

# Expert System for Automatic Analysis of Results of Network Simulation

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## 1. Introduction

The simulation of communication networks is an important task in the process of network planning and optimization processes. Such methodologies assure a higher probability for networks to operate successfully under different critical conditions, which are difficult or unpractical to be tested in the real networks. Typical applications of such simulations are the simulation of military tactical radio networks. The manual analyses of network simulation results, is a very time-consuming task and requires expert knowledge to correctly interpret such results. This is a good motivation to develop the system for automatic analysis with expert knowledge, which will ease the process of mission planning and training. For such needs, we have developed the simulation methodology and tools, supported by the expert system, which are going to be presented in detail within this chapter.

During this chapter, we will briefly introduce expert systems (further ES), Command and Control Information Systems used in NATO and known solutions to simulate such systems.

The ES is defined as an intelligent computer program with a certain level of expert knowledge, which using procedures to solve exactly specified problems. All definitions for expert systems, in many books, are quite similar, and they describe the way such system includes a rigid range of expert (specialized) knowledge or research domain. Within this area, it is capable of creating intelligent decisions. This is some kind of imitation, where a system tries to capture behavior of skills. Using the acquired knowledge; a system can analyze input/output information, solve problems, and utilize utensil decisions within the problem domain. From this point of view, these systems cannot solve all kinds of problems, but they can solve well-known and deduced problems. It is stated in one of the references that expert systems are based on knowledge (Hart, 1998, pg. 7), respectively on an information handler base. Classification by Sauter places an expert system on the right side of the straight line, where we can find systems, which handle information. Expert systems are closely related to artificial intelligence methods. As a rule, they share quality and quantity information, probability theory, fuzzy set theory, and a number of arithmetic and logic rules, based on heuristic expectations.

Output decisions, from the ES, are usually good, but it is unnecessary for them to be optimal. We can use these systems throughout a wide spectrum of human creativity, such as interpretations, announcements, diagnostics, shapes recognition, planning, debugging, repairing, control, etc.

In 2001, the Multilateral Interoperability Programme was established in order to advocate successful and harmonized operational functions for international peace keeping forces. The aim of the Multilateral Interoperability Programme (MIP) is to achieve international interoperability of Command and Control Information Systems (C2IS) at all military levels, in order to support multinational, combined and joint operations and the advancement of digitization within the international area. C2IS (TIS PINK is Slovenian acronym) is designed to control: operations, logistics, and the communication information stored in the C2IEDM (Command and Control Information Exchange Data Model) data bases. In Slovenian case, the Sitaware program packet is the graphic user interface of C2IS system. Replications of data between C2IEDM data bases, regarding individual military units, are managed by the IRIS replication mechanism (IRM) service. Both systems were developed by the Danish company, Systematic.

Simulations with modeling and analyzing of tactical communication system characteristics, has become one of the main network development tools, which enable evaluation prior deployment in the real world. Such methodologies assure a higher success probability for tactically critical operations on military fields. Various simulation systems exist for military tactical networks. NETWARS is a well known program, developed by the US Department of Defense. It is based on the OPNET Modeler simulation technology. OPNET Modeler is one of the most powerful simulation tools for communication networks, devices and protocols as well as their planning, analysis, and optimization.

Our research has been focused on a national project with aims that are directed towards the increase of efficiency, when using Slovenian C2IS information technology. This entailed research into the interdependence between the C2IS information and communication systems as well as the development of simulation methodologies and tools that enable C2 (Command and Control) optimization of communication systems. These tools and methodologies are briefly described in the second section and the main problem of manual analysis of simulation results is introduced as well. This analysis became time-consuming in many cases and very difficult in areas, where thousands of data must be simultaneously analyzed. The primary concept of this paper is located in the third section, where the known expert system theory is briefly introduced. Our definition of tactical network quality measures, and the architecture of our expert system implementation for the automatic analysis of tactical network performance simulations is introduced in the continuation. Section 4 contains an example of the use of our developed expert system. The chapter ends with conclusions.

## 2. Structure of expert systems

In this section, we will describe three main parts of expert systems: knowledge base, reasoning mechanism, and user interface (UI), which is very important as well. Also included is a definition of Fuzzy sets, as part of an expert system reasoning mechanisms, used in our solution.

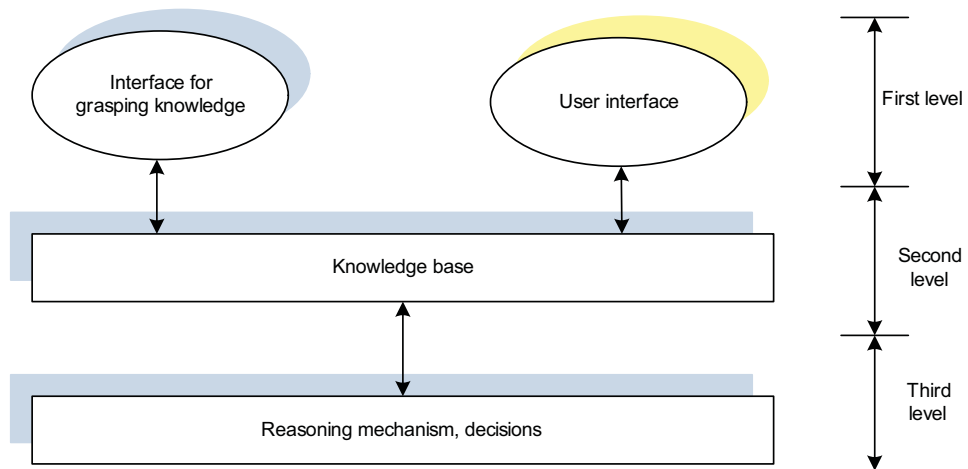


Fig. 1. Basic elements of an expert system.

