Intelligent Network Configuration Optimization Toolkit (INCOT) Initial Prototype

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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 artificial intelligence 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 engine. INCOT will allow less experienced network engineers to perform efficient and effective network engineering while maintaining operational efficiency and robustness. A prototype is being developed to prove the adequacy of the system concepts, interface, and artificial intelligence techniques.

Opportunity
Current OPNET products provide sophisticated network simulation capabilities allowing for the simulation of entire global networks from the global level down to sub-switch level. Due partially to the explosive growth of the computer networking domain in general and the constantly changing array of equipment that is being introduced to the market it is impressive that commercial simulation tool vendors have been able to stay current. Relative to more traditional industries the commercial simulation engine marketplace is a new industry, undergoing rapid change.

The marketplace is essentially in its early adopters stage where providing the capability to perform powerful, correct network simulation is the most critical need and thus the first to be met. The users of the current generation of tools are mainly experts in networking who perceive the present tools of huge utility for they would still need to construct networks even if the present set of tools did not exist.

As any market matures and grows, it must begin to include less specialized users; thus moving from only early adopters to include more mainstream users. Each market is different and a mainstream user in the case of network simulation will still require a working knowledge of communications networks. Now that commercial simulation engine commercial vendors have developed the underlying infrastructure for the marketplace, the marketplace can be greatly expanded if the present solutions can be made accessible to a wider audience of users. Therein lies the opportunity.

By providing an artificial intelligence interface to OPNET products to assist with network configuration and operations, a great advancement will be made not only in the usability of the software but in the development of the commercial potential of theses sophisticated tools. By providing an artificial intelligence 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.

Overview of Artificial Intelligence 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 artificial intelligence interface it is essential that we understand the process of network design and have valid methods for formulating and representing the decision task requirements. SHAI is a premier artificial intelligence company that has completed over 100 projects. Even though our team has formidable networking knowledge, SHAI is supplementing this knowledge with a formal knowledge elicitation process utilizing Air Force experts. Cognitive Systems Engineering (CSE) is the set of methods to provide the detailed information regarding the decision process of expert network engineers. Using this approach, we are developing a thorough understanding of the decision requirements of Air Force network engineers and using these requirements to: identify cognitive functions that need support, develop systems functions for a toolkit, and to provide a basis for assessing the effectiveness of the resulting prototype.

The expert knowledge garnered via the CSE approach is being encoded via the artificial intelligence knowledge representation and reasoning technique called *case-based reasoning* [1], [2] and expert system techniques.

Cognitive Systems Engineering (CSE) is the application of cognitive science in the design of systems so that the cognitive strengths of the human operators are promoted and their cognitive weaknesses are supported. This perspective provides a framework for designers to create human-computer interfaces (HCI), decision support systems, and training systems in which human thought processes are treated explicitly and become an integral part of the final product. Thus, CSE is inherently a user-centered approach to design.

CSE has been shown to be an effective means of identifying decision requirements and for developing a variety of systems. For example, Klinger, Andriole, Militello, Adelman, Klein, and Gomes [3] used CSE to redesign the HCI of the Weapons Director station of the AWACS aircraft. Kaempf, Wolf, Thordsen, and Klein [4] used CSE to develop HCI concepts for the anti-air warfare function of the AEGIS cruiser. SHAI has used CSE to develop a decision support system for Navy Landing Signal Officers; in addition SHAI in cooperation with Miller and Lim [5] used CSE to develop a decision support system for Air Force Weaponeers as they make decisions about bomb damage assessment targeting specific targets. Kaempf and Klein [6] have described the cognitive skills identified through CSE and training strategies that may be used to enhance these skills.

Solution Overview

To meet the challenge of developing INCOT, we are utilizing an integrated approach drawing upon a broad range of artificial intelligence techniques, user interface/visualization technologies, and cognitive analysis. The intuitive user interface and visualization technologies being developed utilizing cognitive analysis will permit the network engineer to quickly conceptualize the operational status of network architectures, depicting how network architectures interact with geography and other aspects of the environment. In addition, artificial intelligence techniques, (e.g., a sophisticated case or knowledge base), will store information about the available components and their capabilities that will be used to make information presentation decisions to prevent information overload and provide for rapid comprehension.

INCOT is being developed to retain all the power of the underlying OPNET products while simplifying the network engineer's user experience and automating many functions. INCOT is being developed as a rapid development toolkit for Air Force network design and optimization, helping the network engineer more easily evaluate how component and topological decisions affect the operation of the overall network. Even though it is being developed for the Air Force, the design methodology will allow INCOT's advancements to be easily directed to other specialized domains.

