

# An Intelligent Tool for Network Configuration and Optimization

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*Abstract*—SHAI, in conjunction with OPNET, is developing an Intelligent Network Configuration Optimization Toolkit (INCOT) for the US Air Force. INCOT's goal is to provide an intelligent interface to OPNET products, allowing rapid design and optimization of communications networks without requiring the user to have programming skills or knowledge of the underlying OPNET simulation products. There is currently a great need for any solution that will dramatically reduce the complexity of network configuration due to the great quantity and diversity of information that must be analyzed, as well as the short decision cycles. By incorporating expert knowledge of network engineering, policies, available components and their characteristics, INCOT is providing an interactive goal driven rapid development tool to the network engineer that can quickly generate a network configuration. INCOT is extending the power of OPNET's network simulation tools, while simplifying its operation for Air Force network engineers.

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## 1. INTRODUCTION

### *Problem Statement*

Modern conflict is becoming ever more dependent on larger quantities of information, and communications, intelligence, and other critical information in the field is often transmitted over networks that may need to be configured under severe time constraints. Given these time constraints, it is imperative that networks in tactical military situations be designed optimally to maximally support the goals of the mission. Thus, a solution is needed to meet the goal of

engineering optimal networks to meet mission critical data requirements, while allowing for the design, testing and optimization of such networks under severe time constraints.

The problem is compounded because network engineering under any circumstance requires expert knowledge that is dependent on the context and environment in which the network will need to operate. In addition, there are various other constraints, including the equipment that will be available, security considerations and other policy-based constraints. Present commercial simulation engines are powerful tools for developing and testing potential networks, but their power has, to date, been accompanied with a high level of complexity, so the utilization of commercial simulation engines has associated with it the need for understanding of the complex software including programming skills, although many aspects of the software may never be used.

Fortunately, the power afforded by the state of the art in commercial network simulation tools is sufficient to simulate the networks that need to be constructed. The major obstacle is that the complexity of the tools does not allow their power to be exploited under the time constraints afforded by modern tactical military situations, except via the most expert users who may not be available. Another way to view the problem is that users with a working knowledge of communications networks (though not necessarily an expert in any network simulation tool) need to be able to construct optimal networks quickly, these less-than-expert users must still build the network as if they had expert knowledge of device characteristics, and they must adhere to all policies.

### *Opportunity*

Current OPNET Technologies, Inc. (OPNET, [www.opnet.com](http://www.opnet.com)) products provide sophisticated network

<sup>1</sup> 0-7803-7651-X/03/\$17.00 © 2003 IEEE

<sup>2</sup> IEEEAC paper #1210, Updated December 10, 2002

simulation capabilities allowing for the simulation of entire global networks from the global level down to sub-switch level. The users of the current generation of tools are mainly experts in networking who perceive the present tools of huge utility. However, the Air Force needs to utilize less than expert network engineers for many of their networking needs.

By providing an intelligent interface to OPNET products to assist with network configuration and operations, a great advancement will be made in the usability of the software to the Air Force. By providing an artificial intelligence [1] toolkit incorporating expert knowledge of device characteristics, goal oriented optimization, and constraints to ensure policy adherence, a non-expert could quickly design or fine tune communication networks without requiring knowledge of the underlying simulation engine.

### *Approach*

Clearly, the decision process employed by network engineers presently to build communications networks is *not* a simple one. Yet, in order to provide an effective intelligent interface, it is essential that we understand the process of network design and have valid methods for formulating and representing the decision task requirements [2]. To meet the challenge SHAI has teamed with OPNET. SHAI is a premier Artificial Intelligence company that has completed over 100 projects, while OPNET Technologies is the developer of best of breed network simulation products. Even though our team has formidable networking knowledge, SHAI supplemented this knowledge with a knowledge elicitation process.

Via the knowledge elicitation we developed a thorough understanding of the decision requirements of the network engineer. These requirements were used to identify cognitive functions [3] that needed support, to develop system functions for INCOT, and to provide a basis for assessing the effectiveness of the resulting evolving toolkit.

## **2. SYSTEM DESCRIPTION AND DESIGN**

The following sub-sections provide the objectives, a functional description and an overview of the architecture for the Intelligent Network Configuration Optimization Toolkit (INCOT).