### 2.1 Knowledge base

Knowledge base is used to store knowledge. Two different kinds of knowledge produce a knowledge base:

- Declaration knowledge describes objects (facts and rules), which are treated by the expert system, and where the relation between such objects exists.
- Procedural knowledge contains information about the previously mentioned objects. This information helps us to find the point, where certain conclusions and final solutions can be obtained.

Knowledge base quality is one of the most important factors in this case. Base quality is a function concerned with base dimensions and knowledge quality. A wide-spread base with high expert knowledge leads to a high-performance expert system. Knowledge must be stored in the base in the right format, because an expert system must understand it, that it can create correct decisions derived from such knowledge. Different methods or formalisms are used for knowledge presentation. From this point of view, its declaration must be hierarchically-settled, heterogeneous, and must have a flexible notation structure. Notation structure flexibility is needed for the later incorporation of new cognitions and also to change records. Hierarchy is needed for vertical connections between superior and inferior types of objects in the knowledge base. The formalisms or methods for knowledge presentation include symbolic presentations, which can be split into four groups:

- production rules,
- logic presentation,
- semantic networks and
- frames.

The most useful is the method that is based on production rules. Logical relations between objects in the problem areas are described by rules of type *if-then*. Generalize therefore, if *A* then *B*, or if condition *P* is fulfilled, then conclusion *S* should be valid with trust factor *G*. An example of logical relation is: if the quantity of atmospheric precipitations is high and

still raining, then with huge probability, we can affirm that people do not suffer from dryness. The left-side of rule  $A$  represents conditions, respectively a situation where the rule is usable; however, the right-side ( $B$ ) defines consequence, decision, or rule action. Each side can contain more elements, which are mutually connected to logic operators, such are: *AND*, *OR*, *NOT* (not very often). We can explain the means of the production rule in the following manner:  $A$  is valid if we can obtain  $B$  from  $A$ , and then we can also consume that  $B$  is valid. This is the principle for deriving facts, respectively inferences, from active production rules. Inference is a process, composed from section and activation. In the section part, the system finds out whose rules are convenient and within a convenient rule set, choose a proper rule for activation. After a successful activation, a procedure must be executed and a proper fact must be obtained. Such obtained facts are then inserted into the knowledge base. All communication directions go through the facts in the knowledge base, because rules cannot activate other rules.

The production rule consists of a rule and a pattern. The pattern represents part of a rule, which is used for further comparisons with facts in the data collection. This rule is used for executions, where we obtain newly derived facts again. When executing inferences as a forward process, the pattern must be on the left-side of the rule and the rule on the right-side. Using the opposite inference process, everything is inverse to this. Each rule is part of the whole knowledge and independent from other rules. The rule addition procedure is relatively simple because records, with production rules, allow system transparency when answering questions, such as *how* and *why*. A huge drawback to these systems is looping complexity; repetition of the mass rules set, and blurred probability during rule execution. Knowledge can also be presented using mathematical logic, with first order predicate computation, etc. Predicate computation has advantages in fast algorithms to prove sentences, which are based on resolution axiom. In this way we can, in the simplest way, define relations and the structuring of data. Furthermore, as in the case of production rules, this method is also not ideal for our needs, because it does not have enough mechanisms for the 'soft' knowledge modeling.

The beginning of the frame theory is described in (Siler & Buckley, 2007) detail and the semantic networks are described in (Van Emden & Kowalski, 2003, Liebowitz, 2004, and Krishnamoorthy & Rajeev, 1996).

## 2.2 Reasoning mechanism

Reasoning mechanism is the main part of an expert system. It controls the operation of the whole ES. The mechanism must actively use the knowledge base to deal with data, coming into the system, and for the derivation of suitable facts.

The mechanism is composed of inquiring and reasoning processes, which help in the solution search process. The most useful is reasoning method, especially in cases, when we want to derive new facts from given knowledge, through the use of production rules and forward or backward reasoning mechanisms.

