OPNET TRANSPORT PLANNER
Graduate Project

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1. Introduction – Graduate Project

**OPNET** Graduate Project is aimed at providing an opportunity to get an insight into the OPNET Transport Planner and is used to design and simulate optical network models. This paper shows how OPNET can be used to design network maps having different network topologies and implementing real time analysis on the topologies to predict how they will act with real time traffic.

For the current exercise, some well known topologies are used to show how OPNET implements these topologies and then they are compared through various traffic and failure analysis.

It is supposed that a network is to be established in North American Region and below are the cities in which these sites exist.

**US Based Cities**
1. New York City, NY
2. Chicago, IL
3. Boulder, CO
4. Miami, FL
5. San Francisco, CA
6. Atlanta, GA

**And three International Cities**
1. Mexico City, Mexico
2. Vancouver, Canada
3. Regina, Canada

2. Scenario's

Considering the main purpose of this graduate project, a number of different scenarios would be designed and simulated using the OPNET Transport Planner. Various tools of OPNET would be used in each design showing the basic understanding of OPNET tool.
For this exercise four different topologies have been designed and simulated in OPNET Tool.

a) **MESH BASED TOPOLOGY**

![Mesh Based Topology Diagram](image)

b) **STAR BASED TOPOLOGY**

![Star Based Topology Diagram](image)
3. Design of Project

All these topologies are well known Topologies however these are selected so to clearly show through various OPNET tools that how each topology has its own advantages and disadvantages considering basic fundamental growth, Failure and cost Analysis of each.
For all the four network topologies, following Network Properties and analysis is made for all.

a. Network and Equipment Properties
   i. Network Topology
   ii. Common settings
   iii. Link Design
   iv. Link Threshold
   v. Network Availability

b. Traffic matrix
   i. Traffic matrix Generation
   ii. Traffic Dimensioning
   iii. Routing Results
   iv. Traffic Variations/growth
   v. Network Costs

c. Failure Analysis
   i. Failure Analysis – Link Failure
   ii. Failure Analysis – Node Failure
4. Topologies

Following are the topologies created in OPNET.

4.1 Mesh Topology

4.1.1 Network Map

Following is the Network map and Topology of Mesh based scenario showing a meshed up network map.

All cities are directly connected to each other with direct links within each city. This is a common meshed up design in which all cities are connected directly having a large number of links in between them.
4.1.2 Network Topology

Network topology showing that there are total of 9 nodes and for a meshed up connectivity total number of links are to be 36. Network Connectivity is therefore 100%.

4.1.3 Network Availability

The network Availability was chose to be 99.99% for all the links, Cables, nodes including the ADM and patch panels. There was no Mean time to failure or recovery given in this.
4.1.4 Network Properties

The following network properties were chosen for the network. Only optical network is being modeled here and therefore that is the reason that Optical Add Drop Multiplexers are used here. Moreover, keeping current high BW requirement, OC 192 has been chosen as the data rate for the network. SONET technology is chosen over SDH keeping in its overall common use in the region. Opaque model has been chosen for OCH layer mode.

4.1.5 Link Usage Threshold

Link usage threshold has been chose as 50% keeping in view the common threshold settings.
4.1.6 Traffic Matrix
Random traffic matrix was generated, where 1 is the lowest and 50 being the maximum traffic. OC-48 chosen to be the data rate for the matrix editor.

4.1.7 Traffic Dimensioning
Following settings were used to dimension the traffic being provided in the traffic editor. 50% utilization was set for the links and for basic mesh network, optimized link sign is also unchecked creating a basic level Mesh network. *Note that no protection method is chosen in the dimensioning settings.*
4.1.8 Routing Results

After the traffic is applied we get the routing results. We have 41% approx utilization in this case and mean hops are 1, as it is a mesh based network therefore each site is directly connected showing that mean hop is 1. No protection method is chosen that is why no links are protected.

4.1.9 Network Costs

Total network Cost comes out to be 360,170 where basic optical equipment was used in the OCH/OTS layers.

4.1.10 Traffic Variations

In traffic variation, growth analysis was performed and it was supposed that how the routing results would differ if there is a 20% increase in traffic in the network. The link utilization increases to 45.5%, less than the required 50% still and it is still 100% routed because of mesh network design.
As shown in the network map, some of the links were manually failed to perform the failure analysis. 5 links were randomly failed, and results were evaluated which show that 223 Wavelengths were lost (12% loss) and none were recovered, though 1618 were not affected. This is quiet less loss as compared to the fact that 5 links were failed but it’s expected because of meshed up network. No wavelengths are recovered as no protection method exists.
4.1.12 Failure Analysis – Node Failure

Two nodes were manually failed simultaneously to perform the failure analysis and results were evaluated. 854 out of the total 1841 were lost in 2 nodes failure, which is almost 46% loss for two simultaneous nodes failure.
4.2 Star Topology

4.2.1 Network Map

In star map, Boulder Colorado has been chosen the main HQ site and all the rest of the cities are connected to it. Either site can connect with each other through Boulder Colorado. It’s a star based map with only one link in each direction.

