JCSS 7.0
Capacity Planning Feature V&V Report

January 2008

Disclaimer: As of October 2007, NETWARS was redesignated by the Program Manager Office as the Joint Communications Simulation System (JCSS). JCSS was selected as the new industry name to better reflect the inherent joint communication capabilities of the software. Users should be aware that no software updates were conducted as part of the software name change.

Prepared by

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Document Change History

The table below identifies all changes that have been incorporated into each version of the document since the release of the NETWARS 2006-2 Capacity Planning Feature V&V Report.

Revision Number	Revision Date	Section	Change Description
__________	_________	__________	NETWARS 2006-2 Capacity Planning Feature Report
7.0 v1	01/10/08	Document	Updated the Resources section in the Introduction Added section on “View Results” window under Report Generation Added description of how Capacity Planner handles UHF Dama and Link-16 in the “View Results” window section Inserted new screenshot (Figure 1) Updated screenshots (Figure 2, Figure 3)

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1. Introduction

The Command, Control, Communications, and Computer (C4) Systems Directorate (J6C) of the Joint Staff and the Defense Information Systems Agency Enterprise Analysis Branch (DISA/GE344) are developing the joint C4 assessment model Joint Communications Simulation System (JCSS). In accordance with the Memorandum of Agreement between J6C and DISA, DISA/GE344 is responsible for JCSS software-related activities, including software testing and communications model verification and validation (V&V).

As the JCSS simulation functionality continues to evolve, JCSS program managers and users recognize the importance of testing and V&V to ensure valid studies can be conducted. To support this initiative, DISA contracted Booz Allen to perform V&V of the JCSS Capacity Planner capability included in JCSS7.0.

1.1 Background

The Combatant Commander’s capacity planning feature provides operational planners a mechanism to expedite the simulation process, without committing the time or resources to conduct a detailed simulation. Given a communications network and its associated traffic, the Capacity Planning “Evaluate” feature will provide quick and analytical snapshots of network performance at various time intervals that are configurable by the user. The Capacity Planning Optimization feature will make network configuration suggestions, which provide near optimal link and network capacities.

1.2 Resources

Resources used in conducting this effort included Government-furnished software and key supporting documents. Specifically, the software evaluated was —

- NETWARS 2007 A.10, dated 8 October 2007
- NETWARS 2007 B.1, dated 15 October 2007
- NETWARS 2007 C.0, dated 29 October 2007
- NETWARS 2007 D.0, dated 12 November 2007
- NETWARS 2007 E.0, dated 26 November 2007
- JCSS 7.0 F.0, dated 7 December 2007
- JCSS 7.0 G.0, dated 14 December 2007
- JCSS 7.0 G.2, dated 20 December 2007
- JCSS 7.0 H.1, dated 14 January 2008

Documentation specifying communications model requirements and describing model implementation approaches included–

- Statement of Work (SOW)
- NETWARS 7.0 Final Software Design Document

Documentation specifying developer test activities and results included–

- NETWARS 7.0 Final Test Plan, OPNET Technologies

Finally, the overall approach for conducting V&V of JCSS communications models was documented in–

- NETWARS 7.0 Communication Model Verification and Validation Plan, Booz Allen Hamilton

1.3 Approach

JCSS 7.0 includes a Capacity Planner tool, which consists of two major functionalities "Evaluate" and "Optimize". The key objectives of the JCSS Capacity Optimization V&V activities were to:

- Ensure problems found during beta testing were corrected
- Validate solutions generated by Capacity Planner

To begin the testing effort, test cases were defined for each elemental requirement to test key features and simulated system performance. These test cases were developed to test the Capacity Planner functionality relative to the documented elemental requirements as well as the implicit functional performance characteristics associated with each feature.

Detailed test scenarios were then designed for each test case. These test scenarios were generally small-scale scenarios developed to test a specific Capacity Optimization functionality. The JCSS Scenario Builder was used to create the requisite OPFACs and to generate simulated traffic in the form of IERs. Capacity Optimization results output was analyzed to determine if simulation results were consistent with expected performance.

Findings from executing the derived test scenarios were combined to associate a pass/fail "score" for each test case. Identified software problems were submitted in trouble reports to the JCSS configuration manager. All submitted trouble reports utilized the severity levels detailed in Table 1.

All testing was performed in accordance with the JCSS Communication Model Verification and Validation Plan and under the guidance of the JCSS program lead for testing and V&V.

Table 1 - JCSS Trouble Report Severity Levels

Level	Type	Definition
0	Urgent	Unrecoverable system failure and/or a potential security issue with no available workaround
1	High	Prevents the completion of an essential capability with no workaround available
2	Medium	Prevents the completion of an essential capability and reduces functionality and fails to meet full requirements but a workaround is available
3	Low	Non-critical functionality or cosmetic change

In addition to submitted trouble reports, complete test scenario descriptions and associated simulation results and findings were documented in detail and carefully archived to ensure repeatability for future regression testing.

Test package verification testing was also conducted, which included executing and analyzing test scenarios provided by the developer, OPNET Technologies.

1.4 Document Organization

The remainder of this report documents results of V&V activities conducted on the JCSS 7.0 Capacity Planner Tool.

2. Functionality

The Capacity Planning Tool provides relatively quick-turnaround analytical support to CINC or Service component communications planners who must compare their mission planning documents and information requirements plans, against the existing operational environment to identify shortfalls in information support.

The Capacity Planning Tool consists of two major functionalities "Evaluate" and "Optimize". The "Evaluate" feature will provide quick and analytical pictures of network performance whereas the "Optimize" feature will make network configuration suggestions, which provide near optimal link and network capacities.

2.1 Evaluate Network

The Evaluate Network feature of the Capacity Planner evaluates the scenario in its original state (i.e. with the current links and networks capacities); it does not perform mutations. It routes the demands and if it detects that a link or network lacked sufficient voice channels or failed, it reroutes the demands.

Capacity Planner allows the user to select the duration and number of time steps that will be used during evaluation. The default setting will be 1 one hour time step beginning at time 0, however the user may configure these settings to different specifications. Once the evaluation is completed, peak and average results for the overall time will be reported. Results will also be generated for each time slice that was specified prior to the evaluation.

Upon completion of the Network Evaluation, Scenario Builder will display the state of the network at the end of the first user defined time step. The state of the network at the end of any subsequent time steps can be displayed by selecting **View->Show Time Controller** menu option. As the view of the network topology changes from one time step to the next, the user can observe the changes that occur in link utilization as a result of IER start and stop times as well as link failures.

2.2 Capacity Optimization

The Capacity Optimization uses an iterative approach to optimize link bandwidths within the solution space. The iterative approach uses a simpler algorithm than the simulated annealing method that was used by previous NETWARS releases. The advantage of using the new approach is that Optimizations will not take as long as in the past.

During an Optimization, Capacity Planner first builds a list of all traffic loads that are present in the scenario and that will be active during the specified time period. At this point, Capacity Planner groups common types of traffic together and prioritizes them within each type. After all traffic loads are grouped and prioritized, Capacity Planner begins routing them. The Capacity Planner then routes the traffic over the network in its current state. When Capacity planner has concluded the routing process, an objective cost is computed for the result. The objective cost is a function of link capacities, link utilizations and the number of unroutable traffic demands. After the objective cost has been computed, Capacity Planner begins to search for more optimal solutions by changing link capacities throughout the network. Capacity Planner will continue to compute objective costs for new solutions and search for additional solutions until a user defined terminating condition is met.

The Capacity Optimization tool is used to optimize the capacity of the links and broadcast networks in a scenario. Given a network and its demands, the Capacity Planner runs the optimization and generates suggestions for optimal link and network capacities. If a link is over-utilized, the Capacity Optimization will suggest an alternate capacity that will support the demands and limit the cost of the link to the required minimum. On the other hand, if a link is under-utilized, the Capacity Optimization Summary will suggest reducing capacity for that link to reduce the cost.

2.3 Speed vs. Accuracy

Users can specify the speed at which the optimization engine runs by adjusting the speed vs. accuracy preference. However, this results in a trade-off where the quicker the run time, the less accurate the optimization results. In most cases where users want the most accurate solution, setting the optimization preference closer to "Accuracy" is advised. However, there are cases where large networks could potentially take a long time to optimize, in this case faster run times may be more desirable.

2.4 Demand Loading

Demands are specified in terms of the number of IERs over a given period of time. Users can optimize link and network capacities using traffic loads that vary from average to maximum values. For average loads, the mean of the inter-arrival time distribution is used to determine the rate of each demand; for maximum loads, extreme values from the distribution are used. If a value in between is used, the percentile will be scaled accordingly.

The load (in bits/second) for each data demand is calculated by dividing the size of the IER by the inter-arrival time. For voice, since the link capacity is expressed in number of channels instead of bits/second, the channel usage of each demand is calculated by dividing the call duration by the inter-arrival time. IER start and stop times will also be considered with respect to time steps. If an IER is active for only a fraction of a given time step, the effective traffic load will be scaled accordingly. For instance, if a traffic load is 100 bps and the IER is only active for half of a given time step, the load will be 100 * 0.5 = 50bps for that time step. Background traffic is specified through the link attributes dialog box.

2.5 Support for OPNET COTS Traffic

OPNET COTS traffic is specified on clients and workstations using the Application and Profile Config objects. In order for Capacity Planner to use COTS traffic, it must first be converted to traffic flows. Capacity Planner automates this process by converting COTS Applications to flows objects at the outset of any Evaluation or Optimization. This traffic conversion is temporary and will be reversed upon the conclusion of Capacity Planner Analysis.

2.6 Layered Routing

Routing is done at the device level one network layer at a time. This means that network devices will communicate within their own family of devices to determine the optimal path without consideration for what is occurring at different network layers. For instance, Prominas will communicate with one another to establish circuits and IP routers will build up their routing tables without specific knowledge of what is occurring at lower network layers. Layered routing will occur in a specific order to accommodate interdependency among different network layers. For example, IP routers separated by a Promina network will be unable to communicate with each other until after the Promina circuits have been established. Layered routing will occur independently within the following families of devices: ATM, Promina/MUX, Frame, Relay, IP, and Voice-capable devices.

