

A Tactical Training System Based on C2IS-in-the-Loop Simulation

Jože Mohorko¹, Matjaž Fras², Žarko Čučej¹

Abstract – The need has become apparent for real time training and simulation tools. Such tools allow for realistic network planning and training of command personnel on real Command and Control Information Systems (C2IS). Real C2IS hardware and software are connected within the simulation loop, where a tactical radio communication infrastructure is modeled on a virtual terrain. Operators of C2IS systems can, by using this system, carry out training, whilst simultaneously evaluating the quality of tactical network planning from the points of view of network throughput, end-to-end delays, radio visibility, etc. In this paper, we proposed the architecture of such training system, based partially on capabilities offered by well-known OPNET Modeller simulation tool and partially on additional tools, which must be developed to enable integration with standard C2IS databases and do evaluate training progress with an expert system. The concept is proven by simple simulation example.

Keywords – Military information systems, Military communication, Training, Simulation; System-in-the-loop, Real time simulation.

I. INTRODUCTION

One important R&D priority of the European Defense Agency (EDA), as well as of the North Atlantic Treaty Organization (NATO), includes technological issues regarding the development of simulation models and systems, devices and equipment for supporting of military education, training and exercises in these areas where battle forces operate, plus the operations of civil protection forces. Special attention is given to digitizing the battlefield, to military computer modeling and simulations, and also to geographic information systems (GIS).

In 2001, the Multilateral Interoperability Programme (MIP) was established to advocate successful and harmonized operational functions for international peace-keeping forces [1]. Interoperability is achieved by C2IS (Command and Control Information Systems) at all military levels. C2IS is designed to control the operational, logistical and communication information stored in the standard C2IEDM (Command and Control Information Exchange Data Model) data bases. The successes of military missions largely depend on a mission's planning quality and on staff readiness. The training and planning of military operations, over the last few years, has quickly moved into the area of computer simulations. This means that simulation becomes an important

task in the process of training and military mission planning. Such methodologies ensure a higher probability of success for critical tactical operations. The deployment of such simulation technologies are enabled by the large processing power of modern computer equipment, software tools for realistic simulation of communication systems, accurate virtual cartography, etc.

A. Offline simulations

Most of the developed tools for tactical network simulations are “off-line” simulation tools, where a tactical network can be analyzed after a simulation run. The more prominent problems in tactical networks are limited bandwidth, big round-trip delays, and the influence of terrain topology and nodes' mobility on radio link conditions [2]. One earlier paper about tactical radio systems' simulation presented a solution [3], where a specialized FORTRAN program was developed in order to simulate radio propagation effects, interference, SNR, etc. The more often used tool in this area is the OPNET Modeler [4], which is also used as a basic simulation tool in our work. The results of tactical network simulations can be used to evaluate the performances of the tactical communication networks [5]. Two well-known tools have been developed specifically for military tactical network simulations based on OPNET. The first tool is NETWARS [6, 7, 8], which enables the simulating of different tactical simulation scenarios by using diverse combinations of tactical network devices and military concepts. Later this tool was renamed to the JCSS (Joint Net-Centric Modeling & Simulation Tool) [6]. The second tool is INCOT, which represents an intelligent specialized tool for the optimization of communication networks [9-11]. Researches are also known on the field of modeling and simulation of Network Enabled Capability, like [12] where simulations are performed in the Java language. In this case, the detailed communication's aspects are not set in the first modeling plan. Recently, efforts on the field of off-line we can find also within the framework of the C2 Wind Tunnel project [39]. This is a multi-model simulation framework for integrating simulations to drive fusion experiments and, which allows modeling, synthesis, and deployment of a networked system of systems. In this framework are integrated different simulation tolls (OMNET, MATHLAB with Simulink/Stateflow, and Delta3D).

We have developed our own OPNET modeler based solution [38], which consists of simulation methodologies and tools for “off-line” analyses of C2 (Command and Control) tactical networks'. This solution is suited to the Sytematic's [13] C2IS software (database Iris Replication Mechanism

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(IRM) [14] and Sitaware tactical GUI [15]) and communication concepts used in the Slovenian Army. This solution includes the TPGEN helper application (Slovenian acronym for Tactical Information Traffic Generator), which enables user-friendly entering and editing of tactical network parameters into an OPNET simulation data model [16, 17]. We have also developed an expert system application, which enables automatic analysis of OPNET simulation results [18]. The tactical player visualization tool [19, 25] combines a 3D view of simulation records with expert system results. The developed solution is devoted to the planning and optimization of tactical radio communication systems. Communication systems are in this case modeled on a virtual terrain. The training system in this article, proposes a step further by including a real tactical C2IS hardware and software, in the simulation loop.

