Advanced Modelling and Simulation Methods for Communication Networks

Jože Mohorko, Fras Matjaž, Klampfer Saša

Abstract – **This paper contains a brief overview of suitable simulation tools available for education and research on network technologies and protocols. Among the mentioned tools we present advanced methods for network simulations using the OPNET modeler simulation tool. This is one of the most widespread simulation tools for network simulations, appropriate for both for teaching and also for the researching procedures of new internet devices and protocols. The basic package is intended for simulating communication networks and for protocols and devices development. There are also additional specific modules, such as a module assigned to the simulation of wireless networks, an ACE module for application analyzing, 3DNV module for visualizing networks on virtual terrain and the "System in the loop" module for simulating networks with real communication equipment in the loop, in real-time.**

Keywords – **Simulation tools, communications, teaching, networks, modelling, OPNET.**

I. Introduction

Computer network development began in the late 1960's, arising from massive mutual linking needs between computer units into entire local networks. The first ideas and requirements came from companies, the military and educational institutions. The main reason was concerned about simple information exchanges', mass data transfers, and with greater data-source exploitation. Such aspirations have many advantages, some of them are: reliability, alternative sources and cost efficiency, which nowadays represent capital driving wheel.

In order to study, understand, and exploit their properties or research new protocols, behaviour etc., we need a computer tool, by which we can model, simulate and evaluate computer networks well as wired and wireless.

OPNET offers varied simulation tools for many solutions:

- Application performance management (ACE, ACE Live, OPNET Load scalar, OPNET Commander, SLA Commander)
- Network operations (IT and SP Sential, IT and SP Netcop)
- Capability management (IT and SP Guru Network Planner, IT and SP Guru System Planner)
- Network R&D (OPNET Modeler, OPNET Modeler Wireless suite, OPNET Modeler Wireless suite for Defence)

The OPNET Modeler is one of the most advanced tools from among OPNET products palette, together with additional modules, such as Wireless for defence, 3D network visualizer (3DNV), Application Characterization Environment (ACE) and system in the loop (SITL) modules allows advanced simulation methods for wired and wireless communication networks.

This paper is organized as follows. Second section has intention to acquaint reader with requirements, which are needed for simulation tools. Same section also gives detailed description of each important part. Third section introduces available simulation tools on the market and theirs most important features. In fourth section is given OPNET Modeler introduction, beside fifth section presents advanced simulation methods, which can be executed with OPNET Modeler simulation tool. Sixth section illustrates OPNET university program structure and their products; meanwhile section seven concludes the paper.

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II. Requirements for Network Simulation Tools

A simulator must fulfil certain individual requirements, which can be combined into the following groups: general demands, implemented modules, statistical capabilities, outlet reports, manufacturer help and support for end-users.

A. General demands

Modelling flexibility is the ability to construct and define new communication protocols, hubs, links, data frames, stations, units, and so on.

Model development simplicity requires friendly and an easy to use interface. It should be possible to construct new model elements from small modifications of existing ones.

Fast modelling is an essential property in those cases where models reaches huge dimensions or in cases where the number of events is huge. This property clearly has economic roots. It is also important in critical situations which need cautious intervention into a real system.

Animation represents a basic element in the simulation procedure, which helps us to locate any faults and errors in a simulation model by changing icons colour, position etc.

Automatic simulation execution with a changeable parameter enables observation of dependences between different parameters, e.g. dependence on delays in a local area network comparison with the number of network users. It requires multiple simulations, where each run has its own parameter [4], [5].

B. Needs upon implemented modules

Different kinds of implemented components have an effect on a smaller model's construction time. Components must be in complete accord with choosing real elements, available on the market (routers, switches, hubs, servers, computer units, protocols, token-rings, Ethernet, FDDI…). It is desirable, that we in simulation can use those specific elements, produced by certain manufacturers. For example, if we want to use Cisco's router series 7507 it should be available in the simulation library.

Component adaptability is the ability to create a new component, by changing parameters in accordance with our needs, or of an existing similar component.

Creating new components. In regard to the above statement it could happen that a similar component is unavailable. In this case we have to create a new one if this is supported by a simulation tool. In those cases where such a possibility is impossible, we are forced to use cognate components, but this decision can have an effect on any results' reliability [5].