2.7 Logical Views

As Capacity planner builds individual routing graphs for each family of devices, the graph of each layer will be held in memory and will form the basis for Logical Views of the network. Each family of devices listed in the previous section will be contained in a unique Logical View. Additionally, Logical Views will be provided for Tactical Radios as well as Transmission Systems such as satellite terminals and layer 1 encryption devices.

In some instances, Logical Views may provide a mechanism for troubleshooting unroutable demands in Capacity Planner. For instance, if traffic must be routed between a pair of routers that are separated by a Promina Network, there must be a properly configured Promina Circuit for the traffic to traverse. If there is no Circuit configured between the Prominas, the problem will be identified in the IP layer Logical View as there will be no logical connection represented between the source and destination router.

2.8 Alternate Path Selection

Capacity Planner always routes all traffic based on the shortest available path in terms of hops. The only exception to this rule occurs when voice/vtc traffic causes a link to exceed 100% utilization. In this case, some or all of the voice/vtc traffic may be rerouted to a path with a greater number of hops assuming that the new path has sufficient bandwidth and voice channels to support the load. If none of the available voice links can support a given instance of traffic, the traffic will become unroutable. In the event that multiple instances of voice/vtc traffic traverse the same path, Capacity Planner will route all traffic so long as it can all be routed without causing link utilization to exceed

100%. If utilization does exceed 100% in this case, higher priority traffic will be routed to the shortest available path first and any remaining traffic will be rerouted to the next available shortest path.

Data traffic, unlike voice traffic, will not be rerouted to a longer path as a result of utilization exceeding 100%. The only condition that will cause Capacity Planner to reroute traffic over a longer path is a link or network failure on the shortest path. All data traffic will traverse the shortest available path regardless of excessive link utilization and alternative paths with more hops.

2.9 Manage Optimizations

After an Optimization is run, Capacity Planner allows the user to save the results. The user may then restore the original link capacities and run another Optimization with slightly different settings. Capacity Planner allows the user to configure the number of Optimizations that may be saved. Link capacities from previously saved Optimization runs may be applied to the network at any time.

2.10 Link Load Visualization

Network links and Broadcast networks in the Scenario Builder will be colored and bolded according to utilization at the conclusion of any Evaluation or Optimization run. Additionally, a corresponding link legend will appear.

2.11 Report Generation

The Capacity Planner currently reports results in two way: Statistics available in the "View Results" window and the Web Based Reports. In JCSS 7.0, Link-16 and UHF DAMA Capacity Planning results are only supported through the "View Results" window.

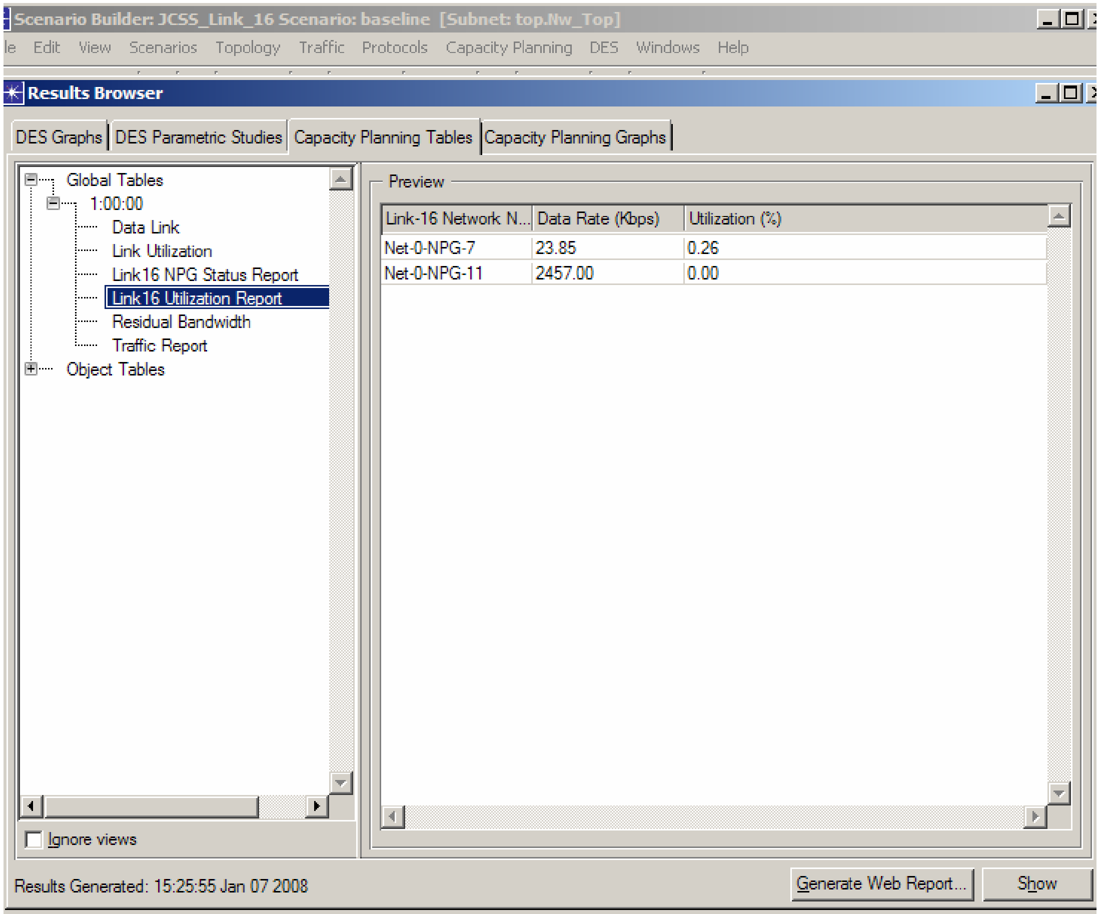
2.11.1 View Results Window

After running the Capacity Planner, the results of the run will be stored in tables that are viewed by right clicking the empty space and selecting "View Results". Switching over to the Capacity Planning Tables tab, the individual results that can be viewed under the Global Tables option include Link-16 NPG Status Report, UHF DAMA Utilization Report, Link Utilization Report as well as other reports that are generated based on the devices and links used in the scenario.

The tables can be sorted to the user preferences before being exported for use to XML, Spreadsheet, or a Web Report. Rows and columns can also be hidden from the table through the choices made by the user in order to reduce the amount of data in view that is not needed for the user.

In addition to the Global Table values, the user can view the IER, Circuit or Application Paths under the Objects Table. From there, each individual IER, Circuit or Application will be listed, and by selecting one, the path from source to destination can be viewed. This includes each specific device and link that the traffic passed over in order to reach the destination.

Figure 1 – Capacity Planner Results in the "View Results" Window



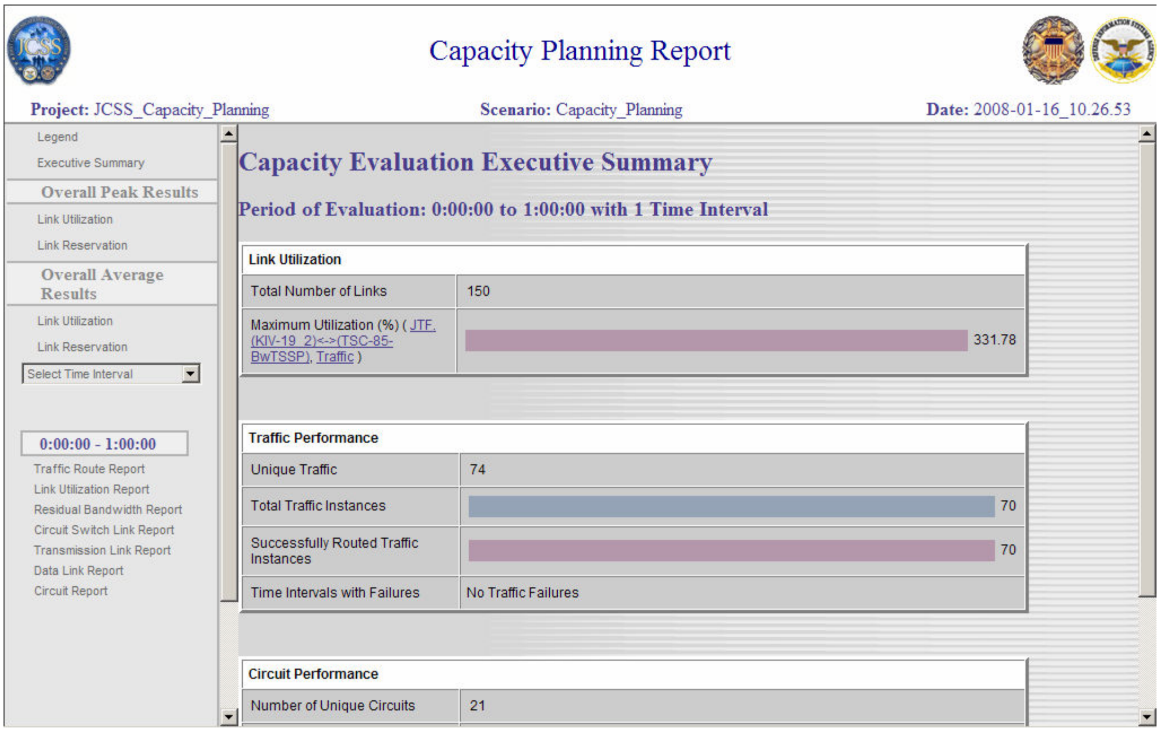
2.11.2 Web Reports

By default, Capacity Planner creates and displays a Web Report after an evaluation is run. The report that will initially appear is an Executive Summary Report. The results available on the Executive Summary Report include: a Link Utilization Report, a Traffic Performance Report, and a Circuit Performance Reports. Additionally, the left hand side of the Executive Summary Report contains links to more detailed web reports as well as a drop down menu that allows the user to navigate to web reports that are specific to a particular time interval. In addition, more detailed reports for Transmission Link Utilization, Circuit Switch Utilization and Data Link Report are also available. Capacity Planning has been enhanced to accurately calculate utilization and circuit reservation. In addition the CP Web Report has been enhanced with the ability to perform column sorting for certain reports.