### *Objectives*

The objective of INCOT is to develop an innovative intelligent toolkit interface to OPNET, a COTS simulation engine, to configure and optimize network configuration and operations. (Reference to 'OPNET' refers to any tool developed by OPNET Technologies, Inc.) This toolkit will allow rapid design and optimization of communications networks without requiring the user to have programming skills or knowledge of the underlying OPNET simulation engine. By incorporating expert knowledge of network

engineering, policies, available components and their characteristics, INCOT will be able to provide an interactive goal driven rapid development tool to the network engineer that will quickly generate optimal network configurations.

### *Functional Description*

INCOT greatly extends the power of OPNET, while simplifying its operation for Air Force network engineers. One of the greatest examples of this extension is the goal or requirements driven design option; instead of building the physical network and then using OPNET to determine if it meets the requirements, INCOT starts with the requirements and then tries to build and optimize the physical network. INCOT does this while only using available devices, allowable services, satisfying security requirements, etc. This process is iterative, with INCOT asking further questions if necessary. INCOT will continue refining and optimizing the network or asking additional questions until the network can no longer be improved.

The adaptable user interface displays the most relevant information, for example animating potential bottlenecks, along with options for presenting different levels of detail or different views. Color-coding and symbology is employed to give the network engineer information about level of performance, state and other information at a glance.

Commands enable the operator to quickly modify network components via a database of known devices, add or delete connections, test for proof of adherence to policies or perform optimization. An iterative session with INCOT helps the network engineer determine the equipment required, cost, end points and performance while taking into consideration geographical constraints, locations of ground facilities, forces and related space-based assets (such as data-relay communication satellites).

Graphical representations (as well as reports) are always available to illustrate the quality of the network coverage provided. INCOT automatically performs sensitivity analysis on the coverage, including where and when coverage gaps exist, and how the failure of one component would affect overall coverage.

Finally, mouse-gestures enable the operator to zoom in on a specific geographic area, to obtain detailed information about a specific sub-network or component, and to quickly assemble alternate displays designed to support specific types of decisions.

### *System Design Overview*

To design and build the best possible INCOT, the foundation provided by the commercial simulation engine must be as robust as possible. This is why SHAI has teamed with OPNET Technologies: their Modeler product as well as other OPNET products provides the industry's leading network technology development tools. Modeler

itself allows for design and analysis of networks, devices, protocols and applications. Modeler utilizes the same object-oriented modeling approach that will be utilized in the design of INCOT. Modeler already provides graphical editors that mirror the structure of actual networks and network components, so INCOT can leverage these as well as many other powerful facilities available in Modeler.

Figure 1 presents an overview of the major components and data flows of INCOT. The following sub-sections describe the major components of INCOT and the user interaction.

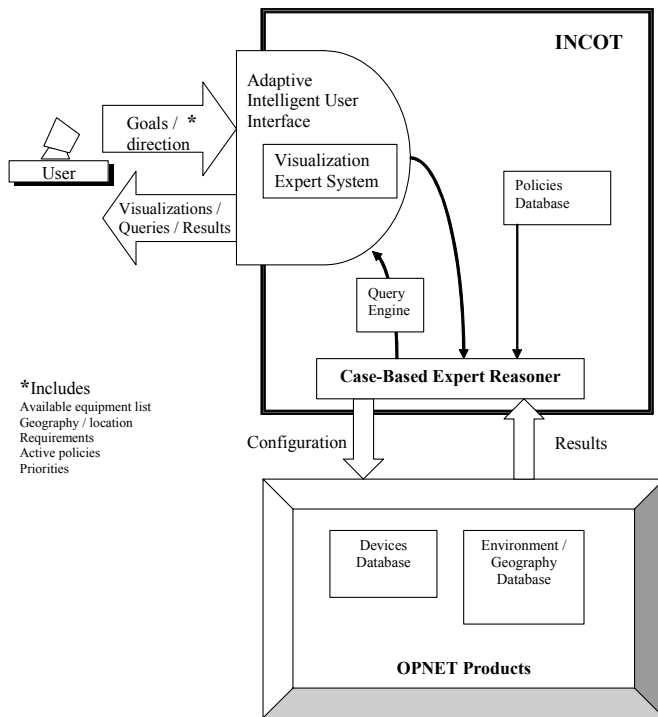


Figure 1. System Design for INCOT

*Adaptive Intelligent User Interface*—The user interacts with INCOT, and indirectly with OPNET, via the Adaptive Intelligent User Interface [4]. Via the Adaptive Intelligent User Interface the user provides INCOT with the

- network goals, with their relative priority,
- the environmental / geographical situation,
- policies, and
- constraint data.

