3)$$

Traffic demand constraint:

$$\sum_{k \in \mathcal{K}^{(s,d)}} b_k^{(s,d)} \leq t^{(s,d)} \quad \forall (s,d) \in \mathcal{S} \quad (4)$$

3. Conclusion

We developed a network design tool that can help solve network design problems when considering different network requirements and objective functions. The tool can solve the main network optimization problems, namely, minimizing the resource allocation and maximizing the supported traffic. Our tool is easy to use and does not require a large amount of computing resources. In addition, it does not require any licensed software to operate, and hence can be used to reduce the lack of educational tools in developing countries.

4. Future Plan

Currently, the tool calculates the traffic paths based solely on the distances of the links. Consequently, it does not reflect the characteristics of optical fibers that affect actual optical communications such as attenuation and dispersion. Accordingly, we plan to add these parameters into the calculation.

In addition, the current version can solve the resource allocation problem in terms of the amount of required wavelength channels and the resource utilization. However, to be more useful, the Routing and Wavelength Assignment (RWA) should also be solved. We plan to add this feature into the next version of the tool.

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$$\text{or } \sum_{k \in \mathcal{K}^{(s,d)}} b_k^{(s,d)} = t^{(s,d)} \quad \forall (s,d) \in \mathcal{S} \quad (5)$$

The traffic demand constraint indicates whether all traffic demands have to be supported or not. For the second objective, which is to maximize the amount of supported traffic, network resources might not be enough to support all traffic demands. In this case, the constraint is relaxed as shown in equation (4). As for the other objective functions where all traffic demands must be supported, equation (5) is used instead.

Wavelength channel utilization constraint:

$$\sum_{(s,d) \in \mathcal{S}} \sum_{k \in \mathcal{K}_{(m,n)}^{(s,d)}} (b_k^{s,d}/T) \leq c_{(m,n)} + d_{(m,n)} \quad \forall (m,n) \in \mathcal{E} \quad (6)$$

$$\text{or } \sum_{(s,d) \in \mathcal{S}} \sum_{k \in \mathcal{K}_{(m,n)}^{(s,d)}} (b_k^{s,d}/T) \leq c_{(m,n)} \quad \forall (m,n) \in \mathcal{E} \quad (7)$$

The amount of wavelength channels that can be used to support the traffic demands is limited by the link capacity. In the situation when the available wavelength channels are not enough and the user would like to determine the number of additional wavelength channels required, equation (6) is used. However, if additional wavelength channels are not allowed, equation (7) is used.

Link capacity constraint:

$$c_{(m,n)} \leq (F \times W) \quad \forall (m,n) \in \mathcal{E} \quad (8)$$

Equation (8) is the link capacity constraint. It requires that the sum of allocated wavelength channels in a link is no greater than the available link capacity.

Constraint for no traffic splitting:

$$b_k^{(s,d)}/t^{(s,d)} \leq v_k^{(s,d)} \quad \forall (s,d) \in \mathcal{S}, k \in \mathcal{K}^{(s,d)} \quad (9)$$

$$\sum_{k \in \mathcal{K}^{(s,d)}} v_k^{(s,d)} \leq 1 \quad \forall (s,d) \in \mathcal{S} \quad (10)$$

The tool also offers an option to allow for traffic splitting. With traffic splitting, traffic between a source-destination pair can follow multiple paths. This allows for path diversity. Also, traffic from different source-destination pairs can be multiplexed into a wavelength channel. Thus, the wavelength utilization can be increased. If traffic splitting is allowed, equations (9) and (10) are not used.