C. Static capabilities of a simulator

Random numbers generator. The majority of events in networks have coincidental sources, for which we need a good generator for generating random numbers. It is desirable therefore; that they contain more-independent random flows with separately defined probability distribution.

Standard probability distributions. Most well-known probability distributions should be implemented into a simulator. Typical examples of probability distribution are: Gaussian, Poisson, exponential, equalization, Weibull distribution, and so on.

Empirical distribution is a characteristic that is closely connected to capability, where we can simulate individual sources with real measured values.

Random shut-out of individual components in a simulation process. This property is useful in cases where we want to observe rare events in system architecture, especially when a specific part of a network deviates from the normal operating manner. Rare-event simulation is useful for sensitive systems, such as military communication systems, bank transfer systems, and security systems [5].

C. Outlet reports

Calculations. The tool must include a function which can calculate averages, trust intervals, standard deviations, minimums, maximums, sum, count, etc. All acquired data must enable save possibilities in many different formats.

Standard reports. After network simulation, is interesting for us to note that that some network parameters such as end-to-end delay, equipment utilization, link utilization, queuing delay, dropped packets etc., are available in easily scanned standard reports.

Accommodation reports. Possibilities for their own design and creative reporting, looking at it from the content and form aspect, should be available to end-users.

Graphs. It is desirable that different graphical possibilities are available for data presentation, such as histograms, curve-graphs, circular-graphs, time-diagrams and so on. The tool's mechanism should also enable mutual comparisons between graphs for dissimilar simulation repetitions [5].

C. Manufacturers' help and support for end users

Today end-users support's a very important part of those program packets available on the market. Support can include advice at the point of sale, software installation guide, education process, technical support, online consultation etc.

Seminars. Software manufacturers must provide educational processes for customers at different seminar sessions if possible at the costumers abode.

Technical support about those errors, warnings, and faults, concerned with specific software packets.

Quality documentation enables easier use of software and greater utilization of all the possibilities offered by the program. Documentation should include a user's manual, a maintenance manual, described and illustrated examples, reference guides, video presentations, animations, model support with voice and pictures, demo presentations, online help, etc.

Upgrades and updates. These must be attainable and not too expensive. Updates, free of charge are usually similarly to software testing or software demonstrations [5].

III. TOOLS FOR NETWORK SIMULATIONS

OPNET Modeler is a graphically oriented simulation tool, which uses project, node and process editors for building communication models [7]. In more details will be presented in next section.

OPNET IT Guru - academic edition. OPNET IT Guru Academic Edition [8], as shown in Figure 1, is a free-of-charge simulation tool, offered from the manufacturer of OPNET, and is intended for educational University programs. It is useful within education process concerned with communication technologies through practical simulation examples. With OPNET IT, we can acquaint under graduate or post-graduate students with the basics of different communication architectures, such as PSTN, ISDN, cable networks, xDSL technologies, fibber networks, and also wireless like Wi-Fi, GPRS and UMTS. Within the widely-supported construction parts' library can be found computer workstations and servers, routers, switches, bridges, stars, access points, links, firewalls, gateways, servers etc. Software is user-friendly, because the whole application can be constructed in a graphical project editor. There are also buttons for observing chosen statistics, graphs, and buttons for running simulations. Each component has changeable attributes, such as; name, queue length, traffic statistics, routing protocols etc. With special components, such as "Application Config", we can

define the behaviour of traffic source generators, according to the required applications, such as video conferencing, VoIP, FTP, web browsing, base access.