INCOT customizes its presentation to keep the amount of displayed information to a minimum and to present it in a form that is both instantly comprehensible and complementary to the network engineer’s natural decision-making. The user interface exploits the visual user interface already available in OPNET. That is, when OPNET already provides a superior interface for certain situations it may be used unaltered; when situations could benefit from an interface different from Modeler a different interface is provided. However, the overall presentation of the Adaptive Intelligent User Interface is consistent so that the user feels they are always in the same environment.

The Visualization Expert System [5] sub-component decides how best to present data that can be displayed visually. For example, if a tradeoff is necessary because all the original goals can not be met, a visualization showing two alternatives might be shown graphically by displaying the parts of the network that are effected by each alternative and a chart showing some aspect of performance that differs the greatest between each of the alternatives.

The user is always in control; throughout the process of INCOT’s reasoning the user is kept up to date by the adaptive intelligent user interface stating what INCOT is doing and can interrupt and modify INCOT’s actions at any time.

*Case-Based Expert Reasoner*—Case-based techniques [6] can assist in making complex, domain-specific decisions, designs, or problem assessments and recommendations based upon previous experiences and patterns of previous experiences. These previous experiences, called “cases”, of domain-specific knowledge and actions, are used in comparison with new situations or problems. The past methods of solution provide expertise for use in new situations.

The input from the Adaptive Intelligent User Interface is used by the Case-Based Expert Reasoner to determine specific or abstract cases that the current situation most similarly resembles. From the goals, available devices, policy constraints and present environmental/geographical situation, the Case-Based Expert Reasoner can hypothesize on network configurations. If more information is needed from the network engineer, the Case-Based Expert Reasoner can formulate questions via the Query Engine that are presented to the network engineer. When the Case-Based Expert Reasoner has enough information to start testing network configurations it builds network configurations and submit them to OPNET Modeler for testing. Results from OPNET are passed back to the Case-Based Expert Reasoner where it decides how to proceed; for example, by asking more questions or formulating new configurations for testing.

*Policies Database*—The Policies Database provides a repository for all the various policies that may need to be in effect. A default set of policies are initially active. The user has the option of relaxing certain policies and activating other policies. This can be done interactively to see if the “bending” of a policy will allow for more of the goals to be reached.

*Query Engine*—The Query Engine is simply an interface between the Case-Based Expert Reasoner and the Adaptive Intelligent User Interface. Again, if more information is needed from the network engineer, the Case-Based Expert Reasoner can formulate questions via the Query Engine. That is, the Query Engine will take the information request

from the Case-Based Expert Reasoner and formulate a query that is easy to understand by a network engineer.

*OPNET Products*—OPNET products handle the network simulations to provide the results for any particular configuration generated by the Case-Based Expert Reasoner. In addition, OPNET products already provide a Devices Database that can be customized so that INCOT will only show the devices that are available. In addition OPNET products include an Environment / Geography Database; that is, topological information for the entire world is supported already as part of OPNET. Therefore, if INCOT proper requires any device or topological information it will query the appropriate OPNET product.

### 3. INCOT PROTOTYPE

The INCOT prototype is implemented using

- OPNET Modeler, with the following add-on modules,
- Radio, and
- Terrain Modeling, which are customized via the
- OPNET Development Kit (ODK).

The Radio and Terrain Modeling add-on modules are powerful tools in their own right and the following summarizes some of their capabilities. The Radio Module provides Modeler with the capability to fully support radio communication modeling. This includes the movement of elements to properly model mobiles (e.g., cars, ships, airplanes) and satellites. Nodes can be assigned mobility through trajectories (exact traversal path) or vector mobility (velocity, ascent, and direction). In order to represent satellite systems, OPNET’s Radio Module includes satellite objects with orbit attributes and visualization. During simulation, OPNET supports full radio link modeling functionality to dynamically establish links, compute contention and interference, and calculate closure (or line-of-site). The Terrain Modeling Module builds on the capabilities of OPNET’s Radio Module, the Terrain Modeling Module allows one to model environmental effects on wireless network communications anywhere in the world, and allows for the creation of elevation maps, line-of-sight profiles, and signal-power comparisons of mobile network models.