Forward-decision process uses an inductive procedure, where, the algorithm tries to find the proper one, from known sets of facts, which leads to the required aim. Induction is a form of reasoning that makes generalizations based on individual instances. A satisfactory solution must be compared with the production rules pattern on the left-side of the rule. If the left-side is equal to the fact on the right-side, the agreement rule must be activated. The activated rule adds a new fact into the operational memory, which is derived from the core,

respectively from the right-side of the rule. Derived facts now have equal rights, as in the reasoning process (Siler & Buckley, 2007, Krishnamoorthy & Rajeev, 1996). A backward-decision uses deductive execution. Deduction is a form of reasoning that proceeds from general principles or premises and derives the particular information. The main goal of backward-decision is oriented towards rejecting or confirming the truth of the goal-hypotheses. Hypothesis can be, for example "water level is high". Firstly, the mechanism checks if it is possible to confirm the goal-hypothesis using a fact in the operational memory, otherwise it looks for a rule, which can confirm the hypothesis (Siler & Buckley, 2007, Krishnamoorthy & Rajeev, 1996). Usually, systems with backward-decisions are more efficient in comparison to forward-decision systems, because they reduce search space, and quickly find a proper solution. Such systems can be used, when in advance-defined trivial goals exists.

### 2.3 User interface

The expert system user interface takes care for a comfortable communication between the system and (unskillful) users. It provides an insight view into the problem solving process, carried out by inference. The user interface translates the information given by the user, in a form suitable for computer manipulation, decisions and interpretations made by the system and present them to the user in an intelligible written textual or graphical form. User interface usually allows interaction with the environment and other systems, as external databases are, for example. The most commonly used expert system user interfaces are in the form of: questions and answers, menus, hypertext, natural language, graphical interfaces, etc. The user interface is one of the most critical elements in the whole expert system, because a bad user interface can lead to limited or ineffective use. Furthermore, user interface design is generally more demanding than the standard computer applications, since the information, that are exchanged between the user and the system, are generally more complex. Data processing in such a system is more demanding as well.

### 2.4 Fuzzy sets

Fuzzy sets are a generalization of regular crisp sets (Krishnamoorthy & Rajeev, 1996). Meanwhile, the appurtenance function of a crisp set has a stock value  $\{0, 1\}$  (a specific element belongs or does not belong to this set); the appurtenance function of a fuzzy set ( $\mu_A$ ) has a stock value within the interval  $[0, 1]$ . We can reason, that a specific element in fuzzy set is contained by appurtenance, which is  $\in [0, 1]$ .

For example, data of received power from the OPNET simulation graph is observed. For a received-power, set  $A = \{x; \text{data in } x \text{ is acceptable}\}$  is defined. Such set contains all acceptable data. If we look at this set as on an ordinary set, we can specify data, which fully belongs to it or even does not fully belong to it (two possibilities). A problem appears about the 'acceptability' definition. In regular sets, passages between appurtenance and non-appurtenance are sharp (discrete). Passages between appurtenance and non-appurtenance in fuzzy sets are soft, slow and continuous.

## 3. Modeling and simulations of tactical networks

In this section the OPNET modeler tool is briefly presented, to the level, needed to understand our simulation methodologies and tools developed around it.

The research project, mentioned in the introduction, incorporates the following working packages, which will be introduced in the continuation:

- development of methodologies for OPNET simulation of hierarchical wireless tactical networks using IRIS Replication Mechanism (IRM) and
- development of the TPGEN helper application, that enable user-friendly entry and editing of tactical network parameters (radio parameters, IRM contract parameters, parameters for statistical description of tactical data sources), to the OPNET simulation data model.

### 3.1 OPNET Modeler

The developed tactical network simulation system is based on the OPNET simulation tools, similar as in NETWARS and INCOT case. We used OPNET Modeler Wireless Suite for Defense, which supports high fidelity protocols and equipment models within a scalable simulation environment, which is capable of simulating wireless and also wired networks. It supports scalable wireless simulations, incorporating terrain influences in path-loss calculations using different propagations models, mobility, and 3D visualization. The OPNET Modeler is an object oriented communication simulation tool, with a hierarchical modeling environment, which uses graphical user interfaces (editors) – network, node and process editors. The *network editor* enables a graphical description of network topology, while a *node editor* is used to describe communication devices, protocols, and connections between them, using layers of the ISO/OSI model. The *process editor* is an upgrade of C language, and uses a powerful finite state machine (FSM) approach to represent different communication algorithms and protocols. The OPNET Modeler is used for modeling and simulation of communication networks and, at the same time, it enables the construction and study of communication infrastructure, individual devices, protocols and applications (OPNET, 2007).

### 3.2 An OPNET model of IRIS replication mechanism

The aim of the project, described in previous sections, is focused towards optimization of tactical communication networks, where units operate under the various conditions. In order to archive this, we need flexible tools that enable the modeling and simulation of communication systems. We chose the OPNET Modeler, which already has a reference in tactical network simulations through NETWARS and INCOT solutions. In regard to modeling the C2IS system for simulation; we were faced with two tasks:

- modeling a tactical radio network and
- modeling the traffic created by the C2IEDM model for information exchange (IRM in our case).

We choose the station model for modeling the tactical radio network, by considering the following:

- The model has to support mobility (possibility to input the trajectory of movement).
- Field influences on a radio wave-spread. OPNET offers a variety of different models for a radio wave-spread, such as the Longley-Rice (Longley & Rice, 1968) and TIREM models (TIREM/SEM Handbook, 1994). TIREM is the best choice for non-urban areas (Chrysanthou, Breakall, Labowski, Bilen, & J., 2007).
- Possibility of setting radio parameters, such as channel frequency, transmitting power, receiver's sensitivity, physical characteristics (frequency jumping)

- Possibility of antenna modeling.