All of the Web Reports contain the Project and Scenario name. In addition, the Web

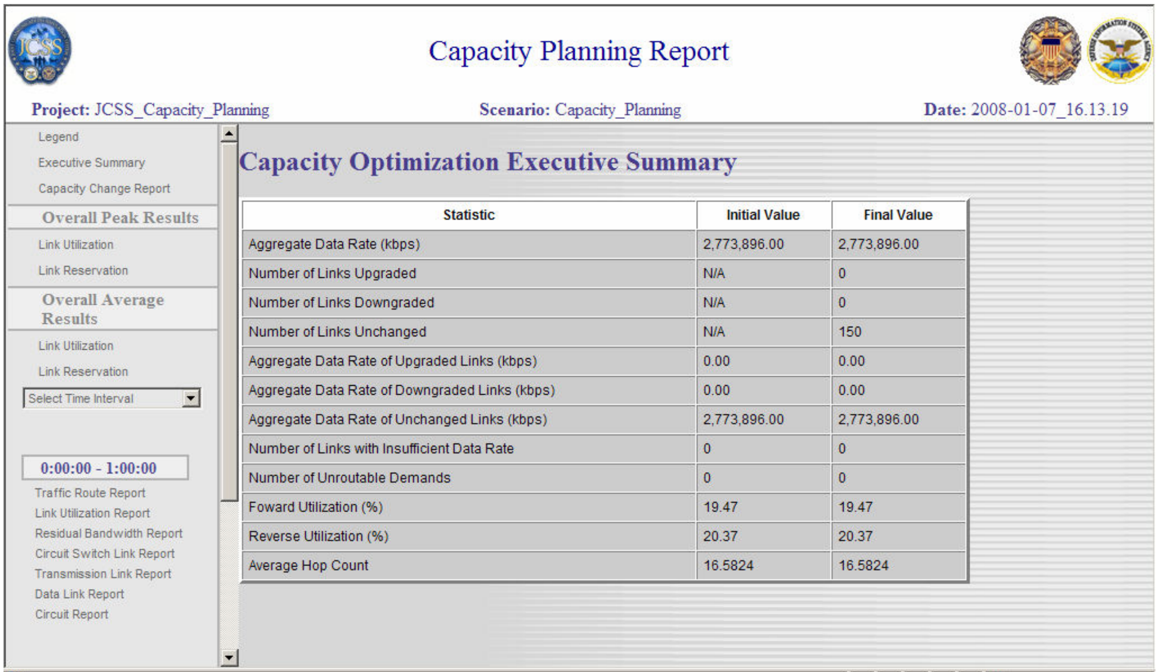
Reports contain links back to the network topology in Scenario Builder. Whenever the name of a network device, link, or OPFAC is referenced in a Web Report, the name is also a hyper link. Figure 1 provides an example of the top portion of the Capacity Evaluation Executive Summary Web Report.

Figure 1 - Capacity Evaluation Executive Summary



Running a Capacity Planner Optimization will produce all of the same Web Reports as an Evaluation with the exception of the Executive Summary Report. After an Optimization is performed on the network, the Executive Summary Web Report will display a comparison between the original state of the network and the new optimized state of the network. The report includes comparisons of the following statistics from before and after Optimization: Overall Data Rate, Number of Links upgraded or downgraded, Number of Links with Insufficient Data Rate, Number of Unroutable Demands, Utilization, and Hop Count. Figure 2 displays an example of the Optimization Executive Summary Web Report.

Figure 2 - Capacity Optimization Executive Summary



Capacity Planning Report

Project: JCSS_Capacity_Planning **Scenario:** Capacity_Planning **Date:** 2008-01-07_16.13.19

Legend
Executive Summary
Capacity Change Report

Overall Peak Results
Link Utilization
Link Reservation

Overall Average Results
Link Utilization
Link Reservation
Select Time Interval

0:00:00 - 1:00:00
Traffic Route Report
Link Utilization Report
Residual Bandwidth Report
Circuit Switch Link Report
Transmission Link Report
Data Link Report
Circuit Report

Capacity Optimization Executive Summary

Statistic	Initial Value	Final Value
Aggregate Data Rate (kbps)	2,773,896.00	2,773,896.00
Number of Links Upgraded	N/A	0
Number of Links Downgraded	N/A	0
Number of Links Unchanged	N/A	150
Aggregate Data Rate of Upgraded Links (kbps)	0.00	0.00
Aggregate Data Rate of Downgraded Links (kbps)	0.00	0.00
Aggregate Data Rate of Unchanged Links (kbps)	2,773,896.00	2,773,896.00
Number of Links with Insufficient Data Rate	0	0
Number of Unroutable Demands	0	0
Foward Utilization (%)	19.47	19.47
Reverse Utilization (%)	20.37	20.37
Average Hop Count	16.5824	16.5824

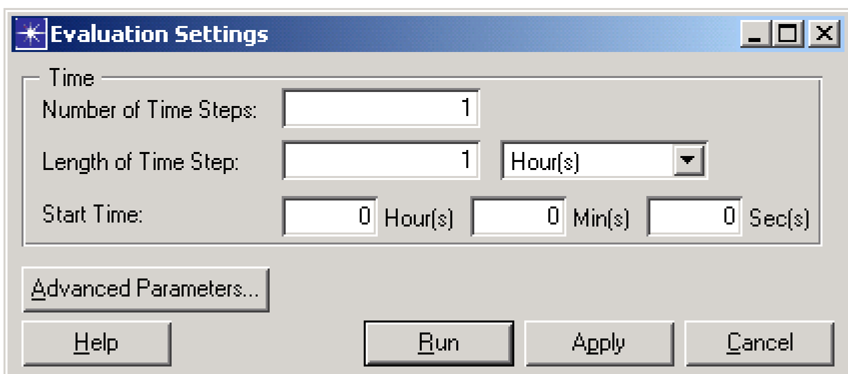
3. Capacity Planner Attributes

This section provides descriptions for attributes which users can use to tailor the Network Evaluation and Capacity Optimization execution for their specific needs.

3.1 Evaluation Attributes

The Evaluation Settings allow the user to define the length and number of time steps to be evaluated. By clicking the Advanced Parameters button, the user can access more options that will influence the routing decisions that will be made by Capacity Planner as well as the nature of the Reports that will be generated. Figure 3 displays the Evaluation Settings GUI and Table 2 describes each parameter and its impact on Evaluation performance.

Figure 3 - Evaluation Settings GUI



The following table describes each parameter and its impact on Evaluation performance.

Table 2 - Evaluation Settings

Settings	Description
Number of Time Steps	Specifies the number of time steps that will be evaluated.
Length of Time Step	Defines the duration of each time step to be evaluated. Evaluation duration can be specified in terms of seconds, minutes, hours, days, or weeks.
Start Time	Specifies when the Network Evaluation will begin.
Advanced Parameters	**Description**
Naming Convention for Reports	Specifies the length of the device name to be used in Reports. Four options are available: device, opfac.device, organization.opfac.device, or Full Name.
Web Report Check Boxes	The first check box specifies whether or not Web Reports will be generated automatically upon running an Evaluation. The second two checkboxes specify whether or not to include individual link and circuit traffic reports. The second two checkboxes are only available if the first checkbox is checked.
Enable IP Load Balancing	Specifies whether or not data will be routed across multiple equal hop IP paths. The number of balanced routes that to be reported may also be defined using this parameter.
Allow ATM SVCs to be Setup	When this checkbox is selected, ATM SVCs will be setup during evaluation when applicable.

3.2 Optimization Attributes

The Optimization engine uses seven main attributes to cater the Optimization outcome. There are more attributes in the advanced section. Figure 4 displays the Optimization Settings GUI and Table 3 describes each parameter and its impact on Optimization performance.

Figure 4 - Optimization Settings GUI

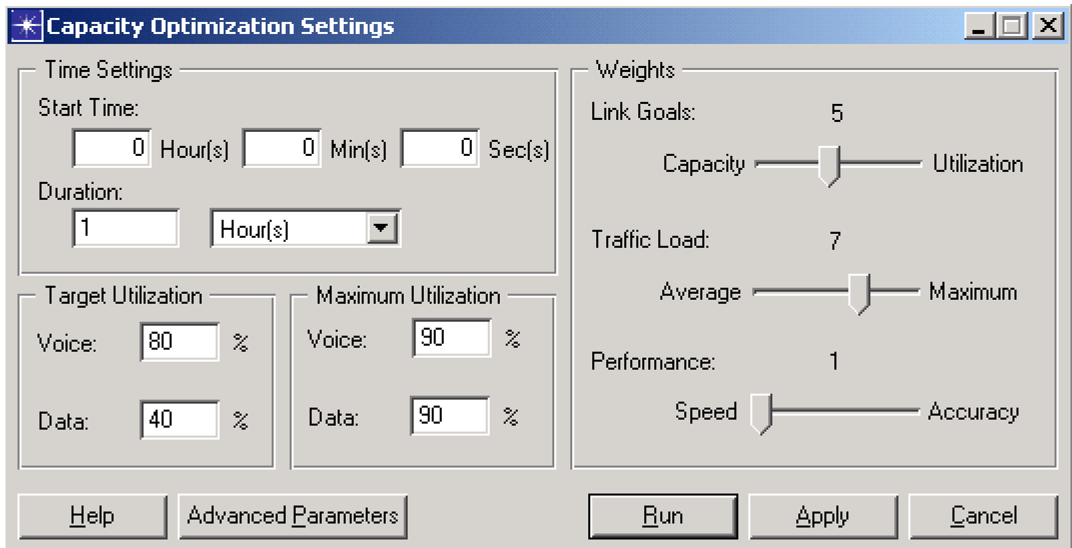


Table 3 - Optimization Settings

Settings	Description
Time Settings	Define the start time and duration of the Optimization.
Target Utilization (%) (Voice and Data)	Influences the utilization cost function for voice and data respectively. Higher costs are assigned as the utilization deviate from the target (either above or below).
Maximum Utilization (%) (Voice and Data)	Defines maximum acceptable utilization percentages for voice and data respectively.
Link Goals (Capacity vs. Utilization)	Specifies a weight for capacity vs. utilization. Moving the slider towards Capacity will produce a solution with reduced capacity, moving the slider towards Utilization will produce a solution in which link utilizations are closer to target settings.
Traffic Load (Avg vs. Max)	Controls the load caused by demands on the network. If the slider is set to 1, the optimization engine will use the mean values from the distribution. As the slider is moved to the right, higher values from the distribution will be used.
Performance (Speed vs. Accuracy)	Defines a tradeoff between the speed and accuracy of the optimization solution. A high slider value will favor accuracy over speed. A lower value will place greater emphasis on speed at the expense of accuracy.