The power of the radio and terrain modeling modules should reinforce the situation that OPNET itself provides a high-degree of completeness in capability that necessitates a certain level of complexity. INCOT’s overall goal includes the simplification and abstraction of this complexity for the Air Force task and automation of as much of this complexity as possible.

A capability of the prototype is to provide a step-by-step guide through the layout of a military network configuration. Figure 2 shows prototypical equipment used by the Air Force [7].

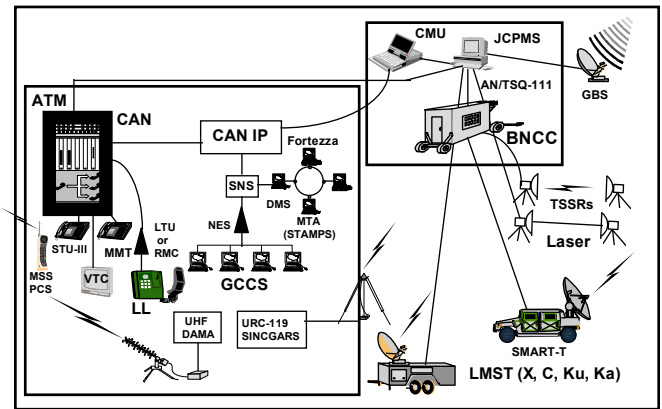


Figure 2. Military Network Components

#### Example: Network Configuration

To illustrate how the INCOT Prototype simplifies and automates, let’s consider a particular scenario. In this scenario a network engineer is tasked with rapidly deploying a camp in Afghanistan (see Figure 4) that consists of two geographically separated sub-networks connected via a microwave connection; the entire camp connects to the rest of the world via a satellite link.





Figure 3. Afghanistan Regional Map

The workflow in INCOT for this situation would follow the major steps:

- Drill down to deployment location via world map.
- Select the closest pre-built generic network layout to deployment.
- Adjust the sub-network locations.
- Add or remove components easily via customized palettes of available components.
- Verify links.
- Have INCOT’s rules automatically determine a viable location for the satellite uplink.
- Review terrain profile between antennae.
- Have INCOT’s rules automatically determine viable microwave antennae locations.
- Analyze the network.
- Modify if necessary.

This scenario and its associated workflow demonstrate some of INCOT's enhancements over using just OPNET tools. These enhancements include:

- Simplified iconized workflow.
- Pre-built networks with pre-configured sub-networks
- Automated rules and algorithms to determine
  -  Satellite uplink location
  -  Line-of-sight antennae locations
- Customized palette to provide only available options.

The following details the major steps.

1. Drill down to deployment location via world map.

When the prototype is started, a splash is first displayed as shown in Figure 4.

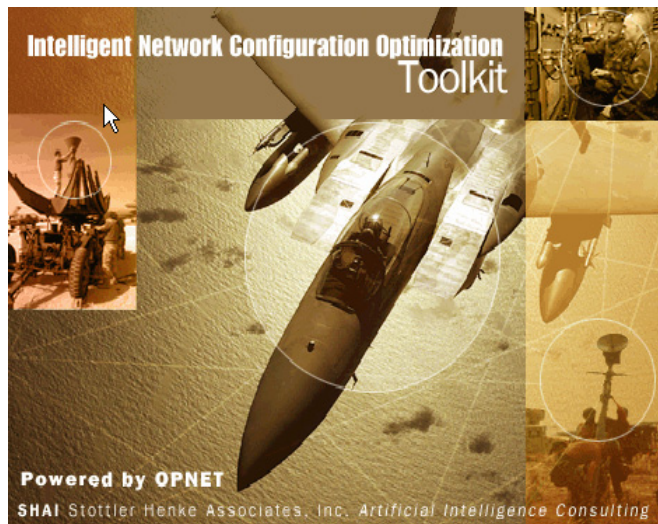


Figure 4. INCOT Splash Screen

After this, the default INCOT window is displayed with a world map. The engineer can use the zoom button to drill down to the location for the deployment. This is shown in Figure 5, where the cursor is over the zoom button.