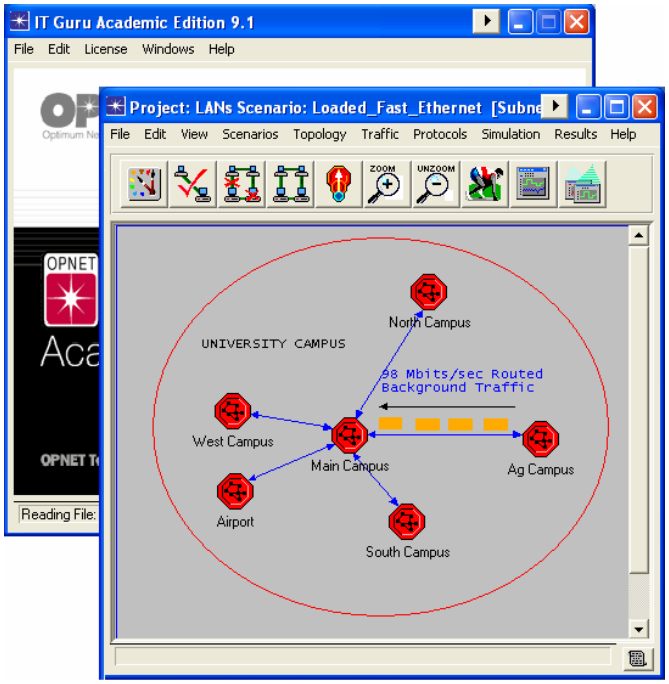

Fig. 1: Simulations in OPNET IT Guru

Network II.5 simulator is designed for the simulation of computer systems and networks. The main constructed parts are devices and programmable modules. In the device classes can be found process elements (CPUs), transfer mediums (bus, LAN), and storage units (hard drives, RAM). All elements are represented by icons (shown on Figure 2), which afterwards must be mutually connected between each other, as in OPNET modeler case. A programmable module consists of an instructions sequence, and running and executing on process elements. They can be executed at different times using random distributions. Global variables (semaphores) are also available, which increase simulation flexibility [2].

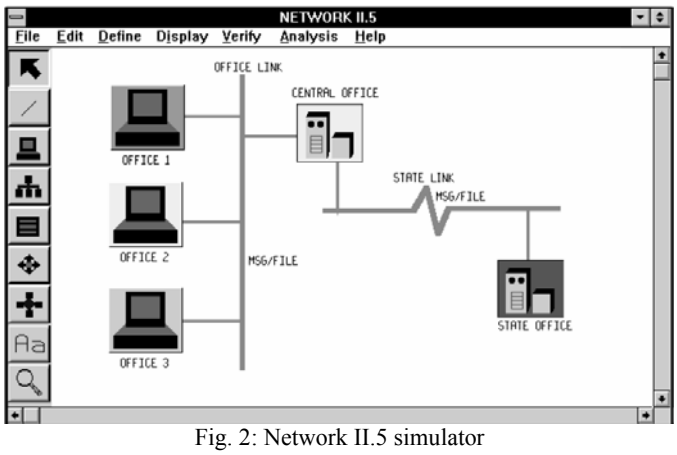

Fig. 2: Network II.5 simulator

SES/Workbench represents a graphically supported, electrical engineering simulation tool which also supports computer systems and communication modelling (example is shown on Figure 3). The main components for communication modelling are nodes, links and transactions. A transaction represents message, forwarded with by oriented graphs. An oriented-graph is composed of nodes, links and special formulation which define hubs' and arts' behaviour. These nodes are not the true nodes in the network, they just represent the activities on messages, for example, creating or destroying transactions, resource handling, and so on. The results are available in both graphical and numerical forms [3].

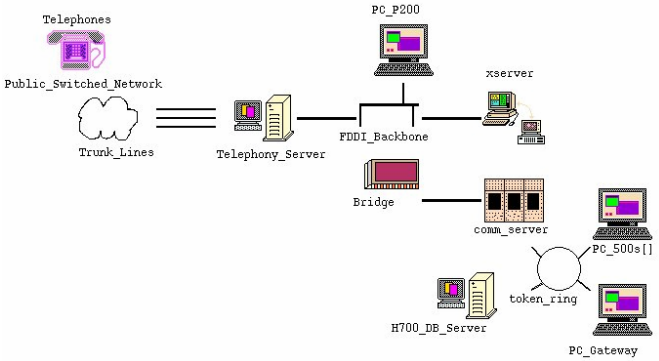

Fig. 3: Example of communication network in SES/Workbench simulator

BONeS Designer, Plan Net and SatLab. (Block, Oriented Network Simulator) is also a graphically supported tool, as can be seen on Figure 4, with the general intention of modelling communication networks. The main building blocks of these models are data structure, and a block diagram. The first of these represents messages and the second defines how the messages travel though the network. Results are available in both, graphical and numerical forms. SatLab is an additional software packet for satellite systems modelling [6]. BONeS Plan Net is a specialized simulator for local area network simulations.