4.2.2 Network Topology

As seen in the network Topology, in this star based design there are a total of eight links and network connectivity is also 22% as compared to Mesh networks 100%.
4.2.3 Network Availability

For comparison reasons, network availability has been chosen to be the same 99.99% for all links and nodes including the ADM and patch panels.
4.2.4 Link Thresholds

Link thresholds were chosen to be 50% for all 8 links of the star based design.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder Colorado</td>
<td>Atlanta</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>Chicago</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>Mexico City</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>Miami</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>New York City</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>Regina</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>San Francisco</td>
<td>0.500</td>
</tr>
<tr>
<td>Boulder Colorado</td>
<td>Vancouver</td>
<td>0.500</td>
</tr>
</tbody>
</table>

4.2.5 Network Properties

The network properties are chosen to be the same with OC-192 being the date rate. Only optical network is being modeled here and therefore that is the reason that Optical Add Drop Multiplexers are used here. SONET technology is chosen over SDH keeping in its overall common use in the region. Opaque model has been chosen for OCH layer mode.
4.2.6 Traffic Matrix

Traffic matrix has been created randomly for all the directions from 1 to 50 with 50 being the highest.

4.2.7 Traffic Dimensioning
With the random traffic generated, traffic dimensioning is done with 50% threshold. *No protection method is being selected.*

### 4.2.8 Routing Results

Routing results show us that link utilization has increased to 48% approx as there are less number of links in a star based design, with mean hops being 1.8 as well. The overall threshold of 50% link utilization has still not been breached though link utilization is pretty high now.

### 4.2.9 Network Cost

Network Cost has significantly decreased because number of links have been decreased in star based design.
4.2.10 Traffic Variations

Network traffic was varied and increased by 20% in order for a growth analysis and we see the link utilization is further increased to our threshold of 49.7% approx, and routed results have decreased too.

4.2.11 Failure Analysis – Link failure

Link failure analysis is done by failing three of the links in which we clearly see that more than 50% wavelengths are lost because of the star based design, which is quiet high as compared to the mesh based design. Only three links failure can created huge losses.
### 4.2.12 Failure Analysis – Node failure

In node failure analysis, two phases are there. First any node other than the central node of Boulder CO has been failed, with results as being shown below.

In this case only 230 Wavelengths are lost which is the traffic being sent to Chicago node only and none are recovered, which shows almost 28%.
In the next phase, main central node of Boulder CO is failed and then the evaluation is made which shows complete network down as all traffic lost and the network comes to a halt. This is a 100% failure of the network. This clearly shows the network reliability issue as a single node failure halts the whole network.

4.3 Multi-Link Topology - Unprotected

4.3.1 Network Map
Ring architecture has been designed by providing each of the sites connectivity with at least three different sites so that even a single failure doesn’t end up disconnecting a site, keeping the central sites of Boulder CO and Atlanta connected to five sites each.

### 4.3.2 Network Topology

Topology shows that in ring architecture network connectivity is 44% with total number of links to 16.

### 4.3.3 Availability settings
Network availability has been chose the same as other topologies so that other analysis can be compared for all three.

### 4.3.4 Link Threshold and Network Properties
Link threshold is chosen to 50% keeping in view the general settings of link threshold; OC-192 has been chosen the main default bit-rate. SONET technology again chosen for the ring based design. Opaque mode is being used for the current network properties.

### 4.3.5 Traffic matrix & Dimensions

Traffic matrix was generated randomly from 1-50 with 50 being the highest.
4.3.6 Network Dimensions

Once the traffic is randomly generated, links dimensioning is done keeping a 50% threshold. 

For this topology as well, unprotected method is being applied still.

4.3.7 Routing results
Routing results provide us with the results given above for the ring based design, as shown the link utilization is in between the star based and Mesh topology i.e. almost 45%. This does make sense as the traffic would require fewer paths as compared to a star based design however as compared to the mesh based design; link utilization should be a little more. No protection method is being applied so no links are protected.