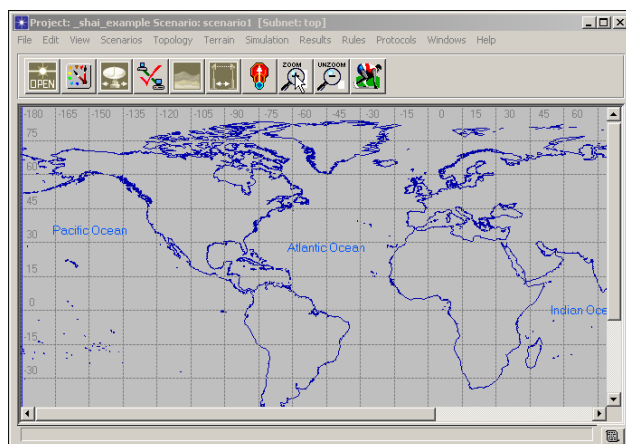


Figure 5. Default INCOT Window.

2. Select the closest pre-built generic network layout to deployment.

After the location has been selected, the engineer can select the most appropriate generic network layout via a list of



layouts, these are accessed via the open icon. After the layout is selected it is automatically placed and the engineer is provided with a graphical view of the network at the location overlaid on a topological map. For our example this is shown in Figure 6, which is an actual correct topological map of a region near Kabul. Note that subnets



are designated by the symbol.

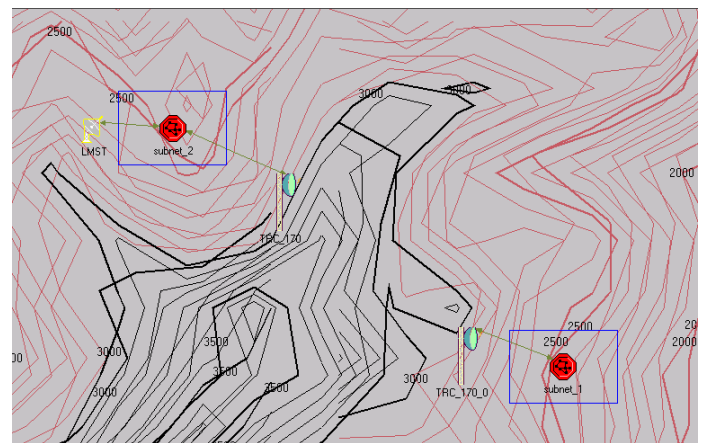


Figure 6. Network on Topological Map

3. Adjust the sub-network locations.

The relative locations of the sub-networks most likely need to be adjusted. So at this point the engineer can simply drag the sub-networks to their desired locations.

4. Add or remove components easily via customized palettes of available components.

Now the engineer can drill down into a subnet. Double clicking on *subnet\_1* reveals the components of *subnet\_1* as shown in Figure 7.

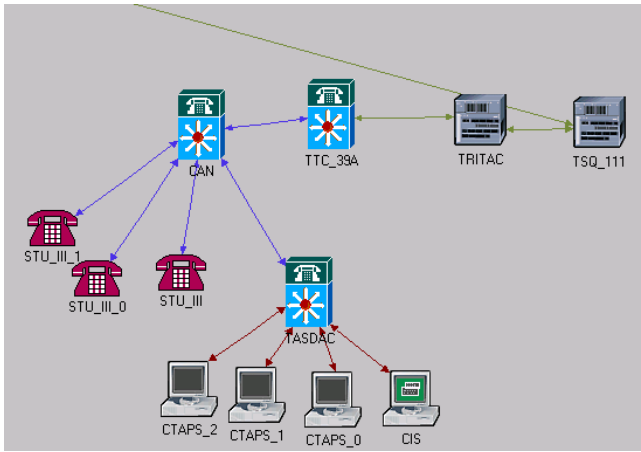


Figure 7. subnet\_1

The engineer can now easily remove or add components graphically. To remove simply click on a component and then hit the delete key. To add components simply drag on from the customized INCOT component palette as shown in Figure 8. The customized INCOT component palette saves the engineer considerable amounts of time and confusion. Instead of having to search through potentially thousands of components that are not even available to the engineer, the engineer simply selects from components that will be actually available and approved for use.

