

An Automated Intelligent System for Designing Communication Networks

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Abstract

This paper presents an automated intelligent system for planning and designing communication networks based on user requirements. Stottler Henke is developing, for the US Air Force, an Intelligent Network Configuration Optimization Toolkit (INCOT) using OPNET's ODK and other tools. INCOT's goal is to provide an intelligent interface to OPNET products, allowing rapid design and optimization of military communication networks without requiring the user to have knowledge of the underlying OPNET products. INCOT greatly reduces the complexity of the network design process via a requirements driven hierarchical workflow and automation of low-level details. We are also performed some integration between INCOT and NETWARS. In addition, INCOT can read in some types of information from TNAPS+, a tool presently in use by the Air Force to perform network configuration.

Introduction

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) products provide sophisticated network 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 presently employed by network engineers to build communication 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 Stottler Henke has teamed with OPNET. Stottler Henke 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, Stottler Henke is supplementing this knowledge with a knowledge elicitation process.

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

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 will display the most relevant information. For example, it may animate potential bottlenecks, along with options for presenting different levels of detail or different views. Color-coding and symbology will be employed to give the network engineer information about level of performance, state and other information at a glance.

Commands will 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) will always be available to illustrate the quality of the network coverage provided. INCOT will 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 Stottler Henke has teamed with OPNET Technologies: their Modeler product as well as other OPNET products provide 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 is utilized in the design of INCOT. Modeler already provides graphical editors that mirror the structure of actual networks and network components, so INCOT leverages 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.

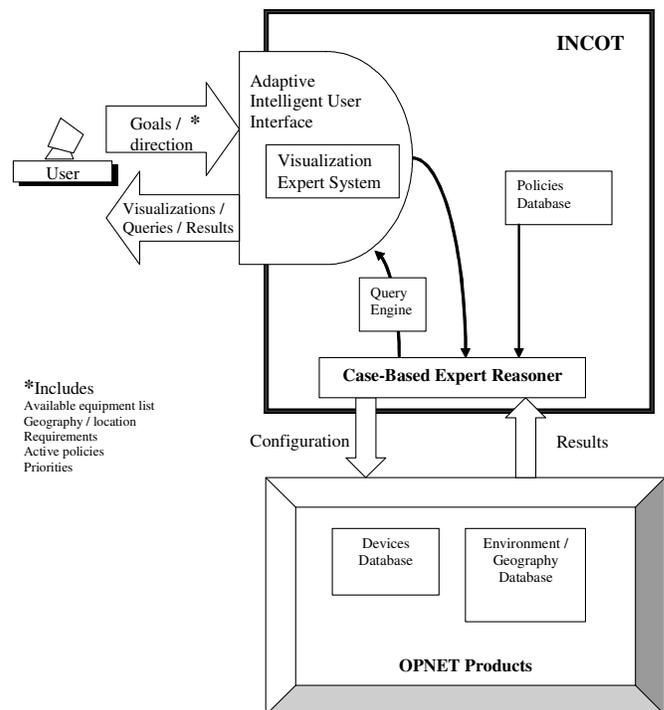


Figure 1. System Design for INCOT

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 a network configurations and submits it to OPNET 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 inventory of 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.

INCOT Evolution: Initial Prototype, Alpha & Beta

INCOT is implemented using

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

INCOT Evolution: Initial Prototype

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].

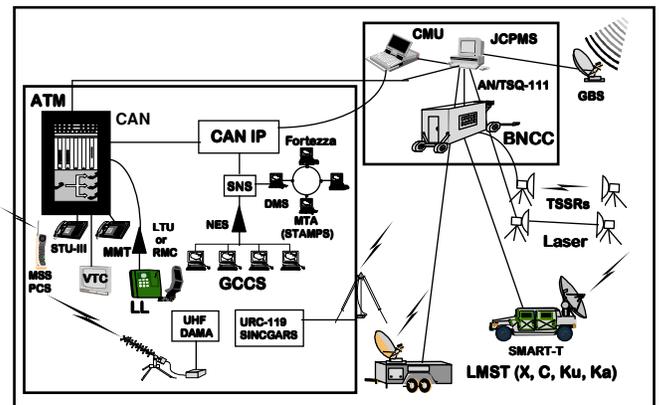


Figure 2. Military Network Components

To illustrate how the INCOT Initial 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 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.

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

- Drill down to the deployment location via the world map.
- Select the closest pre-built generic network layout to the 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.