B. System-in-the-loop simulations

Over recent years, a new concept of on-line tactical network simulation has appeared where simulation is performed in real time. This concept includes two aspects:

- system-in-the-loop (SITL) [20] (also known as hardware-and-loop [21]), where real application software and hardware is included in the simulation loop.
- man-in-the-loop (MITL) [22], where the simulation loop also interactively includes people (operators),

thus forming the basis of modern training-simulation systems. One of the earlier real-time simulators with a military application is the Battle-space communication network planner and simulator [23, 24]. This simulator is based on the OPNET simulation tool, where special communication hardware and software interfaces were developed that allow interconnection with actual command and control (C2) systems. In contrast, this paper describes, our own experiments with real time simulations using OPNET, with its System-in-the-loop (SITL) module, which allows connections between real devices and the simulation. In this case, however, special communication devices are no longer needed, as the SITL module provides packet translation between real and simulated packets [25]. OPNET simulation is the event driven; these mean that simulation is synchronized to incoming packets from real part of network. In this case, there are no problems about time coherency between simulated and real components.

This paper presents the main basic concepts of how to design very realistic tactical training systems based on SITL and MITL. We have named this concept, which incorporates SITL, MITL and C2IS within the simulation loop, 'the C2IS-in-the-loop simulation concept'. This concept is proven using a simple near real-time simulation example, where the real C2IS equipment of tactical units is connected through the simulator. The developed simulation system, in this experiment, enables the testing and training of different tactical missions within a lab-environment, where the radio part of a wireless tactical network is modeled by an OPNET Modeler simulation tool. Within the simulated tactical communication infrastructure, we can like on the real radio equipment, define radio parameters, positions, trajectories of

movement, etc. Different radio-wave propagation models, which depend on virtual terrain models, can be used during simulation. Fig. 1 shows a schematic of connections between real tactical units, equipped with C2IS, and a simulator. External units are connected over the Ethernet hub to the computer where an OPNET simulator is installed. In the simulator, the external connected units are represented as tactical wireless radio devices. During the simulation run, tactical planners and operators can analyses those situations when long delays appear and when units lost radio visibility or data connectivity. Such a simulator enables mission training and early predictions of any possible problems that may appear during a real mission. In such a way, a simulation tool can improve the probability of a mission's success, which also depends on C2IS reliability. This, in a simple example but the presented simulation methodology can be easily adapted to more complex C2IS training systems.

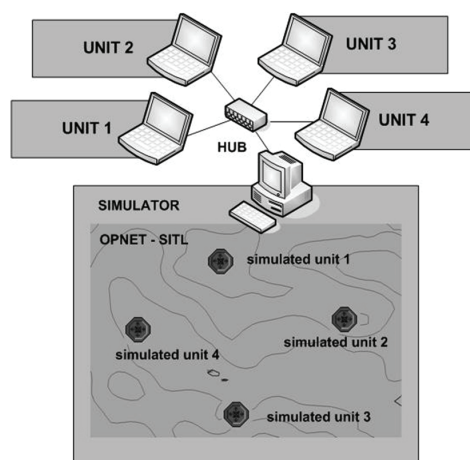


Fig. 1. LAN connections between real tactical units and the simulator, where the tactical radios of tactical units are modeled on a virtual terrain.

This paper is organized as follows. The second section briefly describes the command and control information system (C2IS), as used by the Slovenian Army. The third acquaints the reader with advanced OPNET Modeler modules, which enable real-time simulations. The proposed design concepts of the tactical training system based on C2IS-in-the-loop simulation, is presented in the third section. The proposed concept is tested by example from the fifth section. This paper concludes with some guidelines for future work.

II. COMMAND AND CONTROL INFORMATION SYSTEM IN THE SLOVENIAN ARMY

Command and Control Information System (C2IS) (TISPINK is the Slovenian acronym) is designed to control the operational, logistical and communication information stored in standard C2IEDM data bases. The C2IS system provides information about operational developments, the state of your own and other friendly and hostile units, military inventory, etc. This information is very important for modern international military operations and for the successes of many multilateral international operations. Fig. 2 shows the

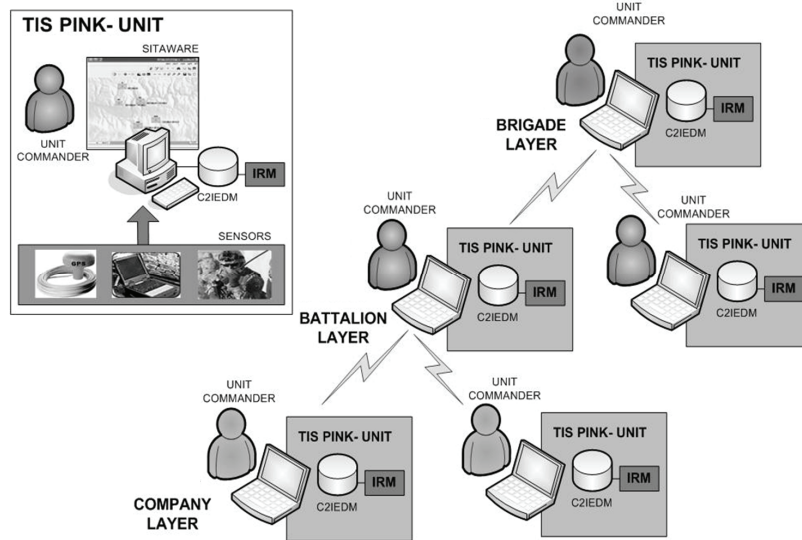


Fig. 2. TISPINK army unit (left), hierarchical structure of tactical network (right).