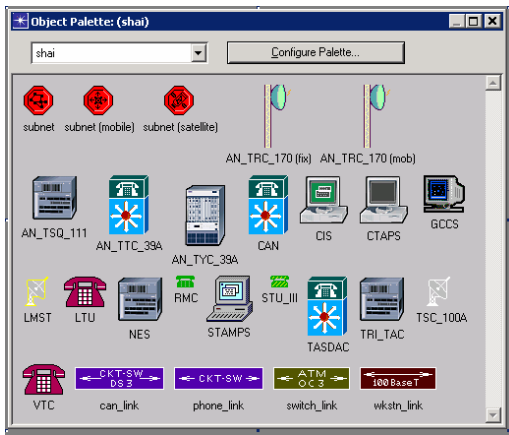


Figure 8. Customized Palette

5. Verify links

The engineer verifies that all the links that may have been added between components are valid by pressing the verify



links icon. If components are connected via an inappropriate link, this will be shown via a red X over the link as shown in Figure 9.

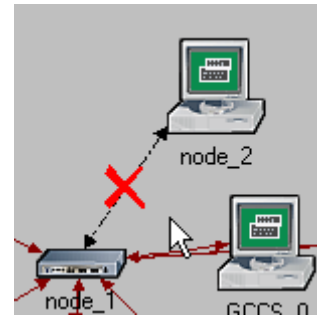


Figure 9. Invalid Link

6. Have INCOT's rules automatically determine a viable location for the satellite uplink

The engineer can optionally place the satellite uplink at a preferred location. With the satellite uplink preferred or default location established, the engineer selects the



*Relocate Uplink to Line of Sight* icon, to have INCOT automatically move the satellite uplink, if necessary, to an unoccluded location close to the default/preferred location. Figure 6, above, shows the satellite uplink in its default location (just left of subnet\_2), which in this case proves to be occluded by a hill. After the INCOT automatic placement is performed the satellite uplink is relocated to the location shown in Figure 10 which is a non-occluded location.

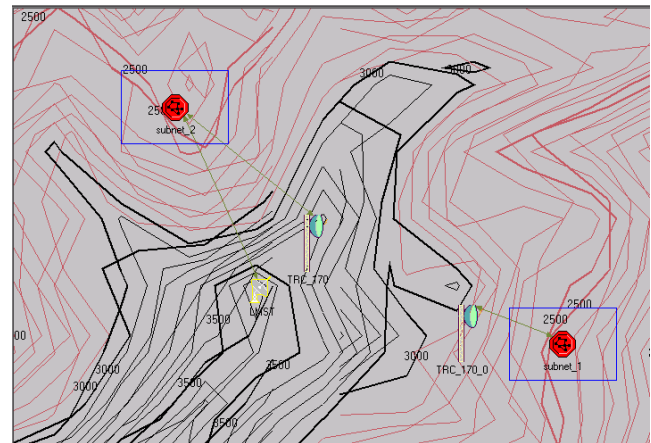


Figure 10. INCOT Determined Satellite Location

7. Review terrain profile between antennae

The engineer can obtain a greater understanding of the terrain profile that lies between the antennae by utilizing the



terrain profile icon, The terrain profile for this example is shown in Figure 11.

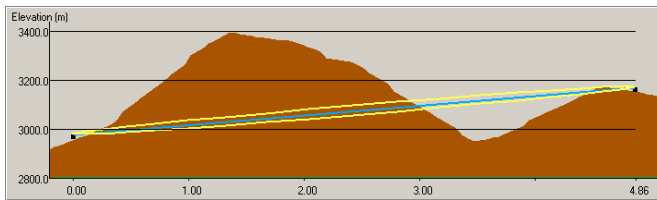



Figure 11. Terrain Profile

The results of the terrain profile may provide insight into where the antennae should be placed manually. If they are not placed manually then INCOT can adjust the locations automatically as described in the next step.