For modeling traffic, as created by IRM, the station simulation model has to enable the following:

- stochastic traffic modeling,
- communication using broadcast IP protocol,
- communication using peer-to-peer IP protocol and
- support for communication protocols used in tactical radio networks.

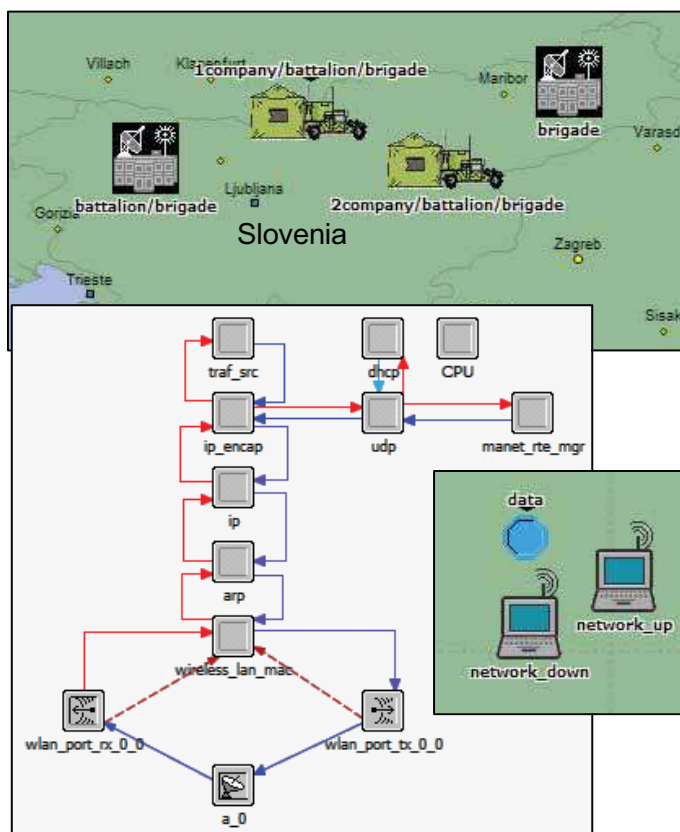


Fig. 2. Above -tactical network example, below right - unit modeled as a mobile subnet with two MANET stations, and dedicated data structure used as a database for storing TPGen parameters, below left - MANET station structure with additional antenna model.

Both modeling tasks are highly correlated, thus they could not approach independently. Considering the above demands, we choose a MANET (Mobile Ad hoc Network) generic station for the OPNET model, which is the best option for both tasks. The topology of the tactical network (shown above in Fig. 2), in the OPNET simulation's tool, is built-up by a specially developed library of tactical units. Each tactical unit (shown below right, in Fig. 2) is modeled by an OPNET subnet, which consists of two MANET stations and an additional process node, used to store additional attributes that are needed to describe a tactical

network. All parameters of the tactical network and tactical units (radio parameters, data sources, IRM contract) are defined by the developed TPGen application. One station is intended for communication with superior units, others for communication with lower units within the tactical network hierarchy. The MANET stations used in these models needed some modification for our purposes; therefore, an antenna was added (below left in Fig.2) in the first phase. This modification gives us an opportunity to choose different predefined antennas or create a new one, by using the OPNET tool, called the Antenna Pattern Editor. In our simulations, we used an isotropic antenna pattern with a uniform transmission gain in all spatial directions.

For traffic modeling, a method that uses traffic generators of the MANET stations have been developed, based on data sources statistical descriptions, regarding IRM contracts. We have developed mathematical mapping of IRM contracts, defined by contract matrices, and data sources, defined by vector of data sources in order to obtain the traffic matrix. This matrix is needed to configure the MANET traffic generators used in TPGen application, as described in (Mohorko, Frás, & Cucej, 2007). The data sources used during this mapping are obtained through network traffic analysis based on the captured (Wireshark, 2008, Chakravarti, 1967) traffic of the test network when IRM replication mechanism and SitaWare are used. During this analysis, we estimate the statistical parameters of network traffic processes, such as packet size and inter-arrival times for each traffic source, such as GPS sensor, manual entry of data, etc. For purposes of estimating statistic parameters we used our traffic defragmentation method, as described in (Frás, Mohorko, & Cucej, 2008).

### 3.3 TPGen application

Developed TPGen (TIS PINK Generator) application has two main purposes. First out of two is a user-friendly entering and editing of parameters of tactical networks, which have an influence on the OPNET simulation model. The second purpose is automatic mapping of simulation parameters into the OPNET model, according to the developed mathematical model. The user interface of TPGen application is shown in Fig. 3.



Fig. 3. TPGen application, where tree-view is visible in the left panel and *network editor* on the right panel.