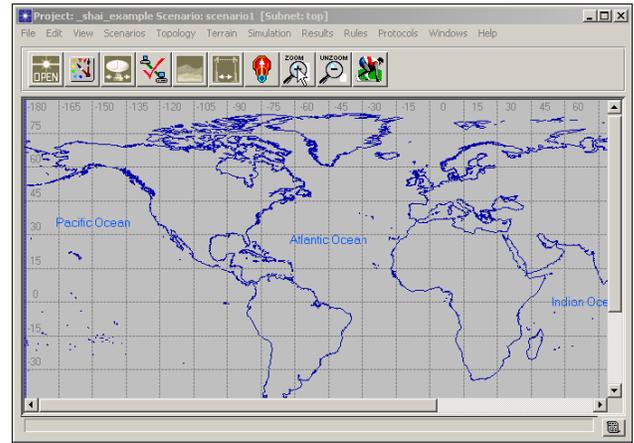


Figure 4. Default INCOT Window

Figure 3 and Figure 4 show INCOT's splash screen and the default INCOT window showing the simplified iconized workflow via the icons along the top of the window, respectively. Note the *satellite uplink location* icon third from the left and the *line-of-sight antennae locations* icon 6th from the left.



Figure 3. INCOT Splash Screen

More details on this initial prototype may be found in [1] or on the INCOT WEB page at www.StottlerHenke.com/INCOT.

INCOT Evolution: Alpha & Beta

The Alpha release occurred *after* the initial prototype.

The INCOT alpha release provides customized, highly interactive, menu tools and dialogs that simplify the workflow of planning a communication network. The following describes some of the simplified and automated capabilities provided in the alpha release.

- The user can define the area of operations giving latitude and longitude coordinates of the deployment location.
- The user can layout any number of subnets at the desired locations in a hierarchical order. The top level subnet is the world, i.e. the world is the root subnet.
- The user can set a satellite linkback from any subnet to predefined base locations.
- The user can create microwave radio communication between any two subnets using microwave antennae.
- The user can create local area networks within any subnet for data communication.
- The user can create local voice networks within any subnet for voice communication.
- INCOT can automatically lay down the backbone of the networks in all the subnets in the deployed area and links the LANs and phone networks to the WAN.

A menu and nine action buttons have been added to the generic Project Editor. The project Editor's user interface is shown in Figure 5.

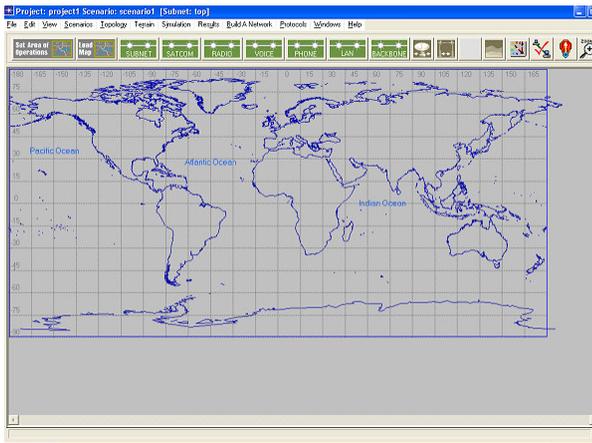


Figure 5. INCOT's Project Editor User Interface

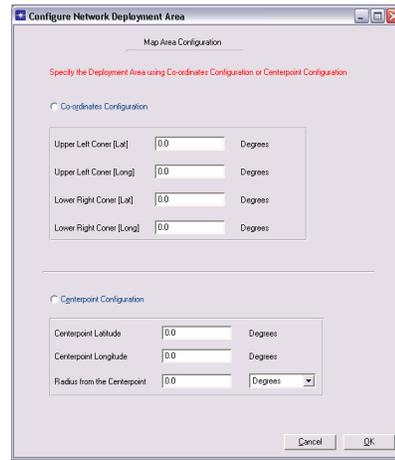
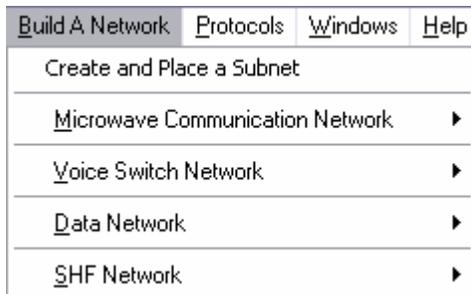


Figure 6. Area of Operations Form

The menu added to the Project Editor is:

Build A Network



This menu contains operations that relate to creating and adding various communication networks and communication devices used by the military, such as:

- Microwave Radio (LOS) Network
- Voice Switch Network
- NIPR/SIPR Data Network, and
- Super High Frequency Network (SHF).

The Project Editor provides action buttons for frequently used operations. The action buttons added to the project editor are shown in the diagram below.



For example, now the area of operations is set via the Set Area of Operations button, , which brings up the form shown in Figure 6.