8. Have INCOT's rules automatically determine viable microwave antennae locations

Similar to the satellite uplink situation, the microwave communications may be degraded or prevented by geographical constraints due to the antennae locations. The

engineer selects the *Relocate to Line of Sight* icon, , to have INCOT automatically move the antennae, if necessary, to unoccluded locations close to the default/preferred location.

9. Analyze the network

The network analysis in INCOT relies on the analysis provided by OPNET Modeler. Once the analysis is run the results are presented in standard OPNET format, see Figure 12. The prototype does not provide any simplification to the analysis of OPNET results.

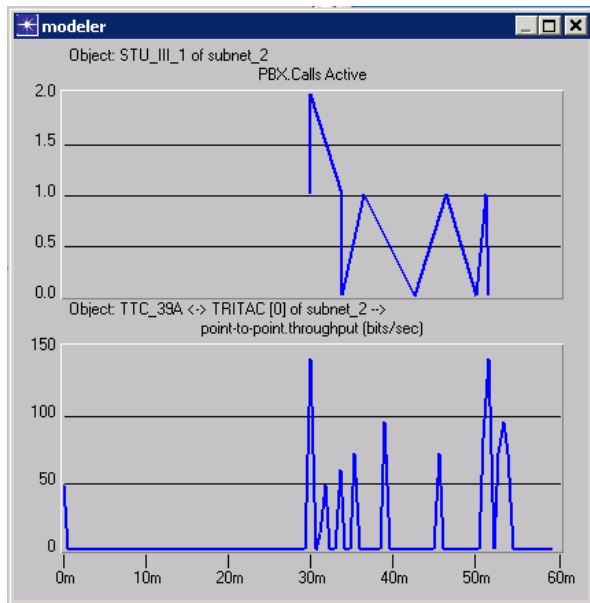


Figure 12. Analysis Results

10. Modify if necessary

Now the engineer would make any needed changes if necessary, based on the results of the analysis. The present INCOT prototype does not provide any automation of this task.

Figure 13 shows the aspects of the overall system design that have been developed in the present prototype. The lighter or grayed text pertains to those portions of the overall system that do not have any representation in the present prototype.

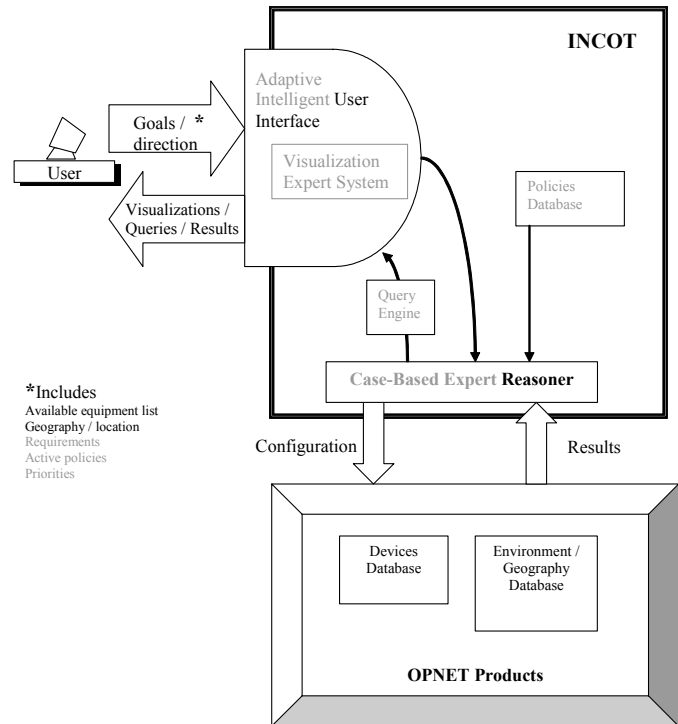


Figure 13. Prototype Design in Relation to Overall System Design

#### 4. CONCLUSION

INCOT is greatly extending the power of OPNET's offerings, while simplifying its operation for Air Force network engineers. By incorporating expert knowledge of network engineering, policies, available components and their characteristics, INCOT is able to provide an interactive rapid development tool to the network engineer. One of the greatest examples of this extension is the goal or requirements driven design option; instead of building the physical network and then using Modeler to determine if it meets the requirements, INCOT starts with the requirements and then builds and optimizes the physical network. INCOT does this while only using available devices, allowable services, and satisfying security requirements.

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