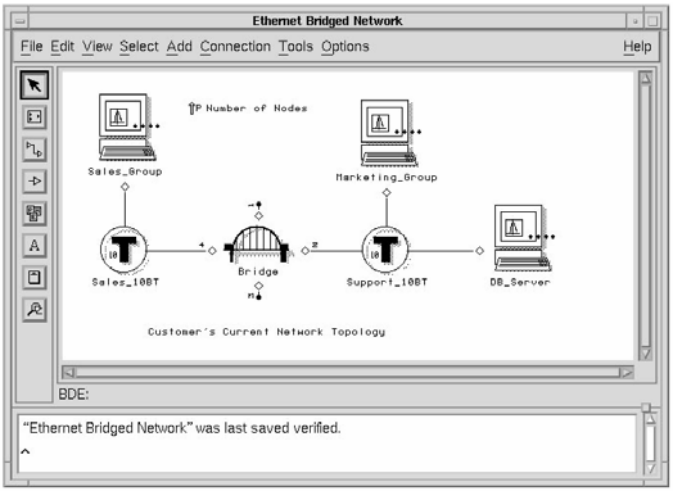

Fig. 4: Example of communication network in BONeS Designer

COMNET III. Represent an object-oriented simulator for LAN and WAN network architecture simulations. The main parts (nodes, links and traffic sources) are represented by icons. The user must connect hubs with links and put traffic sources onto certain such linked-nodes on graphical user inter-

face, as shown on Figure 5. Properties are defined through dialogue boxes. Reports are available in all forms. Flexibility can be achieved by object-development which allows the creation of new parts or changes the existing [1].

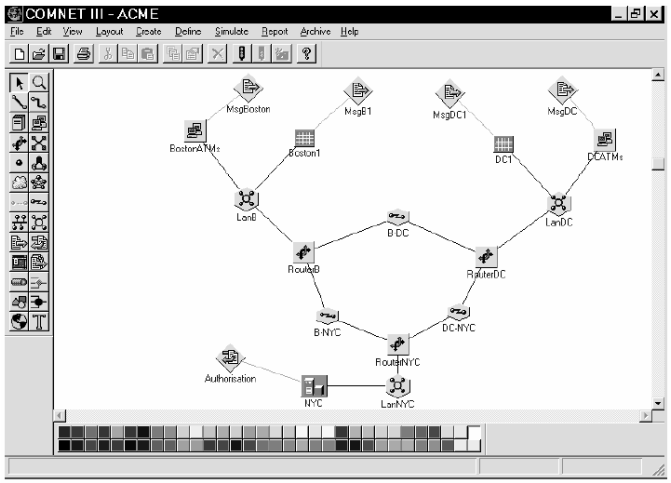

Fig. 5: Example of communication network in COMNET III

IV. OPNET MODELER

The OPNET Modeler is one of the most powerful simulation tools regarding communications. It is especially useful on R&D (research and development) areas for developers of communication devices and protocols. Planners and communication network operators have the possibility to use this tool for network efficiency analyze, optimization, growth analysis, etc. The OPNET Modeler comprises a series of hierarchical user interfaces, which are shown in Figure 6.

The project editor is the main user interface. It allows for graphical representations of communication network topology with components from comprehensive library of devices and models, defining communication links, configuring models' parameters, defining, editing and running simulations, scenarios, checking and comparing results etc.

The node editor enables the editing of these network device models that consist of process modules linked by signal and data paths. Each of these process modules can generate, send, receive and process packets from other modules. The standard model contains visualization of communication devices with all protocol layers (from application to the physical layer), according to the ISO/OSI communication model.

The process editor is intended for process modelling with the help of a FSM (Finite State Machine). Using this editor we can approach supported specifications at any level (even regarding details), which relate to communication protocols, data sources, applications, algorithms, queues etc. Every state in the process model includes C/C++ code, supported by an expanded functions library, intended for programming communication protocols [7, 13].