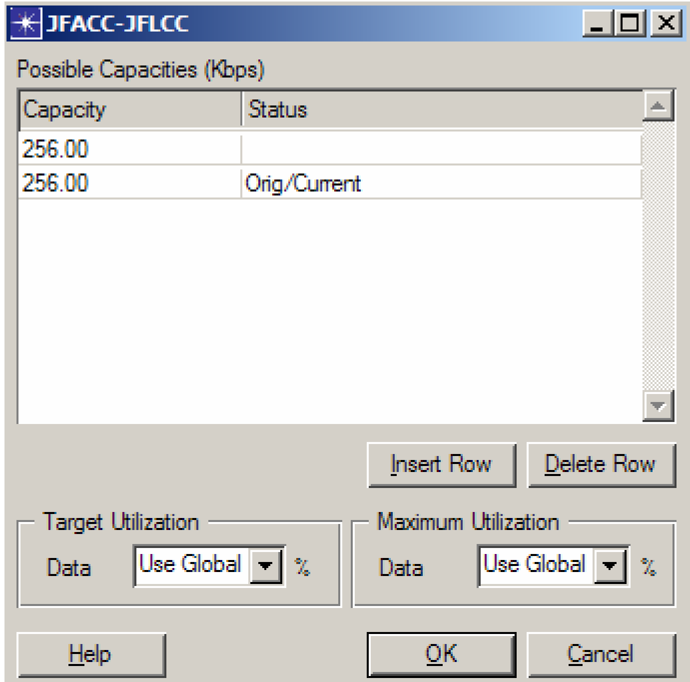
Advanced Parameters	Description
Random Seed	Ensures that the results suggested by the optimization engine are the same for multiple runs if the random number seed is not changed and that the value changes if the random number seed is changed.
Unroutable Demand Penalty	This is the penalty that is added to the objective value of a solution for each unroutable demand.
Number of Solutions to Store	Specifies the number of best solutions to store. The user can switch back forth between the stored solutions.
Alternate Link Cost	When a link becomes overutilized, the optimization may create new links to alleviate the problem. This parameter defines the cost of creating a new link.
Penalize Underutilization	Specify whether underutilized links are costly and optimization engine would influence the optimization result.
Allow ATM SVCs to be Setup	By default, the Capacity Planner ignores the ATM SVC's setup while it evaluates or optimizes a scenario. This parameter allows ATM SVCs to be setup.
Enable IP Load Balancing	This parameter determines whether or not multiple equal hop IP paths will be used. If the parameter is set to "No", the first link that was created will be used.
Per Hop Cost	This is a fixed cost that is computed for each load based on the number of device-to-device hops in the route. If there are multiple solutions that have the same objective cost, adding this cost will ensure that the solution in which the loads have the shortest path is chosen as the best solution.

3.3 Local Optimization Settings

In past NETWARS releases, only one target and maximum utilization setting could be applied in any given Optimization run. In some cases this could be problematic since different links throughout the network topology may have very different ranges of acceptable utilization loads. In the current JCSS 7.0 release, users may set local optimization targets and maximums on a link-by-link basis in addition to setting a global optimization target.

By default, the target and maximum utilization for both voice and data traffic are set to use global settings on all links. However, any link that has local settings configured will use the local settings rather than the global settings that were configured in the Optimization GUI. The user can configure local optimization settings by clicking on the **Optimization Attributes** button that resides within the **Link Attributes** window. Figure 5 shows an example of the Local Optimization GUI.

Figure 5 - Local Optimization GUI

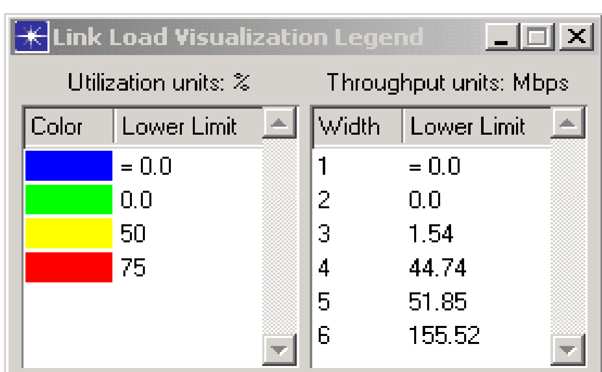


In addition to providing drop down menus to configure local target and maximum utilizations, this GUI also allows the user to define alternate link capacities that will be considered by the Optimization engine.

3.4 Link Load Visualization Settings

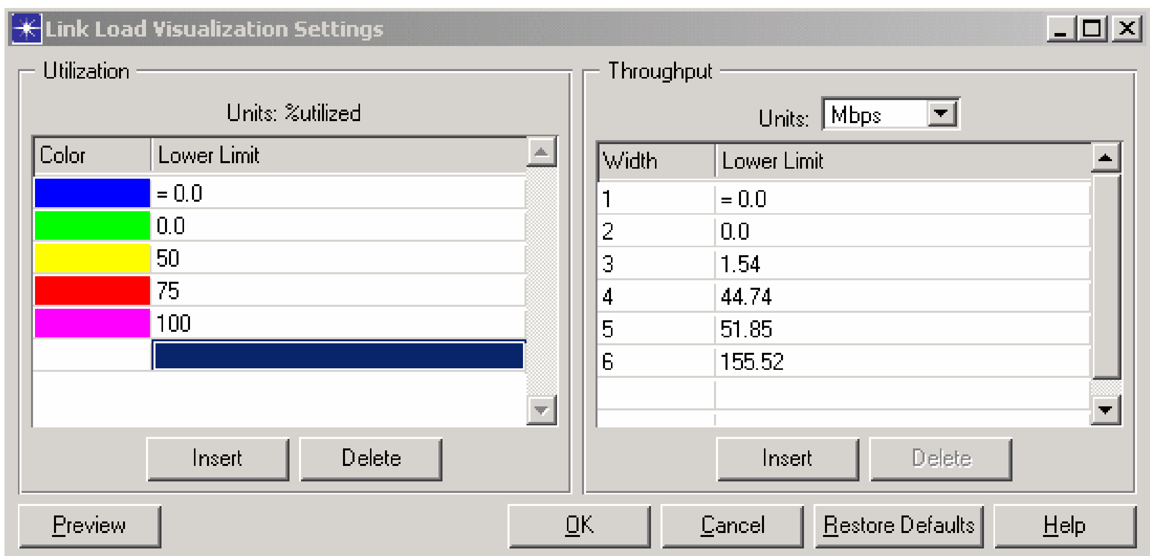
The Link Load Visualization Legend appears at the conclusion of any Capacity Planner Evaluation or Optimization. Figure 6 shows the default Link Load Visualization Legend.

Figure 6 - Link Load Visualization Legend



Although the link legend shown above is the default, the legend can be configured to provide more or less granularity by selecting **View->Visualize Link Loads->Settings**. Figure 7 displays the Link Load Visualization Settings GUI that has already been reconfigured to include an extra color. Any changes made to the Legend can be undone by clicking the **Restore Defaults** button.

Figure 7 - Reconfigured Link Visualization Setting GUI



4. Validation Results

This section provides the Capacity Planner test activities and the conclusive result. The first part describes the elemental requirements test activities and the test result. Second part details the GOTS model list has been tested to work properly within the Capacity Planner.

4.1 Elemental Requirement Verification

To test the performance of Capacity Planner, test cases were defined for each of its several elemental requirements. These test cases were developed to test the Capacity Optimization's functionality relative to the documented elemental requirements as well as its implicit functional performance characteristics associated with each feature.

Test package verification testing was also conducted, which included executing and analyzing test scenarios provided by the developer, OPNET Technologies.

All Capacity Planner elemental requirements have been thoroughly tested. Each elemental requirement was verified against the Software Design Document and to ensure that the software conforms to the intended design.

Please see Appendix A – Elemental Requirements for detailed information regarding the verification of elemental requirements.

4.2 Models Tested

In addition to elemental requirements verification, scenarios were executed to validate the performance of the Capacity Planner. These scenarios were relatively complex networks consisting of multiple network models and links with realistic traffic loads and were used to validate the performance of node models within the Capacity Planner. During the course of Capacity Planner Validation, it was determined that all JCSS Standard Models function properly within Capacity Planner.

4.3 Validation of the Capacity Planner Link Utilization

The Capacity Planner provides a quick analytical evaluation of link and network utilizations based on a given network topology and the associated traffic inputs. The following section provides details of testing efforts conducted to validate the result of the Capacity Planner link utilization. The validation approach focused on a comparison of link utilization outputs produced by the Capacity Planner evaluation function and the simulation results produced by the Discrete Event Simulation (DES).

To compare the link utilization results, a simple data network was developed in the Scenario Builder and executed in the DES. Identical scenarios were then evaluated in the Capacity Planner. Link utilization output from each tool was compared to develop a conclusion on the validity of the results.