Defining the rest of the network occurs mainly via the action buttons which lead the user through a series of forms.

A powerful new feature of the Alpha release is its ability to automatically lay down the backbone connections and hardware in all the subnets. That is, the user essentially defines the leaf nodes in all the subnets (e.g., number of computers, number of phones, etc.) and the user also defines the type of connections between the subnets. From this information, INCOT can automatically generate the rest of the network, such as laying out the needed hubs, switches, multiplexers and interconnections. This automation is simplified somewhat in the military domain since there is a restricted set of equipment from which to build the rest of the network from.

More information on the Alpha release may be obtained on the INCOT WEB page at www.StottlerHenke.com/INCOT.

INCOT Evolution: Beta

The Beta software implements a new Wizard interface that was derived from the Task Manager in NETWARS. The Network Warfare Simulation (NETWARS) software is developed by the Defense Information Systems Agency (DISA). NETWARS is a communications modeling tool, built on top of OPNET tools, that enables the warfighter to credibly model tactical and operational communications demands with all the stresses that combat places on communications systems. The NETWARS WEB page is located at www.disa.mil/tis/netwars.

The Task Manager in NETWARS and the Wizard in INCOT look essentially the same, Figure 7 shows the Wizard in INCOT. The difference is that the Task Manager is only a Help system, it informs the user on what to do for each stage textually. The Wizard provides the same information but *also* walks the user through the whole process.

When a user starts a new project in INCOT the Mission Requirements Workflow portion of the Wizard (displayed in Figure 7) is presented. Using The Mission Requirements Workflow, the user defines the equipments available in the mission, the areas of operations, JTF and STEP sites, sites (organizations) in the operation area and the transmission system backbone.

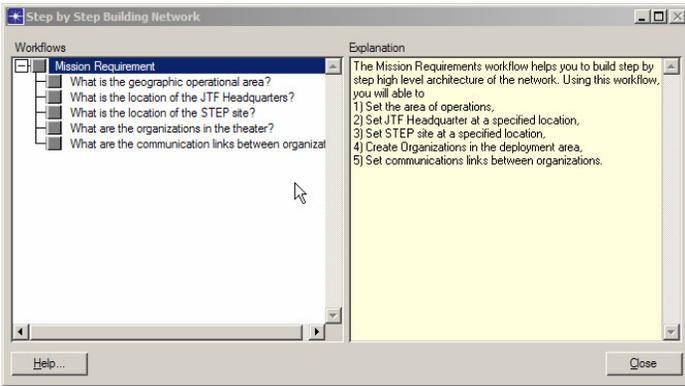


Figure 7. INCOT Wizard Interface

If the user selects the first option, “What is the available equipment for the operation”, the user will be taken to the *Add Equipment* dialog, shown in Figure 8. The user can set which inventory to use in this mission via a pull down menu. Each inventory has list of equipment with quantities.

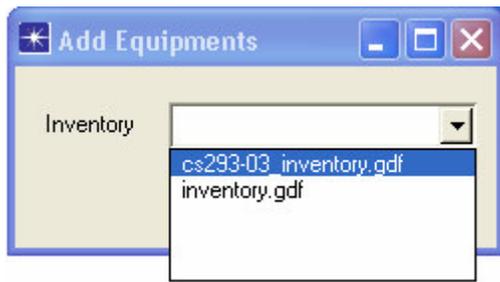


Figure 8. Add Equipment Dialog

The rest of the Wizard works similarly, that is, the user selects a step in the workflow and Wizard guides the user through the process of providing the information. As another example, when the user selects the “What are the organizations in the theater?” step the *Add Organization* dialog will be presented as shown in Figure 9.