There are different possibilities for simulation results' visualization. One of them is shown in Figure 7, where the numerical labels represent:

– choosing statistics for visualization in the right-window,
– hoosing types of graph showing (individually or more statistics on the same graph),
– choosing the numerical operation or chosen statistics (average value, logarithmic scale, distributions)
– displaying a graph in the independent window.

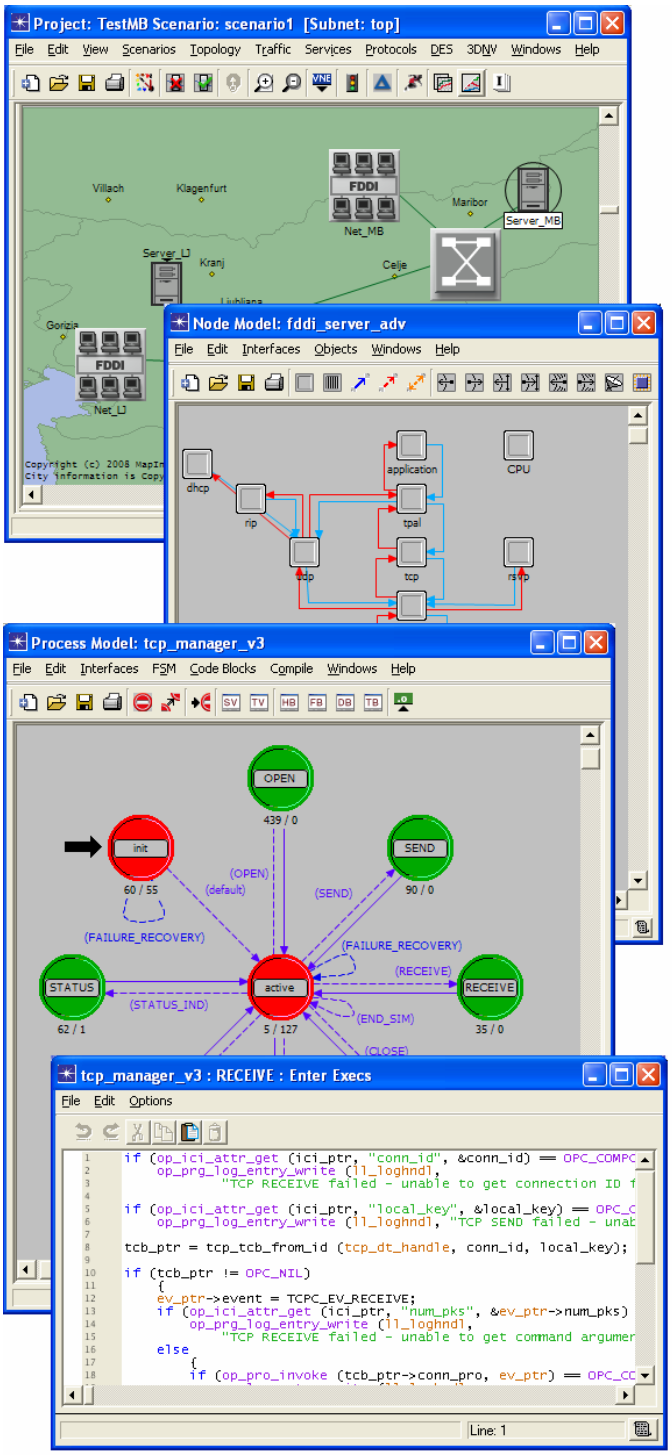

Fig. 6: Formation of basic network model (project editor), detail workstation model (node editor) and process coded level (process editor)