Consider a particular scenario for coverage of Kuwait to illustrate how the INCOT is being developed to operate. Visual tools will allow the network engineer to define areas of interest and add information at the level of abstraction desired by the network engineer. For example, the network engineer could simply call up a world map and select the region of interest, i.e. Kuwait, as shown in Figure 1.

Figure 1. Areas of interest map

The network engineer could then build the network graphically with physical components with the toolkit verifying that all policies and procedures are satisfied. As the network is constructed different views would be available, e.g., as shown in Figure 2.

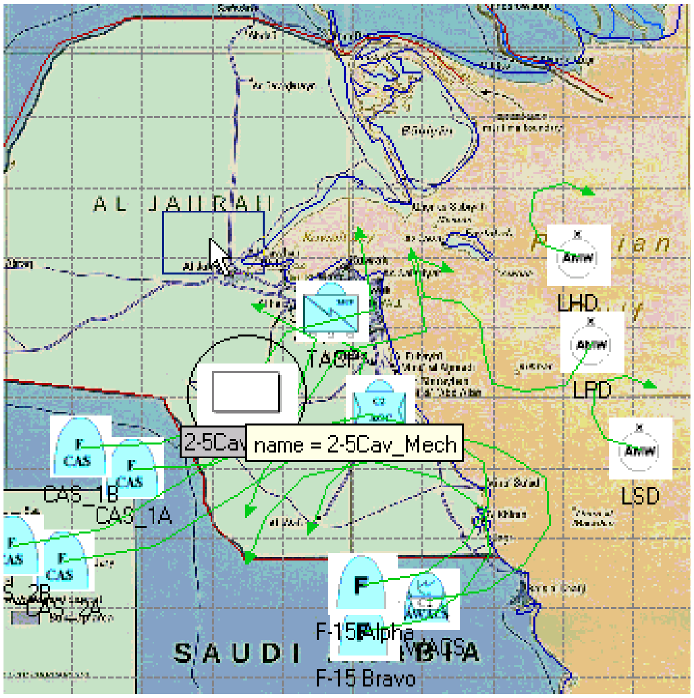

Figure 2. Example overlay on area of interest map

However, the network engineer could also develop a network at a higher level of abstraction: the goals/requirements level. That is, instead of building the physical network and then determining if it meets the requirements, the toolkit will allow the user to graphically describe the requirements for the network and then will try to build and optimize the physical network that will meet the requirements while only using available devices, allowable services, satisfying security requirements, etc. This process would be iterative, with INCOT asking further questions if necessary. For example, if all the initial requirements cannot be met INCOT might inquire into what requirements or constraints might be relaxed. INCOT would continue refining and optimizing the network or asking additional questions until the network could no longer be improved.

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

Prototype – Technical Objectives

The short-term objectives that are currently being met are:

1. Perform knowledge elicitation to determine network engineer decisions, decision-making processes, data inputs, and outputs: Using CSE, the most critical decisions are being identified as well as the process used by network engineers to make those decisions.
2. Identifying decision support and rapid development requirements and opportunities: Determining how INCOT can best support the network engineer in configuring and optimizing the network.
3. Identifying the particular artificial intelligence techniques required to support the network configuration and optimization toolkit.
4. Designing INCOT: Designing an architecture for communicating with OPNET's tools in a powerful but flexible manner; in addition the architecture will provide a powerful graphical user interface to the network engineer for rapid comprehension of information and easy manipulation of entities, while minimizing the information transfer time and the network engineer's cognitive load. The presentation will complement their natural decision-making process.
5. Proving the feasibility of our ideas through the development of a proof-of-concept, limited prototype that demonstrates critical aspects of each of the above components.

Design

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 products are the industry's leading network technology development environments. OPNET's products allows for design and analysis of networks, devices, protocols and applications. OPNET's products utilize the same object-oriented modeling approach that is being utilized in the design of INCOT. They already provide 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.

Figure 3 presents an overview of the major system components of INCOT. This takes into consideration the network goals, the environmental / geographical situation and constraint data. The user interface consists of visual displays and, possibly, audio input/output as well. INCOT will customize 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.