Data exchange, between OPNET Modeler and application TPGen, is performed by XML formatted OPNET model data files. The basic components of the TPGen application user interface are: hierarchical tactical network tree-view visualization, network editor (sensitivity, transmitted power, channel capacity, etc.), traffic source's editor (statistical descriptions of traffic sources) and IRM contract editor (to define which data sources will be mediated between tactical nodes and which type of communication protocol will be used). TPGen editor also incorporates libraries of: military units, stations, data sources and contracts, and they considerably ease the work of tactical network planners. Application TPGen also ensures an automatic entry of certain parameters into MANET station models, which are invisible to the user, but are required for OPNET simulation (IP address, destination IP address, BSS identifier, etc.). TPGen application usage, when we simulate tactical networks, is schematically presented by the use-case diagram in Fig. 4.

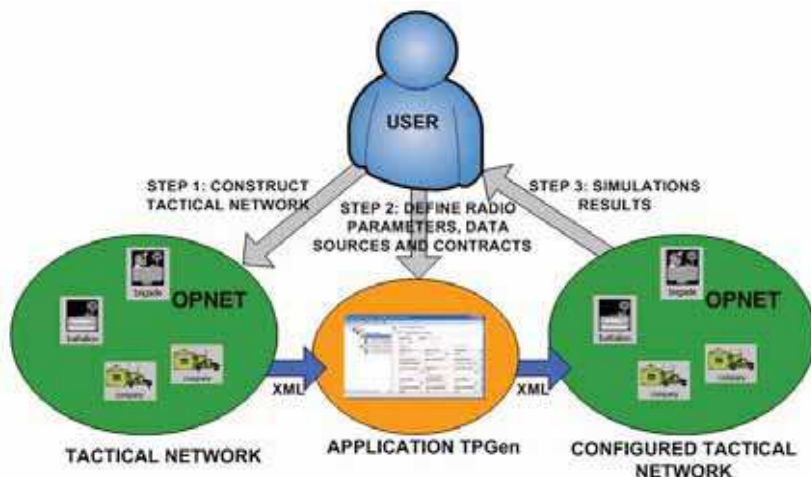


Fig. 4. Use-case diagram of tactical network simulations.

The whole modeling procedure consists of the following four basic steps:

1. In the first step, user must compose a hierarchical tactical network, by placing icons from the libraries of military tactical units on a virtual terrain-map of the OPNET *project editor* (see upper part in Fig. 2). Then a simulation scenario must be exported as a XML model file for use in TPGen application (step 1 in Fig. 5).
2. User then imports the XML model file into TPGen application. For each tactical unit, radio parameters must be defined, and data sources and IRM contracts as well. All entered parameters are stored in prepared data structure inside the OPNET models, as shown in the lower right corner of Fig. 2. Users then export modified XML model file from the TPGen application.
3. In this step, user must import configured XML model file of tactical network back into OPNET Modeler. Trajectories of movement can be defined for individual units. A user can then choose statistics that he/she wants to observe after the simulation, simulation parameters defined, and after the simulation and analyze results are run (step 3 in Fig. 4).
4. For new scenarios, it is necessary to repeat steps 2 and 3 on Fig. 4.

#### 4. Expert system for analyzing performances of tactical network

This is the main part of the chapter in which we describe our expert system solution for automatic analysis of network performance.

There are many reasons why we decide to build such an expert system:

- Network simulation results (output vectors), obtained by OPNET modeler simulation, are represented graphically in a form, which is not user friendly, in order to identify whether results satisfy our expectations or not (Fig. 5).
- Some of the tactical network parameters are not measurable directly by a single simulation statistic. It is necessary to develop expert algorithms that perform complex analysis over many simulation statistics simultaneously, in order to evaluate parameters, such as radio visibility, message competition rate, etc.)
- During OPNET Modeler simulation, statistics are not included in regards to geographical positions of individual tactical units, which can also be mobile. This information is crucial within the tactical network optimization process. For this reason, we implement functionality into the expert system that enables linking between expert system results and the positions of tactical units, with the use of the developed tactical player tool (Globacnik, Mohorko, & Cucej, 2008).

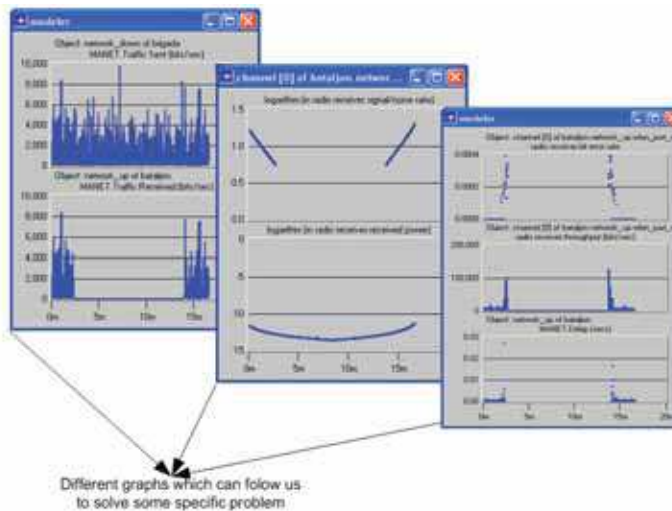


Fig. 5. Obtain graphical simulation results from OPNET.