### 4.3.8 Network Costs

![Network Cost Table]

Network costs are again greater than star based design and lie between Mesh based and star based at 303,640.

### 4.3.9 Traffic Variations

![Traffic Variations Graph]

Traffic variations are done to perform a growth analysis and we see that the link utilization increases to almost 49% if we suppose a 20% increase in traffic.
4.3.10 Failure Analysis - Link Failure

Two links as shown are failed to perform a link Failure analysis and we see that almost 355 wavelengths are lost out of the total 1008 that amounts upto a 35% loss which is quiet less as compared to star based design. Though it's more for a meshed up design as was expected.

4.3.11 Failure Analysis - Node Analysis

In node analysis, the central node of Boulder CO is failed which connects up to 5 different sites, however the loss is still almost 42% because of a ring based design the loss is pretty less as compared to a star based design.
If we fail another central node of Atlanta, considering the traffic the OPNET Tool failure analysis tool shows us that we have a 37% loss of traffic in this case.

4.4 Ring Topology 1+1 Protection

Another topology has been designed keeping the same common network properties, link threshold and general availability settings of the ring based topology without protection. Though in this design, ring architecture is made and in traffic dimensioning 1+1 protection method is selected.

4.4.1 Ring Architecture

In this network topology, rings were created in order to provide different paths for the traffic to reach their destination. In case of failure, it would be shown later how rings architecture helps in failure of a link or a node. No other change is made in number of links or topology. Following shows links properties with data rate as OC-192.
4.4.2 Traffic Matrix
4.4.3 Traffic Dimensioning with 1+1 Protection method

As shown, in this dimensioning all the other options are same with 50% threshold; however a protection method has been chosen with 1+1 protection. This may cost a little more as would be shown in the network costs however it provides protection against failure.

4.4.4 Routing Results and Network Costs
Routing results show that the link utilization is a bit more than a normal without ring based topology at 47% but provides protection of the links as well. As a protection method is chosen here so routing results show links are protected as well. Below show the cost of the network and its shoes that because of the ring architecture and then 1+1 protection method, it’s costly and also optimization was not selected in dimensioning.

![Network Cost](image)

### 4.4.5 Traffic Variations

Traffic variations show how an increase of 20% in traffic would result in over increase to 49% in link utilization.
4.4.6 Failure Analysis – Link Failure

As shown in the failure analysis, if we fail three links in this case with multi path rings in our architecture and 1+1 protection also enabled, only 3 wavelengths are lost and 286 are recovered. This shows a highly reliable network with link failures are recovered immediately. 1+1 protection method actually provides link protection which is clearly visible that all but 3 are lost that is less than 1% loss.
4.4.7 Failure Analysis - Node Failure

First a central node of boulder is failed and it shows that 160 wavelengths are lost, however 105 are still recovered. Therefore only 160 are lost in total which shows a 19% loss. This is quiet less as compared to all the other topologies that were discussed earlier.
In this failure node analysis, another central node of Atlanta is being failed. This causes 179 wavelengths to be lost with 249 being recovered. This gives a loss of almost 21% which is again less as compared to other topologies.

4.5 Scenario Comparison Tool

4.5.1 OTS Layer Topology Comparison

OTS layer topology showing link connectivity of all four scenarios along side other topologies information for all four scenarios.
### 4.5.2 OCH Layer Comparison

OCH layer comparison shows clearly how each scenario has got link utilization, and here it shows that only the last scenario has actually got any protection. It also shows a number of other comparison areas.

This scenario comparison tool in OPNET further helps to compare each design like this and then use it to find out which design best works for one.

### 4.6 Conclusion

Four different topologies were chosen and with different variations it was shown that how each topology has its own advantages and disadvantages.

Mesh based topology creates a meshed up design with a large number of links which causes the network cost to go up and the link utilization is also minimum as compared to other scenarios. Though the best thing about meshed up network design is its nature incase of failures, it has low percentage of loss because of the direct connectivity with all nodes.

On the other star based design was considerably cheap cost wise with only 8 links however in failure analysis we came to know that how a failure at central node could cause the whole network to come to a halt. This creates reliability issues.
Multiple path scenarios was an appropriate design having appropriate cost, also in failure analysis the loss was less as compared to a star based design. On the other hand Ring Based design having a 1+1 protection method was very well versed in Failure analysis of links with just under 1% loss. Though this came at a price that was shown in network costs. OPNET is a handy optical networking tool as it has a number of different tools which are there for network developers, which can design the network according to their own needs and then simulate there, design in a real time traffic environment. Various analysis tools provide further idea how the design would work in case of failures or growth in traffic.