4.3.1 Test Description

To support this effort, 64 different scenarios were created and analyzed.

4.3.1.1 Network Characteristics

For the simplicity of the validation process, the same topology was used in all 64 network scenarios. The traffic load (demand size), traffic directions (uni-directional or bi-directional traffic) and inter-arrival mean were varied based on the following scenario values:

- Link size (LS): T1 (1,544,000 bps)
- Demand size (DS): 50,000, 100,000, 500,000, 1,000,000 in bytes
- Target utilization (TU): 20%, 40%, 60%, 80%
- Protocol (PR): TCP, UDP
- Uni-directional and bi-directional traffic (UB)

To determine the inter-arrival mean associated with a given target utilization and demand size, the following equations was utilized:

inter-arrival mean (in seconds) = (demand size * 8 bits per byte) / (link size * target utilization)

The equation ensured that the Capacity Planner values would be identical to the target utilizations.

The link utilization collected from running these scenarios in the Scenario Builder and Capacity Planner were recorded and compared against each other. The Result Analyzer was used to view link statistics obtained from the simulation engine of the Scenario Builder while the link utilization web reports were used to view the link statistics generated by the Capacity Planner.

4.3.2 Assumptions

The following assumptions were used for all scenarios:

- No background traffic
- Exponential distribution was used as the distribution type in the test networks

4.3.3 Validation Procedure

The validation process is fairly simple but labor intensive. All 64 scenarios were individually evaluated in the Capacity Planner for 1 one-hour time interval to collect link utilization.

To collect DES link statistics, the scenarios were executed for one hour each in the Simulation Domain. The Results Analyzer was used to interpret the link statistics and the link utilization was recorded.

4.3.4 Validation Results

Table 4 shows the details of data link utilization collected from the Capacity Planner and the Scenario Builder. One observation from **Table 4** is that the data link utilization obtained from the Capacity Planner is always the exact values as expected since the Capacity Planner calculates link utilization analytically and traffic overhead associated with transport, network and link layer protocols are not taken into account.

The scenario naming convention for data networks used in this validation as follows:

TrafficType_Protocol_LinkSize_DirectionalTraffic_[SYM]_ExpectedUtilization_MessageSize

Where [SYM] is optional and to indicate whether the bi-directional traffic is symmetric (traffic generated from both directions in equal amount).

Example1: DATA_TCP_T1_UNI_20_2000 meaning:

- ***TrafficType:*** DATA
- ***Protocol:*** TCP
- ***LinkSize:*** T1 (1,544,000 bps)
- ***DirectionalTraffic:*** Uni-directional traffic
- ***ExpectedUtilization:*** 20%
- ***MessageSize:*** 2,000 bytes

Example 2: DATA_UDP_T1_BI_SYM_40_10000 meaning:

- ***TrafficType:*** DATA
- ***Protocol:*** UDP
- ***LinkSize:*** T1 (1,544,000 bps)
- ***DirectionalTraffic:*** Symmetric bi-directional traffic
- ***ExpectedUtilization:*** 40%
- MessageSize: 10,000 bytes

Table 4 - Link Utilization Capacity Planner vs. DES

#	Scenario	Link Size (bps)	Inter-arrival Mean (sec)	A->B Utilization (%)	B->A Utilization (%)	Demand Size (bytes)	DES FWD Link Utilization (%)	DES REV Link Utilization (%)
01	DATA_TCP_T1_UNI_20_50000	1,544,000	1.295350	20	0	50,000	19.896883	0.281155
02	DATA_TCP_T1_UNI_20_100000	1,544,000	2.590674	20	0	100,000	20.805071	0.286619
03	DATA_TCP_T1_UNI_20_500000	1,544,000	12.953368	20	0	500,000	21.441727	0.290116
04	DATA_TCP_T1_UNI_20_1000000	1,544,000	25.906736	20	0	1,000,000	17.448890	0.235840
05	DATA_TCP_T1_UNI_40_50000	1,544,000	0.647675	40	0	50,000	40.861275	0.565139
06	DATA_TCP_T1_UNI_40_100000	1,544,000	1.295337	40	0	100,000	42.216599	0.575928
07	DATA_TCP_T1_UNI_40_500000	1,544,000	6.476750	40	0	500,000	37.929410	0.512716

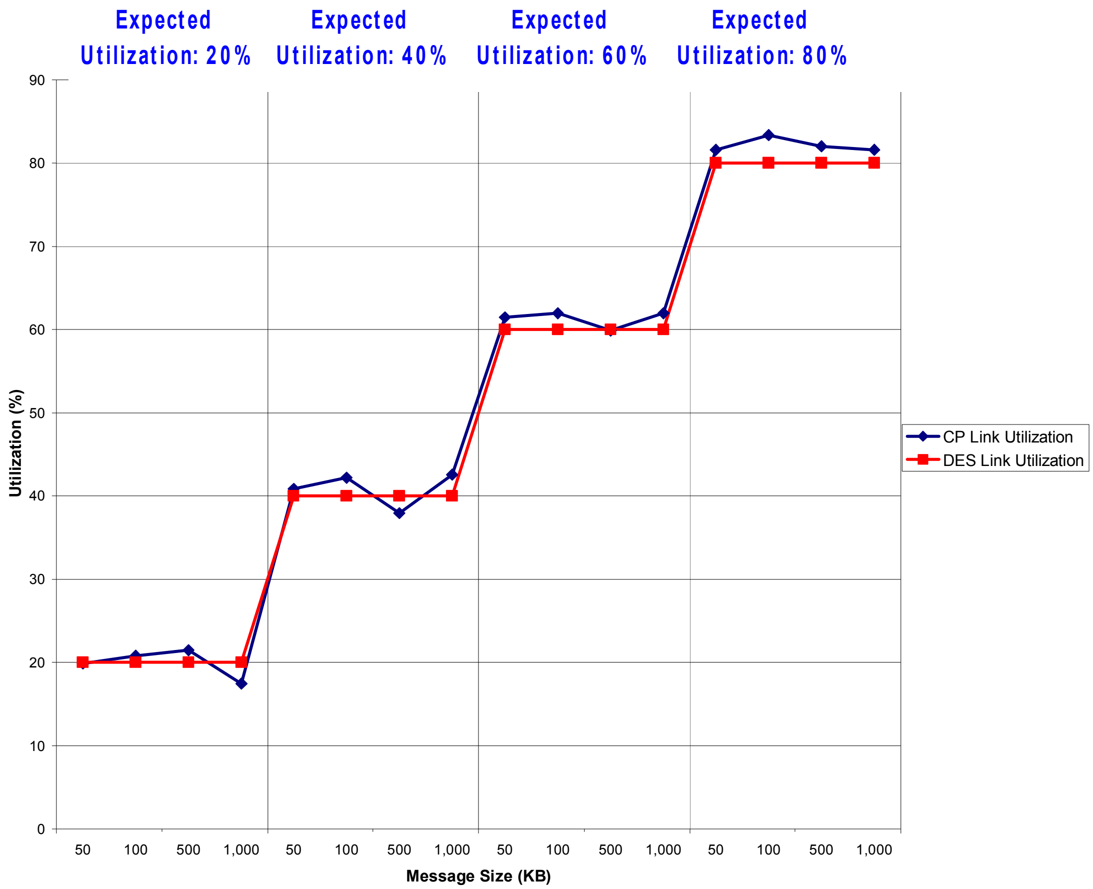
#	Scenario	Link Size (bps)	Inter-arrival Mean (sec)	A->B Utilization (%)	B->A Utilization (%)	Demand Size (bytes)	DES FWD Link Utilization (%)	DES REV Link Utilization (%)
08	DATA_TCP_T1_UNI_40_1000000	1,544,000	12.953368	40	0	1,000,000	42.586578	0.574645
09	DATA_TCP_T1_UNI_60_50000	1,544,000	0.431783	60	0	50,000	61.458673	0.839808
10	DATA_TCP_T1_UNI_60_100000	1,544,000	0.863567	60	0	100,000	61.968325	0.840585
11	DATA_TCP_T1_UNI_60_500000	1,544,000	4.317833	60	0	500,000	59.912293	0.808709
12	DATA_TCP_T1_UNI_60_1000000	1,544,000	8.635579	60	0	1,000,000	61.957516	0.835473
13	DATA_TCP_T1_UNI_80_50000	1,544,000	0.323835	80	0	50,000	81.601418	1.105963
14	DATA_TCP_T1_UNI_80_100000	1,544,000	0.647675	80	0	100,000	83.370751	1.126112
15	DATA_TCP_T1_UNI_80_500000	1,544,000	3.238375	80	0	500,000	82.059063	1.106481
16	DATA_TCP_T1_UNI_80_1000000	1,544,000	6.476684	80	0	1,000,000	81.593438	1.099751
17	DATA_UDP_T1_UNI_20_50000	1,544,000	1.295350	20	0	50,000	20.200819	0.000026
18	DATA_UDP_T1_UNI_20_100000	1,544,000	2.590674	20	0	100,000	19.876449	0.000026
19	DATA_UDP_T1_UNI_20_500000	1,544,000	12.953368	20	0	500,000	20.793546	0.000026
20	DATA_UDP_T1_UNI_20_1000000	1,544,000	25.906736	20	0	1,000,000	21.742451	0.000026
21	DATA_UDP_T1_UNI_40_50000	1,544,000	0.647675	40	0	50,000	40.543115	0.000026
22	DATA_UDP_T1_UNI_40_100000	1,544,000	1.295337	40	0	100,000	41.620842	0.000026
23	DATA_UDP_T1_UNI_40_500000	1,544,000	6.476750	40	0	500,000	37.866116	0.000026
24	DATA_UDP_T1_UNI_40_1000000	1,544,000	12.953368	40	0	1,000,000	38.965112	0.000026
25	DATA_UDP_T1_UNI_60_50000	1,544,000	0.431783	60	0	50,000	60.500259	0.000026
26	DATA_UDP_T1_UNI_60_100000	1,544,000	0.863567	60	0	100,000	59.580073	0.000026
27	DATA_UDP_T1_UNI_60_500000	1,544,000	4.317833	60	0	500,000	64.066891	0.000026
28	DATA_UDP_T1_UNI_60_1000000	1,544,000	8.635579	60	0	1,000,000	63.330301	0.000026
29	DATA_UDP_T1_UNI_80_50000	1,544,000	0.323875	80	0	50,000	80.303768	0.000026
30	DATA_UDP_T1_UNI_80_100000	1,544,000	0.647675	80	0	100,000	80.740470	0.000026
31	DATA_UDP_T1_UNI_80_500000	1,544,000	3.238375	80	0	500,000	79.259616	0.000026
32	DATA_UDP_T1_UNI_80_1000000	1,544,000	6.476684	80	0	1,000,000	77.866146	0.000026
33	DATA_TCP_T1_BI_SYM_20_50000	1,544,000	1.295350	20	20	50,000	20.359813	21.300880
34	DATA_TCP_T1_BI_SYM_20_100000	1,544,000	2.590674	20	20	100,000	21.199336	21.170304
35	DATA_TCP_T1_BI_SYM_20_500000	1,544,000	12.953368	20	20	500,000	20.615717	21.126322
36	DATA_TCP_T1_BI_SYM_20_1000000	1,544,000	25.906736	20	20	1,000,000	18.801325	23.686385
37	DATA_TCP_T1_BI_SYM_40_50000	1,544,000	0.647675	40	40	50,000	41.147089	41.982929
38	DATA_TCP_T1_BI_SYM_40_100000	1,544,000	1.295337	40	40	100,000	41.322778	40.826784
39	DATA_TCP_T1_BI_SYM_40_500000	1,544,000	6.476684	40	40	500,000	41.466797	43.217474
40	DATA_TCP_T1_BI_SYM_40_1000000	1,544,000	12.953368	40	40	1,000,000	42.536834	40.494239
41	DATA_TCP_T1_BI_SYM_60_50000	1,544,000	0.431783	60	60	50,000	62.250648	63.007560
42	DATA_TCP_T1_BI_SYM_60_100000	1,544,000	0.863567	60	60	100,000	61.030617	62.272463
43	DATA_TCP_T1_BI_SYM_60_500000	1,544,000	4.317833	60	60	500,000	63.175473	63.165287
44	DATA_TCP_T1_BI_SYM_60_1000000	1,544,000	8.635579	60	60	1,000,000	57.027030	58.455373