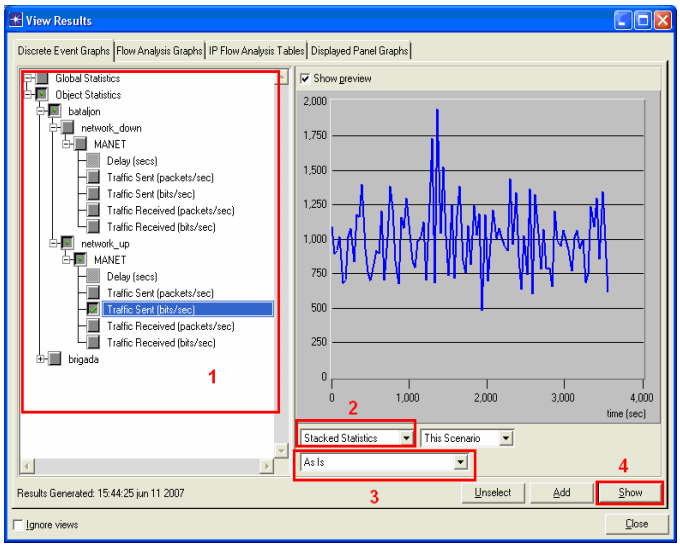

Fig. 7: Window "View Results" with simulation results

V. ADVANCED SIMULATON METHODS WITH OPNET MODELER

OPNET Modeler Wireless package for wireless network modelling. Wireless links are simulated by using an open-concept called a transceiver pipeline. The transceiver pipeline enables delay computations during the spread of radio waves, closes radio links, considerate of an aerial's emissive diagram, background noise, modulation effects, interference, bit-error rate, forward error corrections, etc. A very important task of the transceiver pipeline is also consideration of these effects caused by field influences over the modelled terrain, such as fading, diffraction, reflections, atmospheric absorption etc. These are considered by propagation models such as Free Space, Longley-Rice, and the most sophisticated TIREM [9, 10]. The virtual field is modelled in the form of Digital Terrain Elevation Data (DTED) maps. It is possible to simulate various wireless communication technologies such as MANET [11, 14], 802.11 [13], 3G/4G, Ultra Wide Band, WiMAX, Bluetooth, ZigBee etc.

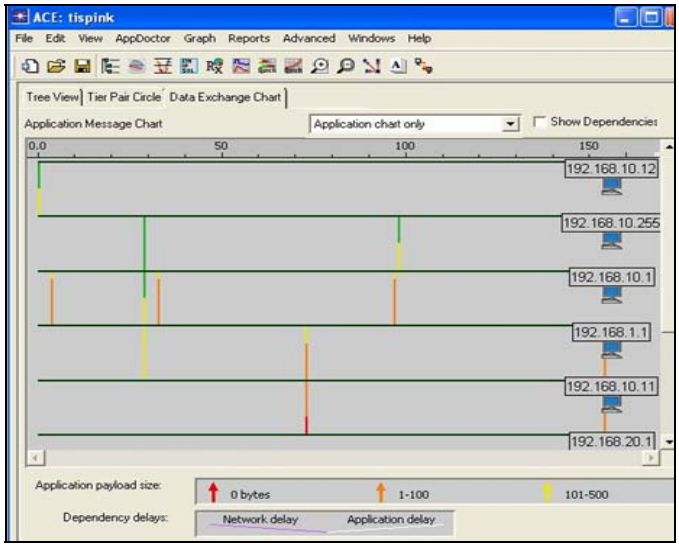

Fig. 8: Packet flow analysis with ACE module.

The ACE (Application Characterization Environment) package allows virtualization, analyze and prediction of any network applications' problems. It also helps us with analysis during the phase of developing new applications. This module allows the import procedure of real traffic, and analysis of captured traffic. It allows diagnostics for properties such as information concerning blockages, and delays in networks. The user interface of this module is shown in Figure 8.

The 3DNV module, shown in Figure 9, is in combination with OPNET Modeler, and it enables the playing of simulated mobile network's 3D animations. Every communication device in the OPNET Modeler can be illustrated by 3D models, in 3DNV environment, by vehicles, soldiers, planes, helicopters, satellites, etc. This tool enables the interactive direction regarding viewpoints of observation 3D scenes similar to video game consoles.