Our expert system, shown in Fig. 6, uses two input data sets. The first is the XML file which contains information about tactical network topology and settings. The second input data set is the OPNET Modeler simulation output vector file with data records of the chosen statistics. From both files, a hierarchical data structure is then built, which is used as unified input data for our analysis system. An expert system algorithm performs data operations on this data structure and stores results into the same structure. The report generator produces two report files. The first is for detailed analysis using Tactical player, and the second one is user readable, which contains information about network performance and directions for network improvements.

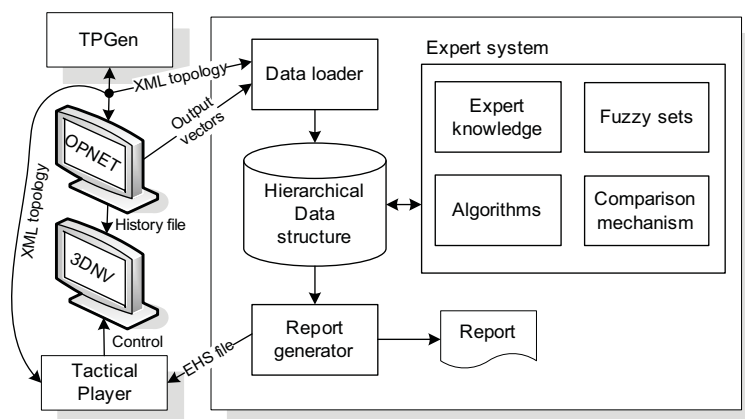


Fig. 6. A block diagram of expert system, and correlation with other developed modules.

#### 4.1 Tactical network evaluation algorithms

**Transmitter bandwidth utilization analysis, using the fuzzy-set theory:** Traffic between tactical radio network participants is determined by the so-called IRM contracts, which define who communicates with whom, and which data sources they should use for this. The intensity of data sources is defined by a statistical description of transaction size and transaction packets inter-arrival time. Contract can be of a broadcast type, which means that traffic can be received by all participants of the subnet, or peer-to-peer type, where communication is performed between pairs of participants. Bandwidth utilization is an important network parameter, and it is a good indicator of bandwidth overloading, which can lead to extreme delays or data loss, caused by timeouts. Near to 90% of long term utilizations are alarming situations. In such cases, the intensity of data sources must be decreased or network topology must be redesigned. Utilization is a parameter that can be easily measured, because it is a generic OPNET Modeler statistic. In our expert system, for this statistic, we have defined alarming conditions by using fuzzy logic methods.

**Traffic delay analysis:** Traffic delay is also one of the generic OPNET Modeler statistics. This parameter is a good indicator for Quality of Services (QoS) in tactical networks, which is very important for applications such as Voice over IP (VoIP). Analysis of delays is treated in a similar way as in the utilization case.

**Message completion rate** is a very important evaluation parameter of tactical networks. It is the ratio between the number of received and transmitted messages. This parameter is very difficult to estimate from generic OPNET Modeler statistics, particularly for complex tactical networks. Tactical radio units simultaneously receive traffic from many sources. Graphical simulation results are cumulative, and there is not any information about source addresses for particular received packets. This is the reason, why we decided to modify the OPNET tactical unit model on the C programming language level, in order to perform additional logging of all received and transmitted traffic, with information about time-stamp, transaction packet size, destination, and source IP address. Using expert analysis algorithms, we search and count the number of transmitted messages that are also received on another side. In such way, the new statistic is build-up. Such created statistics are not originally presented in OPNET Modeler tool. Different factors, such as terrain agitation,

vegetation, transmitter power, the receiver sensitivity, interferences, etc., have an influence on the message completion rate. In broadcast type of transmissions, such an estimation of message completion rate is credible. In the peer-to-peer case, it is expected that this is an estimation of lower boundary, because the application level protocols that are not implemented by OPNET simulation, increase this level in the really tactical networks, through the use of retransmission mechanisms.

**Radio visibility analysis:** Radio visibility is a parameter, which tells us whether if radio transmitters and receivers can communicate. It depends on transmitter power, receiver sensitivity, the distances between them, terrain influences, etc. In contrast to the previous described analyses, we developed a special OPNET modeler simulation scenario, where for each military unit; we allocate a precisely defined time slot during which the transmitter transmits short packets (pings). All time slots of units from the same subnet form periodically-repeated sequences. Expert analysis algorithm check, if the packets have been received within the expected time-slots or not. Those areas where packets are not received do not have radio visibility. An attentive reader will ask oneself why it is necessary to design a new simulation scenario, and why the packet must be as short as possible? The reason for the new scenario with uniquely defined time slots is, that in the cases of simultaneously active multiple receivers and transmitters, impossible to detect the appearance of points on a graph, using statistics such as received power, signal to noise ratio, bit error rate, etc. This is because each of these points can be caused by multiple transmitters. Minimal packets must be selected using reason that induces minimal influence on transmitter delays. Received power can also be reused, but only the statistic which is chosen on each receiver. In this case, fuzzy set membership function is used, obtained from experimental measurements.