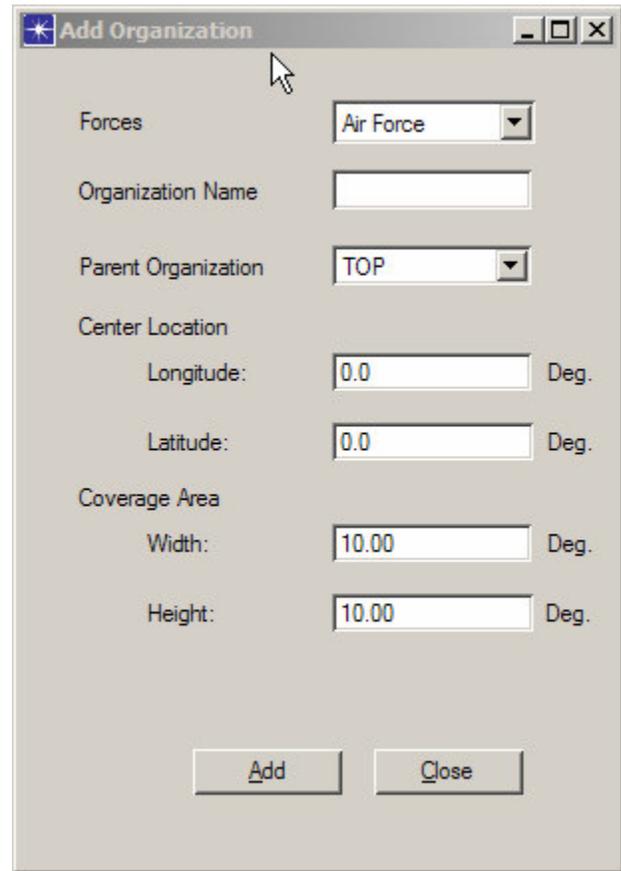


Figure 9. Add Organization Dialog

For example, by selection *Data Requirements* the user defines the number of secure and non-secure workstations or servers in the organizations via the dialog shown in Figure 10.



Figure 10. Data Network Requirements Dialog

When the user has completed defining all the data and voice requirements, they can select *Auto Build Backbone* to have INCOT build the rest of the organizations network based on the data and voice requirements and the inventory of equipment that is available.

This Beta release of INCOT demonstrates how we can further enhance NETWARS by evolving the Task Manager to a Wizard and adding automated network construction. We are working with DISA to get these enhancements incorporated into NETWARS.

TNAPS+ Integration

The Tactical Network Analysis and Planning System Plus (TNAPS+) is a PC-based tool utilized by the Air Force and other military branches for tactical communications planning and control (<https://esc-digd.hanscom.af.mil/Tnaps>). TNAPS+ assists the planner in building an exercise or operation database that consists of state-of-the-art commercial equipment and TRI-TAC equipment. TNAPS+ produces a series of output records describing the resulting networks and equipment configurations. The system controller can use this database, with program support, to monitor, manage, and reconfigure in-place communications. It is a detailed planning and engineering tool built around a database management system (DBMS). TNAPS+ supports tactical communications planning and control at two levels: the network level and the nodal/equipment level. Most of TNAPS+ is a Windows product with a small portion running under DOS but operating on the same database. An example of TNAPS+ Windows user interface is shown in Figure 11.

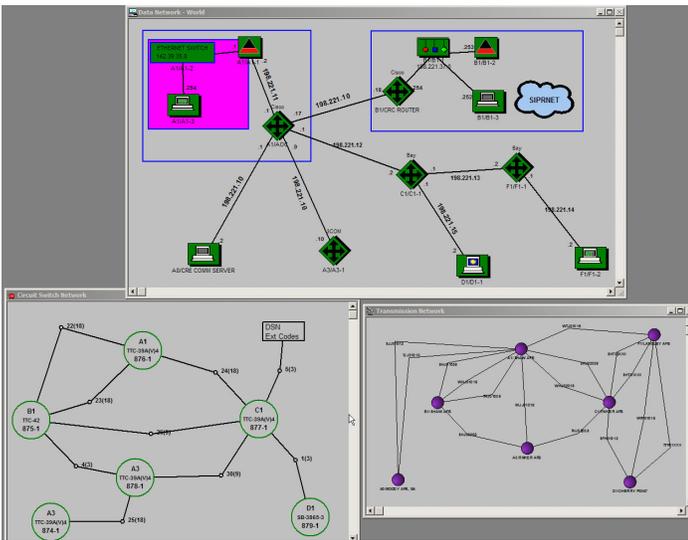


Figure 11. TNAPS+

Building the network in TNAPS+ is a requirement for many Air Force deployments, therefore users would not wish to duplicate anything in TNAPS+ and INCOT. Because of this, the INCOT Beta has the capability to read a subset of data from TNAPS+. This allows the TNAPS+ user to benefit from much of the additional functionality provided by OPNET tools and INCOT without having to rebuild the network in INCOT.

This also makes the training much simpler, because Air Force trains users to use TNAPS+ but not OPNET tools. By reading information from TNAPS+, much less knowledge needs to be learned about OPNET tools or INCOT to be productive.

INCOT/OPNET tools have many capabilities beyond TNAPS+, an example is location. TNAPS+ does not store geographical location information with entities, one can record textually where something is but this has no meaning to TNAPS+. So once information is imported, location information could be added so the wireless transport analysis could be performed., etc. Most other types of analysis are not available in TNAPS+ either.

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 inventory. By enhancing NETWARS concepts INCOT will be benefiting the next generation of military networking tools, (e.g., Joint Network Management System (JNMS)), and by interfacing to TNAPS+ INCOT is allowing the Air Force to reach the next generation sooner.

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