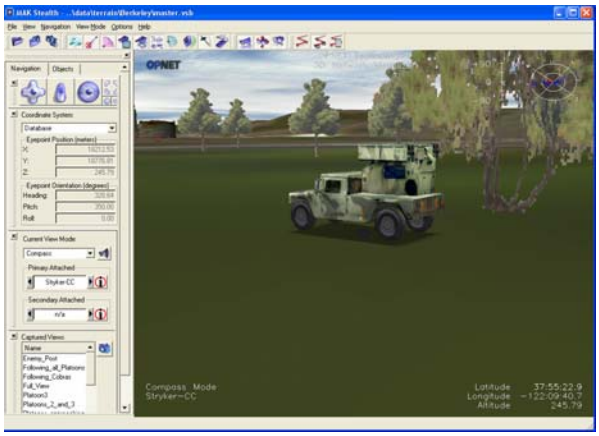

Fig. 9: 3D visualization of communications unit on virtual field

The System-in-the-loop - SITL module brings the additional ability to simulate in real time, with real communication equipment in the simulation loop. The module of SITL is suitable for:

- Studying how simulated network's impact on real network and vice-verse,
- Using OPNET simulator as a traffic generator for loading a real network,
- Testing of new protocols and device prototypes,
- Scalability testing by adding virtual (simulated) devices on a real network, and so on.

Simulated network can have an influence on real network through parameters, as are packet-loss packages, delays, jitter, packet doubling on receiver side, etc. External-devices are connected to the simulation loop over SITL gateways, which are bridges between communication simulation environment and host computer Ethernet interfaces as one of the typical configurations [15]:

- Real-Sim-Real: Real network with real network over simulated network. An example is shown in Figure 10.
- Sim-Real-Sim: Simulated network with simulated network over real network.
- Sim-Real: Simulated network with real network.

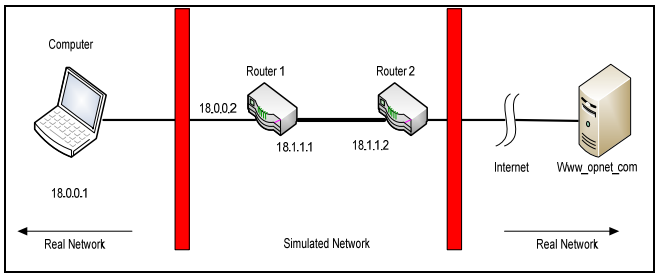

Fig. 10: Use case for "Real-Sim-Real" SITL simulation.

VI. OPNET UNIVERSITY PROGRAM

Although OPNET was created for specific University program, its products are also available as simulation tools for nonprofits purposes such are teaching and academic research. There are presently about 20,000 students and professors around the world using these products. Numerous text books and accompanying lab examples are also available. Two options exist when using the OPNET University program [16]:

- Full-featured OPNET Modeler software which includes an extensive model-library with around 800 protocols and vendor device models. These models are also supported by source code and provide technical support at discount prices.
- The second option is the free OPNET IT Guru Academic edition, which provides a feature set for use at networking levels (without any possibilities of modelling new processes and protocols, as with the OPNET Modeler). IT GURU academic edition provides solution testing for different protocols and network technologies: studying various wired and wireless routing protocols, visualizing TCP/IP mechanisms and variations, understanding LAN/WAN/MAN network architectures [12], designing reliable wireless networks [13], and implementing efficient network security.

VII. CONCLUSION

The OPNET Modeler is used for modelling and simulation of communication networks and, at the same time, it enables construction and study of communication infrastructure, individual devices, protocols and applications. In this paper we show some possibilities of using the advanced simulation methods for simulating the tactical networks. Real time simulations using introduced OPNET SITL module in fifth section, is the novelty on the network simulation area. Although SITL module has still some deficiencies, we can claim, that this module will have the great impact on the area network simulations. SITL module was developed for the tactical networks purposes, but his functionality can be also used for other purposes, for example; it can help in development of a new protocols and devices.

OPNET IT Guru, is very similar to an OPNET Modeler. The main differences are that it does not include a process editor the possibilities of editing code level in C language, and various advanced modules. From that aspect, we cannot change existing communication models or create new components. Maximum network expanse, which can be simulated, is also bounded in OPNET Guru. In spite of this entire Guru is especially suitable for educational processes during Faculty undergraduate programs. For research proposes and educational processes for post graduated study programs the OPNET Modeler is a more suitable choice. Modeler is also available through the OPNET University program but is not completely free of charge like IT Guru.

From the rich experiences gained from over the last few years, we can claim, that the OPNET tools are appropriate for use in communication research activities [10, 14, 15] and teaching objectives for under-graduate [12, 13] and post-graduate [9, 11] programmes.

ACKNOWLEDGEMENT

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