During the analysis procedure, each parameter is compared with a predefined membership function, as is defined in Fig. 7. A similar approach is used in the case of delay and estimation of utilization values, where a similar membership functions are in use, which determines appearance of observed parameter to the fuzzy set. The following appearance functions can be used: Gaussian, triangle, trapezium, sigmoid, etc. Our case uses half of the left side trapezium function. In regards to Fig. 7, values which are under 80% of appearance to the fuzzy set are marked as critical values, where radio communication falls down, meanwhile values between 80% and 95% appearance are conditionally acceptable, 96% to 99% acceptable, and values equal to 100% fully acceptable. A description also worth for the delay and utilization values classification, but there are different ranges declared for the appearance function.

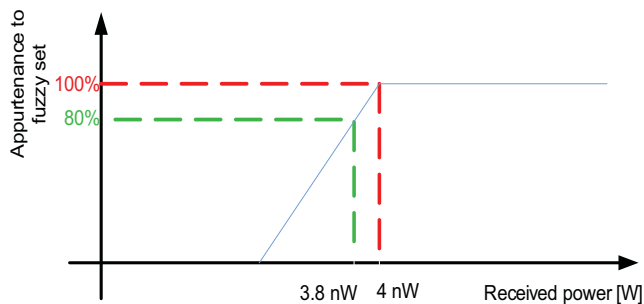


Fig. 7. Definition of fuzzy set membership function example, for received power.

## 4.2 Expert system design

Expert system user interface, as is shown in Fig. 8, enables users to choose any interesting OPNET Modeler simulation statistic from the analyzed output vector. User can also observe the additional results which are obtained during the expert analysis process, described in the previous section. When the analysis of desirable parameters is chosen, then the procedure of expert analysis begins.

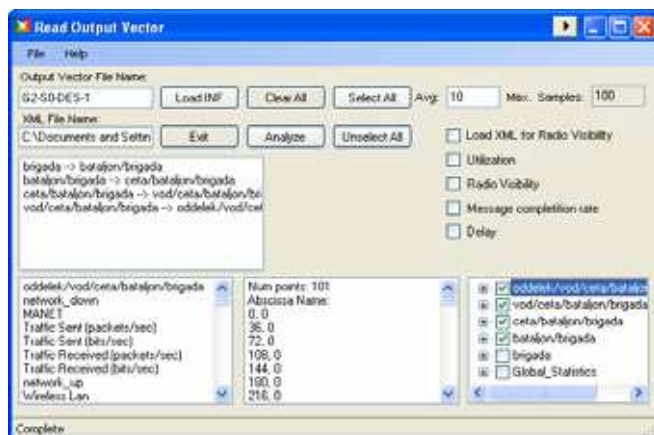


Fig. 8. Expert system user interface.

The expert system creates two output files. The first is user readable in a report form and the second is the so-called expert history system (EHS) file intended for the Tactical player. The EHS file is comma-delimited formatted textual file. Each record (message) in this file has information about time-stamp, statistic name, value, error condition, and comments about possible problems. Such messages are then displayed in our developed Tactical Player software, for each time-stamp and for each unit; position of units is also synchronously visualized over a virtual terrain in 3DENV player, as shown in Fig. 12. Messages are displayed in the form of subtitles. Another type of expert system output file is the user readable report file. This file contains tabular and textual descriptions as a result of expert system analyses for the specific observed tactical network. This is a description about the percentage of radio visibility between tactical node pairs; message competition rates, etc., throughout the whole tactical mission. The user report consists of three parts: global, node and summary reports (Fig. 9).

Global report	Node reports	Sumarize report		
	Node	Statistic	Value	Comment
	Global	MANET Delay	0.00604	
	Global	Common Utilization	0.65541	
	Global	Avarage Transmitters Utilization	0.16901	Avarage in [%]
	Global	Avarage Receivers Utilization	1.14182	Avarage in [%]
	Global	MANET UP avg. Delay	0.0083	
	Global	MANET DOWN avg. Delay	0.0083	
	Global	Wireless LAN UP avg. Delay	0.00557	
	Global	Wireless LAN DOWN avg. Delay	0.003	
	Global	Message Completion Rate	97.77077	Completion Rate [%]
	Global	received power (W)	-56.71	dB
	Global	bit error rate	0	BER

Fig. 9. Global report for a person who plans the tactical mission.

- The global report (Fig. 9) contains data about the entire tactical network. Means that presented average global parameters are displayed as a global delay, global transmitters/receivers utilization, global delay on transmitters/receivers, global average radio visibility loss, global average percentage completion rate, etc. These parameters are in correlation with the entire network, observed as one unit.
- The node report contains all average information about each individual participating unit/node within the communication process.
- The summary report is formed in a similar way, with information about radio visibility loss in percentages, in regards to the entire simulation time and information about message completion rates percentage, and also in regards to the entire simulation time for each individual participation unit within the communication process.