#	Scenario	Link Size (bps)	Inter-arrival Mean (sec)	A->B Utilization (%)	B->A Utilization (%)	Demand Size (bytes)	DES FWD Link Utilization (%)	DES REV Link Utilization (%)
45	DATA_TCP_T1_BI_SYM_80_50000	1,544,000	0.323835	80	80	50,000	83.039614	84.555706
46	DATA_TCP_T1_BI_SYM_80_100000	1,544,000	0.647668	80	80	100,000	84.669378	82.440240
47	DATA_TCP_T1_BI_SYM_80_500000	1,544,000	3.238375	80	80	500,000	81.006169	83.541207
48	DATA_TCP_T1_BI_SYM_80_1000000	1,544,000	6.476684	80	80	1,000,000	80.050706	81.161705
49	DATA_UDP_T1_BI_SYM_20_50000	1,544,000	1.295350	20	20	50,000	20.558290	19.852653
50	DATA_UDP_T1_BI_SYM_20_100000	1,544,000	2.590674	20	20	100,000	20.212101	20.139128
51	DATA_UDP_T1_BI_SYM_20_500000	1,544,000	12.953368	20	20	500,000	22.471619	20.647622
52	DATA_UDP_T1_BI_SYM_20_1000000	1,544,000	25.906736	20	20	1,000,000	22.763907	17.802545
53	DATA_UDP_T1_BI_SYM_40_50000	1,544,000	0.647675	40	40	50,000	40.080611	40.270286
54	DATA_UDP_T1_BI_SYM_40_100000	1,544,000	1.295337	40	40	100,000	41.095474	40.219856
55	DATA_UDP_T1_BI_SYM_40_500000	1,544,000	6.476684	40	40	500,000	38.960511	38.949865
56	DATA_UDP_T1_BI_SYM_40_1000000	1,544,000	12.953368	40	40	1,000,000	40.242013	39.690887
57	DATA_UDP_T1_BI_SYM_60_50000	1,544,000	0.431772	60	60	50,000	60.632337	61.038652
58	DATA_UDP_T1_BI_SYM_60_100000	1,544,000	0.863567	60	60	100,000	59.585504	61.689630
59	DATA_UDP_T1_BI_SYM_60_500000	1,544,000	4.317717	60	60	500,000	58.075953	59.681062
60	DATA_UDP_T1_BI_SYM_60_1000000	1,544,000	8.635579	60	60	1,000,000	60.120010	61.107455
61	DATA_UDP_T1_BI_SYM_80_50000	1,544,000	0.323834	80	80	50,000	79.980822	79.525771
62	DATA_UDP_T1_BI_SYM_80_100000	1,544,000	0.647668	80	80	100,000	81.463641	81.195151
63	DATA_UDP_T1_BI_SYM_80_500000	1,544,000	3.238342	80	80	500,000	85.524785	79.488272
64	DATA_UDP_T1_BI_SYM_80_1000000	1,544,000	6.476684	80	80	1,000,000	78.652140	79.755063

4.3.5 Conclusions

The Capacity Planner generates link utilization in which the results are consistent with the target utilizations in both directions. This was expected due to the nature of the capacity planner loading equation that does not incorporate network overhead. Figure 8 shows the forward link utilization obtained from the Capacity Planner is equal to the target utilization whereas the link utilization collected from the Scenario Builder is slightly higher than the expected utilization. This is due to the network overhead associated with TCP and IP overhead that is included by the DES. For reverse link utilization during the uni-directional tests, the Capacity Planner generated 0% link utilization whereas the DES generated low link utilization values (<5%) due to the TCP control messages associated with the positive acknowledgement algorithm employed by TCP.

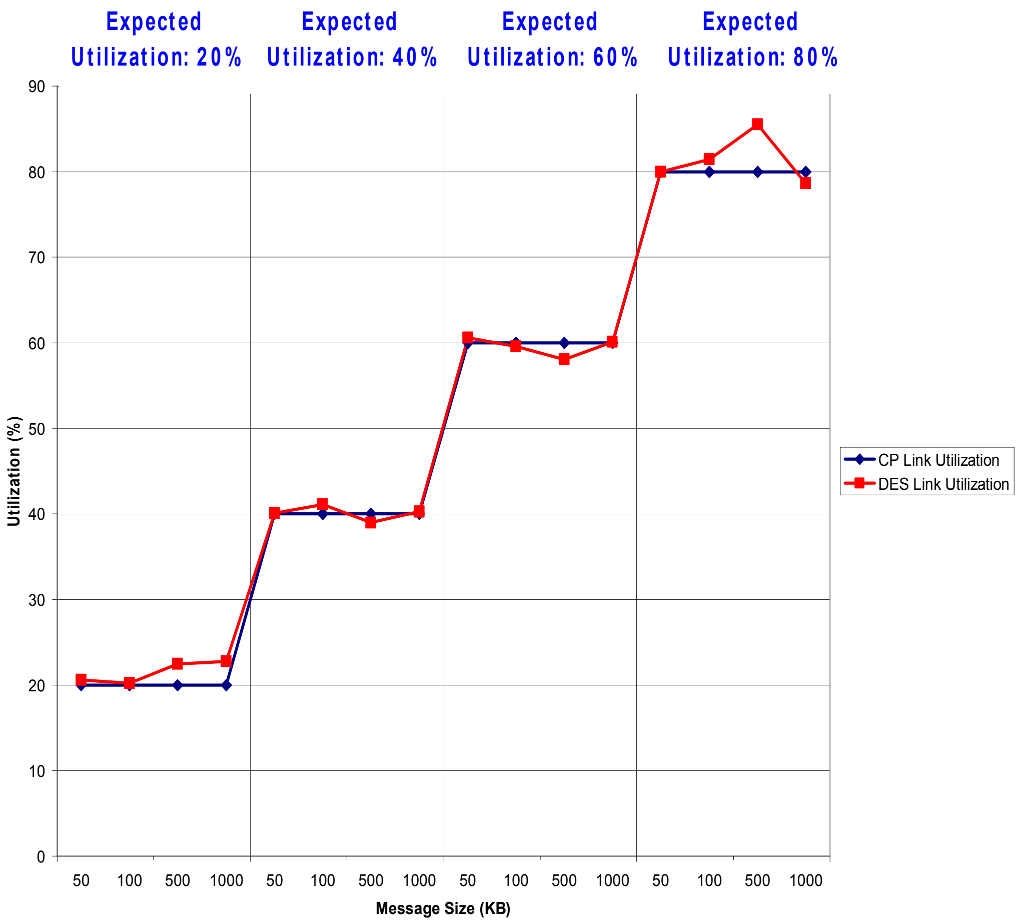
Figure 8 - CP vs. DES Link Utilization - Uni-directional Traffic (TCP)



The difference between the forward utilization in each case was expected to decrease as the packed size increased. This was expected because the network overhead is directly related to the number of packets and the smaller the packet size the greater the number of packets. The random nature of the exponential distribution for the traffic prevented this trend from being illustrated in this comparison. However, if a longer DES run time had been used in the comparison it is likely that the expected behavior would be demonstrated.

Figure 9 shows the forward and reverse link utilization of UDP unidirectional traffic. Note that the UDP DES results include a smaller network overhead in comparison to the similar TCP results. Also notice that as packet size increases in several of the cases, the DES simulation results are less than the target utilization. This is due to contention and is a larger factor in the higher utilization cases.

