

# MONTE CARLO WDM NETWORK IDENTIFICATION AND EVALUATION TOOL

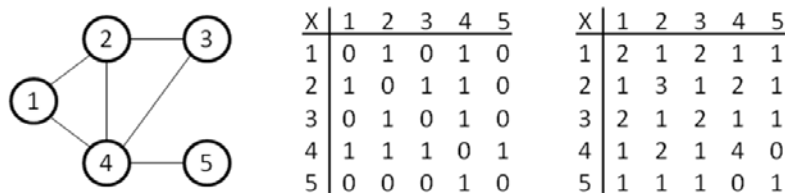
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## Introduction

Wavelength Division Multiplexed Local Area Networking (WDM LAN) is evolving for potential application onboard aerospace platforms. Tools are needed to optimize and evaluate network topology viability for avionics systems. In this paper, we describe a software tool to create, optimize, and evaluate candidate networks. This tool started as a network traffic simulator for evaluating user-defined node-based networks, such as ring, mesh, active star or hybrid variants [1] [2]. We then developed the ability to generate a random, but constrained, adjacency matrix representing a candidate network. Through repeated simulation, these candidate networks are selected to optimize desired parameters, such as minimizing the number of jumps, minimizing the number of wavelengths needed, or increasing system redundancy.

## Network Characterization

In the tool, networks are recorded as adjacency matrices, shown in Figure 1. An  $m$  node network is represented by an  $m$  by  $m$  binary matrix. A one in row  $i$  and column  $j$  signifies that node  $i$  and node  $j$  are directly connected. When an adjacency matrix is raised to the  $n$ th degree, the value in row  $i$  and column  $j$  represents the number of unique paths between node  $i$  and node  $j$  using  $n$  jumps. Only bidirectional candidate networks are considered, meaning an adjacency matrix will always equal its transpose. A network of any size or complexity can be evaluated. Simulating broken nodes is as simple as setting their value to zero in the adjacency matrix. For avionics WDM LAN situations, redundancy is desired or even required. This is achieved by creating a two identical 2D networks and layering them on top of each other. The default setting uses this second layer only to route around broken links or nodes.



**Figure 1. Example network (left) and its corresponding 1<sup>st</sup> and 2<sup>nd</sup> power adjacency matrices (right)**

## Network Creation

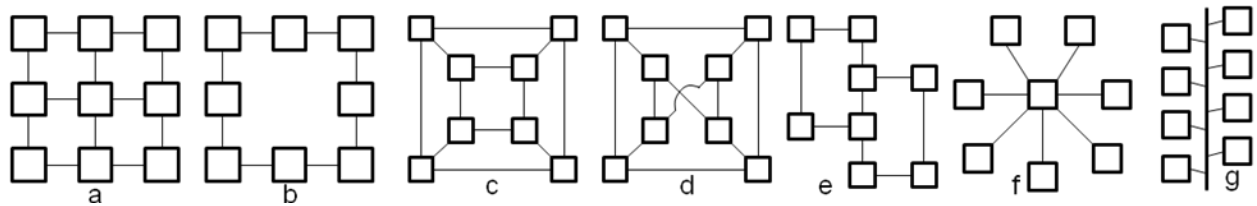
Networks are created using Monte Carlo means. A random  $m$  by  $m$  matrix is populated by ones and zeros, with constraints placed on the number of connections allowed per node. For every possible network connection, the number of jumps needed is recorded. Using this data the maximum path length and average path length is used to compare candidate networks. During a series of iterations, the networks with the lowest maximum path length and lowest average path length are saved. The Cross-Cube network shown in Figure 2d was found using this method. This procedure can also be used to optimize the number of wavelengths or amount of redundant connections.

## Traffic Simulation

To determine the minimum jumps between two nodes, the tool finds powers of the adjacency matrix until a non-zero value appears. The original adjacency matrix can be used to find the actual routes for each connection. When multiple data transfers are simultaneous, priority is given to routing through separate nodes and links. Rather than adding more jumps to a connection to avoid overlap, both offending transfers are assigned different wavelengths.

## Network Evaluation

The network architectures, shown in Figure 2, are directly compared through Monte Carlo means. Identical sets of random connections are sent through various networks using the traffic simulation code and data is collected. This data includes the maximum and average number of jumps needed, the number of wavelengths necessary for each configuration, and the number of possible connection configurations. This procedure is completed for numerous sets of connections and compared, see Table 1 below.



**Figure 2. Network types a) Mesh b) Ring c) Cube d) Cross-Cube e) Pentagons f) Active Star g) Bus**

**Table 1. Data used to evaluate 2D networks. This data is averaged over 10,000 random connection configurations. Each configuration included between 1 and 6 individual links. (\* = exact value)**

	<b>Mesh</b>	<b>Ring</b>	<b>Cube</b>	<b>Cross-Cube</b>	<b>Pentagons</b>	<b>Active Star</b>	<b>Bus</b>
<b>Average Number of Steps per Connection</b>	2.06	2.12	1.76	1.63	2.10	1.66	2.00*
<b>Maximum Number of Steps per Connection</b>	3.02	3.36	2.50	1.99	3.03	1.99	2.00*
<b>Unique Connection Configurations</b>	3.14	1.17	4.51	2.02	1.05	1.00*	1.00*

## Conclusion

The use of Monte Carlo means to create, simulate and evaluate WDM networks has been shown. The 8-node Cross-Cube network discovered by Monte Carlo means was found to require fewer jumps than other tested network architectures. This is to be expected, as the tool was optimizing for fewest number of jumps. Both the mesh and cube architecture were found to be more flexible in terms of different redundant connections; however, the tool could be adjusted to optimize for redundancy if desired.

## References

- [1] R.J. Voigt and R.B. Jenkins, "Demonstration of Bidirectional Add Drop Multiplexers and Mixed Signals in a DWDM Mesh Architecture," *Proc. Of European Conference of Optical Communications*, 2008.
- [2] A.S. Glista and M.W. Beranek, "Wavelength Division Multiplexed (WDM) Optical Technology Solutions for Next Generation Aerospace Networks," *Proc. Of 22<sup>nd</sup> Digital Avionics Conference*, pp. 11.0.1-1 – 11.0.1-12, 2003.