### 4.3 Tactical player

We have developed Tactical player (Globacnik, Mohorko, & Cucej, 2008) to visualize the ES results. Tactical player makes user friendly data examination, by emphasizing those data, which are marked as problematic by the ES, in order to control 3D visualizations of tactic radio units, etc. The input of Tactical player is the output file of expert system EHS.

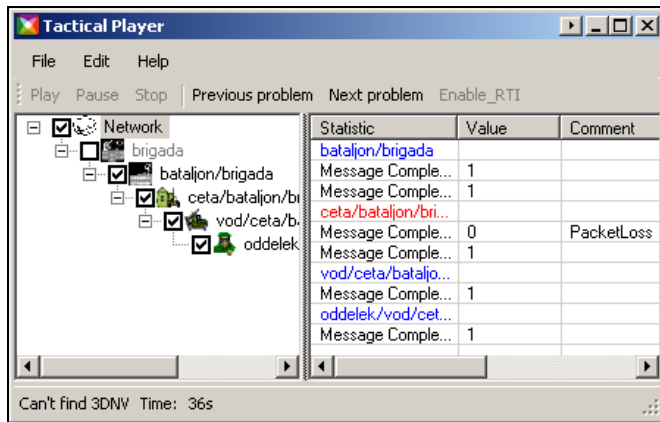


Fig. 10. Developed Tactical player, and players' user interface (main window).

Fig. 10 shows the main window of the developed Tactical player. This Tactical player is divided into two parts. Located in the left window is a topological tree-structure of participating units in the communication process. This part is similar to the TPGen application. The right window shows data and messages from the expert system. Located in the toolbar, on the top of the window, are the controls for the OPNET history player, and above those are menus. The status bar at the bottom of the program lets us know about the presence of a History player and about the recognized history player time, which is necessary for time synchronization. The program supports two working modes; so called "online" and "offline". In an "online" mode, the program works in conjunction with the 3DNI history player, as it is shown in Fig. 11 and Fig. 12.

Inside the OPNET, 3DNI history player runs a recorded simulation history. Time synchronization between the Tactical player and the 3DNI history player is performed with the help of a time code OCR recognition. In this mode, we can also use 3D presentation with

MAK Stealth 3DNLV, where we can see realistic movements of military units over a virtual terrain, and their simulation data. A simple example of 3D visualization is given in Fig. 12, where we can see one of the units (in this case a helicopter), and the data of node statistics around it. The second mode is the so-called “offline” mode, where we do not use any external program. In this mode, it is only possible to directly jump to a desired time and move over the EHS data, which are marked as problematic by the expert system.



Fig. 11. OPNET Modeler (above) and History player (below).

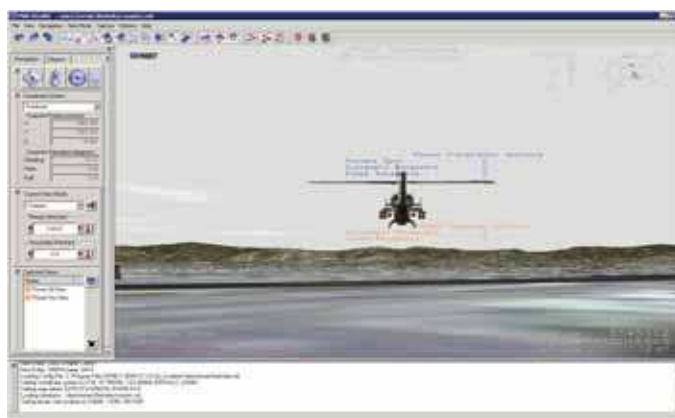


Fig. 12. 3DNLV visualization with MAK Stealth application.

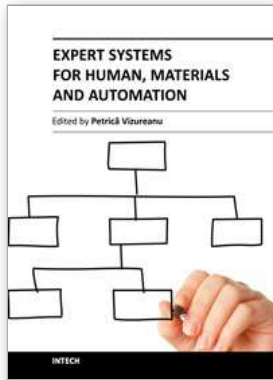
## 5. Conclusion

Manual performance evaluation of tactical communication networks, using OPNET Modeler simulation results, is a very time-consuming task, which also needs a high degree of expert operational knowledge. The developed expert system, with the help of a knowledge base, will automate this process and suggest steps for solving the communication problems of tactical networks. Developed expert system for tactical network evaluation is, in combination with Tactical player, a solution, which offers a deeper understanding of simulation results for a specific planned tactical mission. This leads to a development of better and more reliable tactical networks, which play a critical role in military operations.

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## Expert Systems for Human, Materials and Automation

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The ability to create intelligent machines has intrigued humans since ancient times, and today with the advent of the computer and 50 years of research into AI programming techniques, the dream of smart machines is becoming a reality. The concept of human-computer interfaces has been undergoing changes over the years. In carrying out the most important tasks is the lack of formalized application methods, mathematical models and advanced computer support. The evolution of biological systems to adapt to their environment has fascinated and challenged scientists to increase their level of understanding of the functional characteristics of such systems. This book has 19 chapters and explain that the expert systems are products of the artificial intelligence, branch of computer science that seeks to develop intelligent programs for human, materials and automation.

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