Figure 9 - CP vs. DES Link Utilization - Uni-directional Traffic (UDP)



Figures 10 and 11 shows the link utilization for the bi-directional cases. The behavior is similar to the uni-directional cases except the reverse utilization values reflect the target utilization values.

Figure 10 - CP vs. DES Link Utilization - Bi-directional DATA Traffic (TCP)

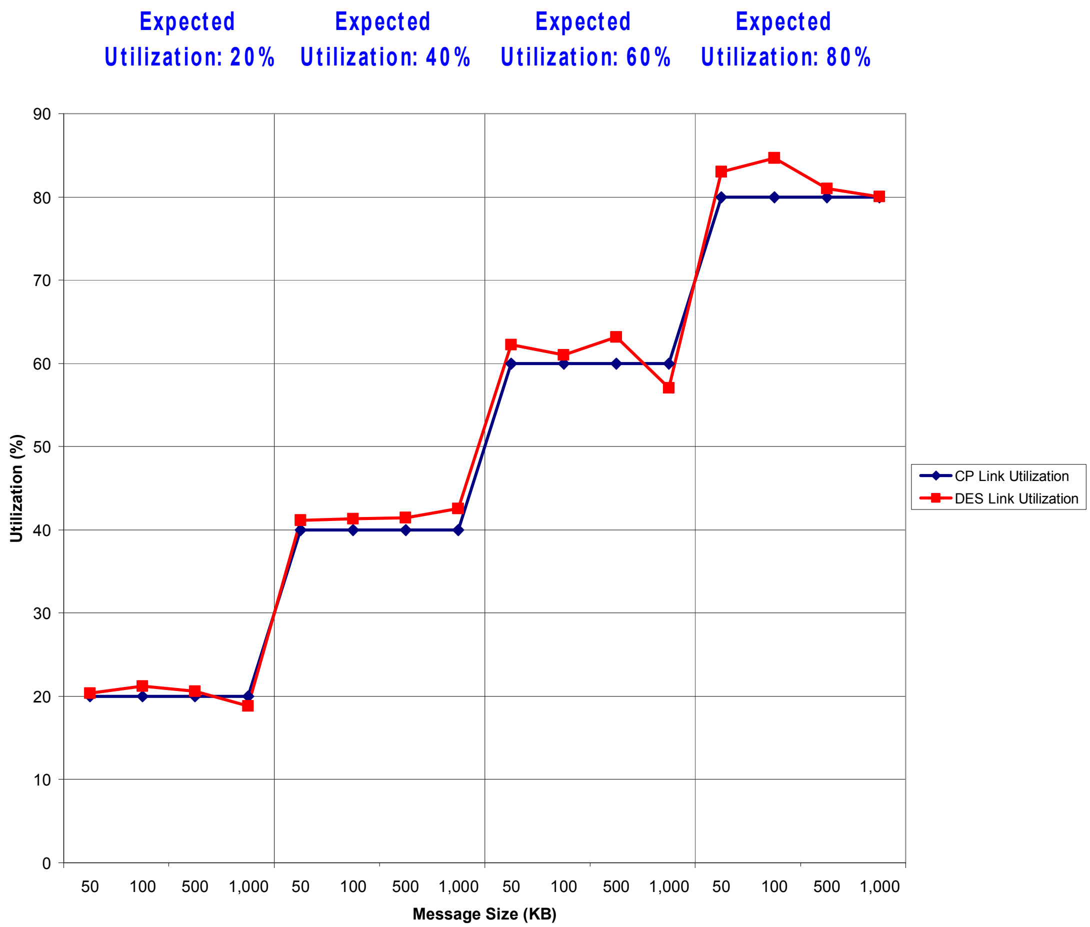
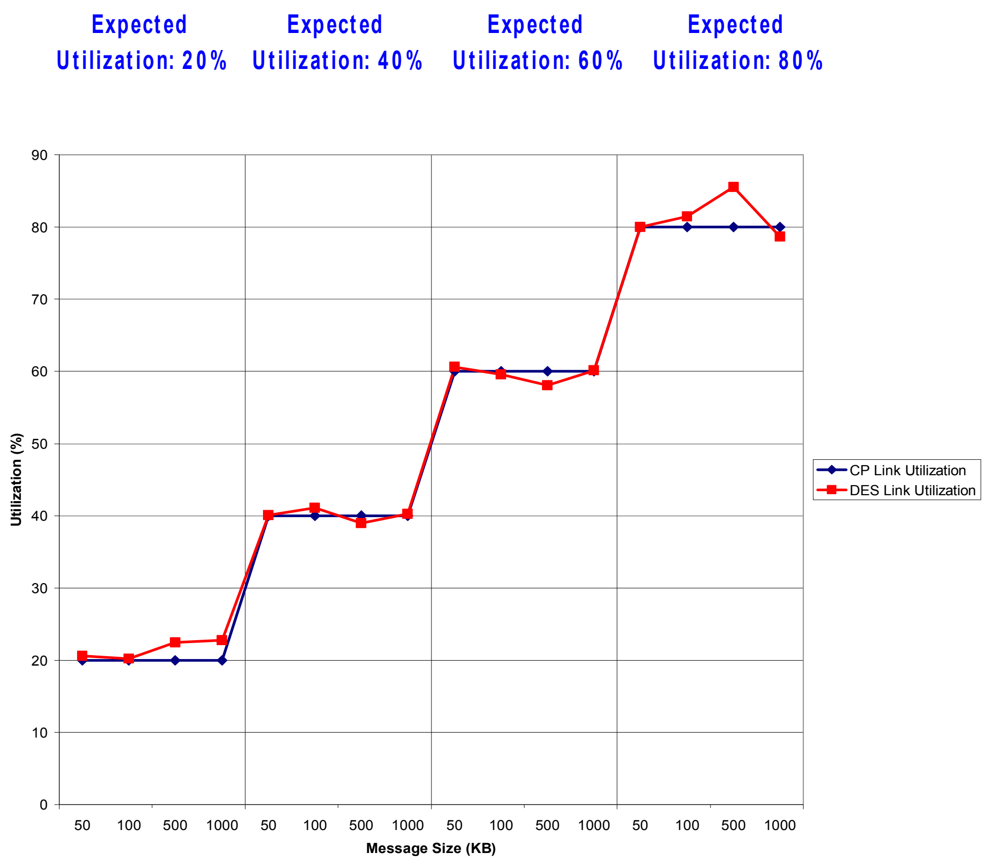


Figure 11 - CP vs. SB Link Utilization - Bi-directional DATA Traffic (UDP)



4.4 Validation of Alternate Path Selection and Failure Analysis

The Capacity Planning tool routes all data traffic over the path with the fewest number of hops. All data traffic will continue to flow over the shortest path regardless of congestion on network links along the path. The only time that data will be routed over a longer hop path is in the event of a link failure on the shortest path. The following section is designed to validate whether or not Capacity Planner is correctly routing data traffic over the shortest hop path and correctly rerouting the same traffic after a link along the original path has failed.

4.4.1 Test Description

To support this effort, a network was built in Scenario Builder containing one shortest hop path between source and destination OPFACs. After a link along the shortest path fails, Capacity Planner will route the traffic along the next available shortest hop path. Capacity Evaluation results were generated before and after link failure to demonstrate the difference in the way the traffic was routed by Capacity Planner in each case.

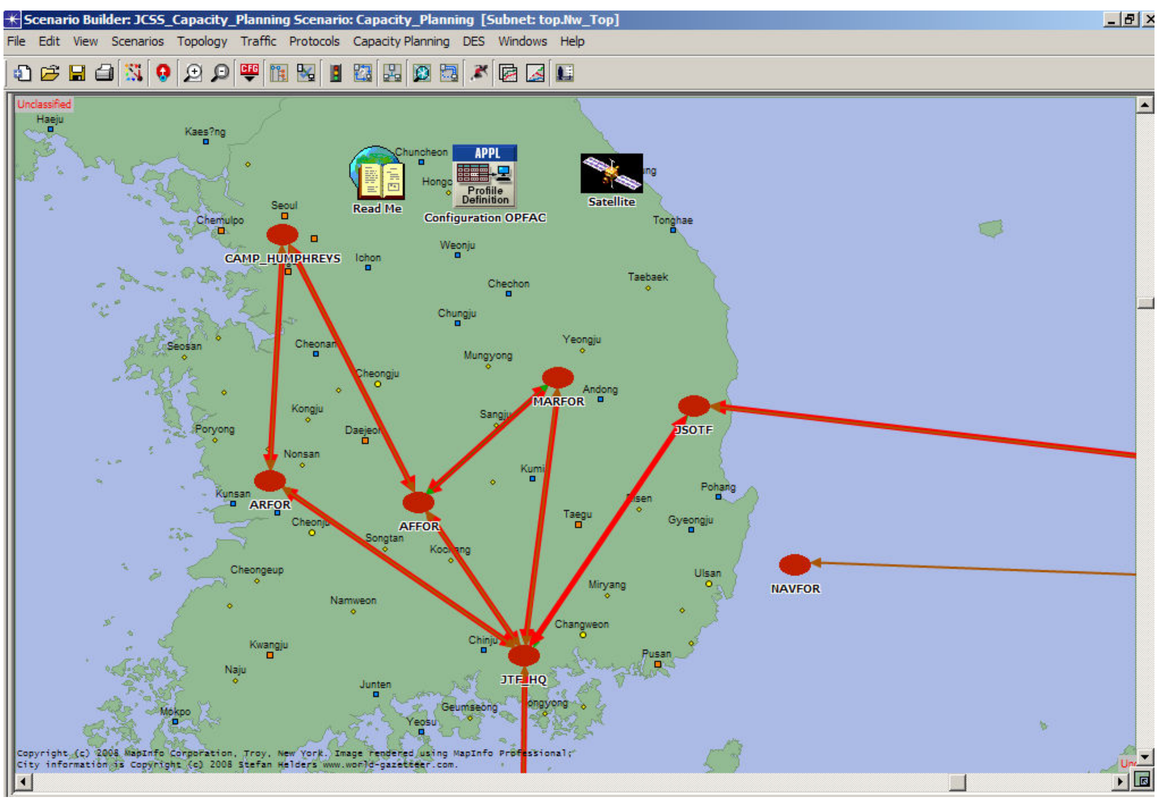
4.4.2 Validation Procedure

The test scenario was evaluated first in its original state to ensure that Capacity Planner routed the traffic over the shortest hop path. The scenario was then evaluated a second time after a link along the shortest hop path had been failed. The purpose of the second evaluation was to ensure that the Capacity Planner rerouted the traffic to the next shortest hop path and identified the failed network link in the topology.