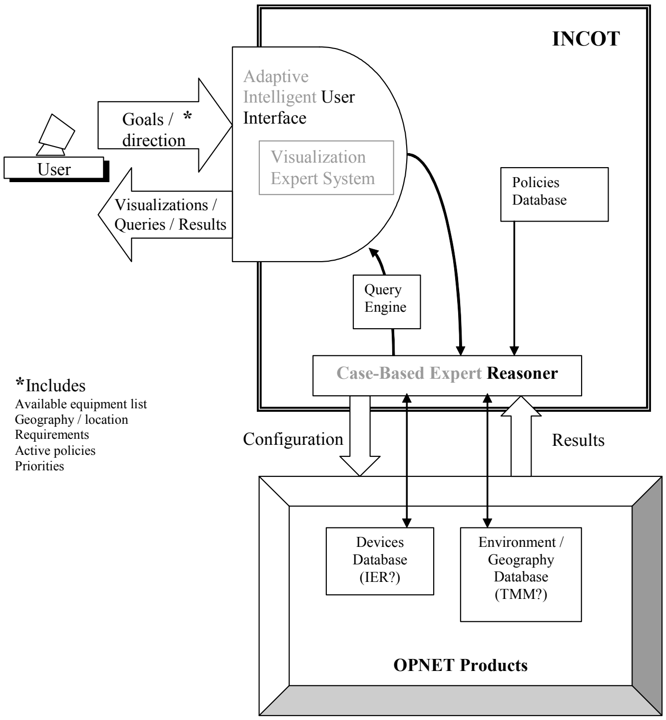

Figure 3. System design for INCOT

The *goals* input are 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 hypothesis on network configurations. If more information is needed from the network engineering the Case-Based Expert Reasoner can formulate questions via the Query Engine that will be presented to the network engineer. When the Case-Based Expert Reasoner has enough information to start testing network configurations it will build network configurations and submit them to OPNET Modeler for testing. Results from OPNET Modeler will be passed back to the Case-Based Expert Reasoner where it will decide how to proceed; for example by asking more questions or formulating new configurations for testing.

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

An iterative session with INCOT will help the network engineer determine 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).

The variables that INCOT takes as input, (be it from the user or from Air Force policies), and INCOT's output is summarized in Figure 4. Global input/output. This is a macro view of the input and output, during the development of a network INCOT may query the user for more information as mentioned above. This macro view shows a higher level including all the initial input and then the resulting output where INCOT is no longer able to improve the network. The feedback shown as 'User modifications' represents the situation where the user decides independently of INCOT prompting to modify an input.

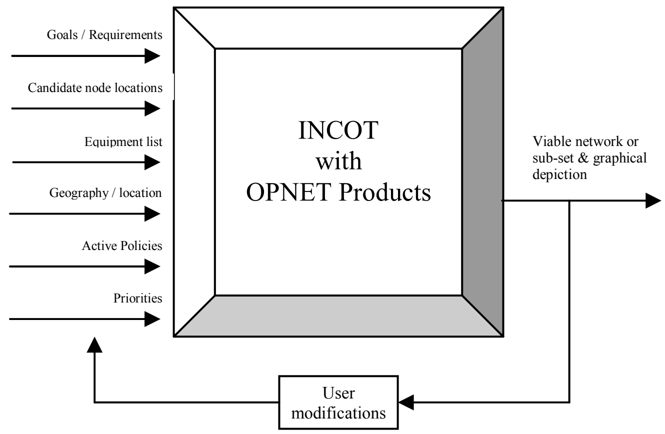

Figure 4. Global input/output

Prototype: The prototype is being developed utilizing much of the complete INCOT design. Referring again to Figure 3. System design for INCOT, note that some of the text is lighter. The lighter text represents portions of the design that are part of the INCOT design but are not being implemented for the prototype. That is,

- The prototype's user interface is leveraging the present OPNET user interface options without adding any new adaptive intelligence.
- The prototype will leverage the visualization capabilities of OPNET without adding any visualization expert system extensions.
- The prototype's reasoner may use simpler rules and not a case-based expert reasoner.

Even considering these limitations, the prototype provides a rich enough foundation to demonstrate the overall design.

Conclusion

INCOT will greatly extend the power of OPNET's offerings, while simplifying its operation for Air Force network engineers; and other network engineers in the future. By incorporating expert knowledge of network engineering, policies, available components and their characteristics, INCOT will be 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 will start with the requirements and then will try to build and optimize the physical network. INCOT will do this while only using available devices, allowable services, satisfying security requirements, etc. This process will be iterative, with INCOT asking questions if necessary. INCOT will continue refining and optimizing the network or asking additional questions until the network can no longer be improved.

References

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