4.4.3 Validation Results

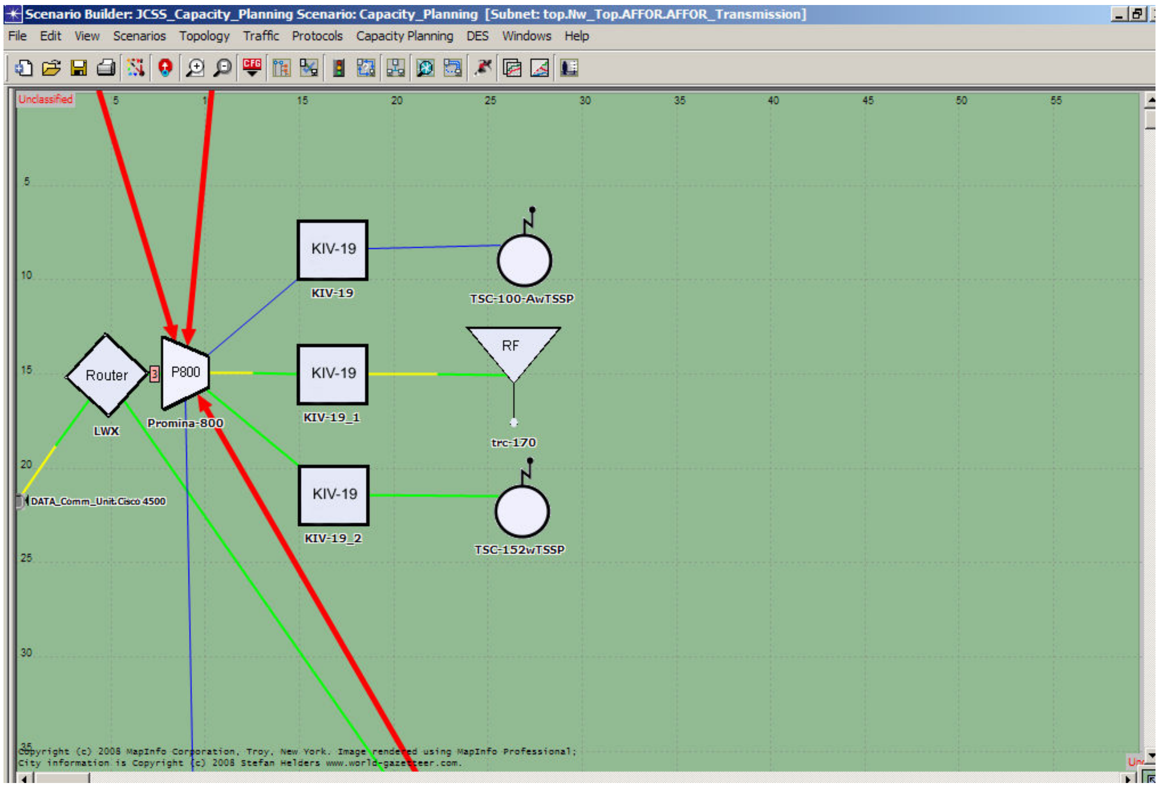
Figure 12 shows the Network Topology that was used for this validation. The red arrow is a representation of the aggregate traffic flow between the source and destination OPFACs in the scenario.

Figure 12 - Network Topology Before Evaluation



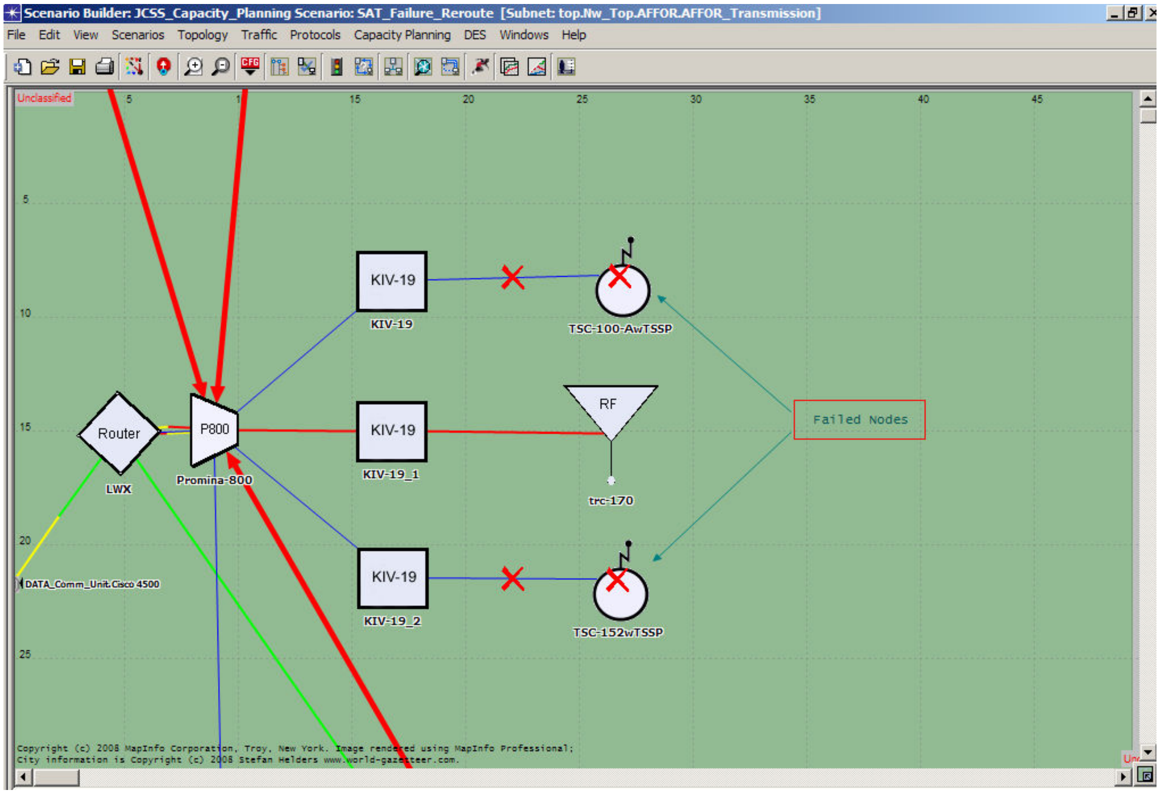
After Capacity Planner has evaluated the network, the links that have routed traffic are colored according to the Link Load Visualization Legend. **Figure 13** illustrates the traffic traversing the shortest hop path between the JFLCC-DATA and MAGTF-DATA OPFACs.

Figure 13 - Traffic Routed Along Shortest Hop Path



The shortest hop path carries traffic over the link between CFH and MAGTF OPFACs. After that link fails, Capacity Planner must reroute the traffic over the next shortest path. **Figure 14** illustrates the Evaluation Results after the link has failed.

Figure 14 - Traffic Rerouted After Link Failure



As a result of the link failure, Capacity Planner was forced to route the traffic to the next shortest path. Notice that the failed link has been marked with a red X in the network topology. Instead of traveling directly from CFH to MAGTF, the traffic now traverses a slightly longer route from CFH to JFMCC and then on to MAGTF.

4.4.4 Conclusion

In the initial Evaluation run, Capacity Planner correctly routed the traffic from source to destination via the shortest hop path. Following a link failure on the shortest hop path, Capacity Planner correctly rerouted the traffic to the next available shortest hop path. Additionally, Capacity Planner identified the failed link by marking it in the network topology. The combination of these features shows Capacity Planner to be an effective tool for conducting failure analysis on a simulated network.

5. Summary

All Capacity Planner elemental requirements have been thoroughly verified. There were several cases that were impossible to generate test cases to test requirements, but they were verified through a consistent series of repeatedly correct solutions.

The link utilization values calculated by the Capacity Planner have been verified to conform to the results obtained from the discrete event simulation engine. Although a small variance existed between the results generated by Capacity Planner and those generated by Discrete Event Simulation, the speed of the Capacity Planner makes the tool an attractive option when there is limited time to conduct detailed simulations.

The ability to consider failed network links and reroute traffic to the best remaining path proves that Capacity Planner can be used as an effective tool in failure analysis studies. The Capacity Planner will be most beneficial and generate the best results to users who understand the scenario, its associated infrastructure and demands, and optimize the scenario in the most accurate mode.

6. Appendix A – Acronym List

Acronym	Description
C4	Command, Control, Communications, and Computer
CD	Compact Disk
CDM	Communications Device Model
CM	Configuration Management
COTS	Commercial-Off-The-Shelf
CSCI	Commercial Satellite Communications Initiative
DISA	Defense Information Systems Agency
DISN	Defense Information System Network
DoD	Department of Defense
GOTS	Government-Off-The-Shelf
IATAC	Information Assurance Technology Analysis Center
IER	Information Exchange Requirement
JS	Joint Staff
JTF	Joint Task Force
JNMS	Joint Network Management System
JTIDS	Joint Tactical Information Distribution System
OE	Operational Element
OPFAC	Operational Facilities
OSPF	Open Shortest Path Routing
OT	Operational Testing
SCM	Simulation Control Module
SINCGARS	Single Channel Ground and Airborne Radio System
SOW	Statement of Work
SPR	Software Problem Report
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
V&V	Verification and Validation
WAN	Wide Area Network
WIPT	Working Integration Process Team
WOD	Word of Day