main structure of the TISPINK unit. The core of the TISPINK system represents two main programs developed by a Danish company Systematic Software Engineering A/S [13], in accordance with MIP recommendations. These programs are IRIS replication mechanism (IRM) and Sitaware. IRM [14] is responsible for data exchange (replications) between the C2IEDM data bases of military subjects in accordance with so-called agreements. The agreements set between the subjects, comprise the addressee of the military unit, the data collection to be shared, and the used communication protocol (peer-to-peer or broadcast). This replication mechanism enables flexible control and supervision over information exchange in tactical networks.

The Sitaware program packet [15] is a graphical user interface of the C2IS. It is used for the planning, checking and analyzing of tactical units' activities on the battlefield. It enables the operators or planners of the operations to ascertain information about the situations of individual units in the field, and then share this information with other military units. Sitaware is distinguishable by its powerful graphical interface supported by GIS (Geographical Information System). GIS in turn, supports various geographical map formats and has different user layers, thus enabling the entering of different information about tactical conditions on the battlefield.

Fig. 2 (left) shows a typical C2IS tactical unit. Each unit has its own C2IEDM data-base, IRM replication mechanism and Sitaware. Various sensors can be connected to the tactical units, such as GPS. TISPINK units compose the hierarchical tactical network, as shown in Fig. 3 (right), where units can communicate by inferior and superior units as defined by IRM contracts, described in more details in [14].

III. OPNET MODELER USED AS A REAL TIME COMMUNICATION'S SIMULATOR

The proposed design of a tactical network training system is based on the OPNET simulation tool [4, 6, 7, 8, 16, 17]. The OPNET Modeler Wireless Suite is used for Defense, because it supports high-fidelity protocols and equipment models

within a scalable simulation environment. It also supports, among other things, those wireless simulations incorporating terrain influences in path-loss calculations using different propagation models, mobility, and 3D visualization.

A. System-in-the-loop module

The system-in-the-loop (SITL) [4, 20, 25] is an OPNET Modeler program module, which provides an interface between physical and simulated networks. It provides packet exchanges between real and simulated communication devices. SITL gateway represents an external device by which the simulation exchanges the packets. There the WinPcap [27] library is used to route those packets, selected by user defined filter, from an Ethernet network adaptor to the simulation process. In such a simulation manner, physical hardware and simulation can interact as a unified system. There are three main simulation topologies for using the SITL module: real-to-real (communication between real devices over a simulated network), as shown in Fig. 3, sim-to-sim (communication between simulated devices over a real network) and sim-to-real (communication between real and simulated devices)

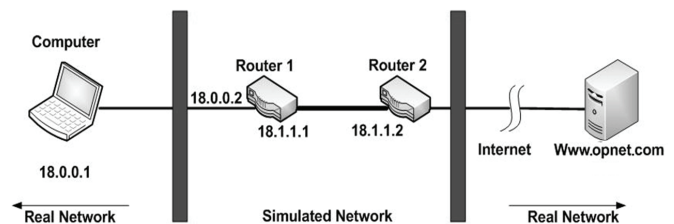


Fig. 3. Example of real-to-real SITL simulation, where real devices (client and server), communicate through a simulated network consisting of routers.

B. Wireless package and Terrain Modeling Module (TMM)

The OPNET Modeler Wireless package is a flexible and scalable environment for the modeling and simulation of wireless networks [28, 29, 31]. All the characteristics of

wireless networks are integrated into the lower layer's protocols, which enables the modeling of all aspects regarding a wireless transmission, such as the spreading of RF electromagnetic waves [30] by considering ground impact to the diffraction, fading, interferences, characteristics of the receiver and transmitter, nodes' mobility, etc. In the OPNET Modeler's wireless package, wireless links between transmitter and receiver are simulated using an open-concept called a 'transceiver pipeline'.

The Terrain Modeling Module (TMM) is a special OPNET module which enables improvement in the accuracy of wireless network simulations, by taking into account signal-loss due to the effects of a terrain. They include the impact of natural barriers on simulations (mountains and the earth's curvature), and the physical characteristics of the environment (conduction, permeability, refractivity) on the spread of radio waves. TMM supports various propagation models: free-space propagation model [32], Longley-Rice model [33, 34], TIREM model [35] as the most detailed and with the fewest limitations.

C. Network Visualizer

A 3D Network Visualizer (3DNV) [36] is an additional OPNET Modeler module (also known as MÄK Stealth [37]). It enables 3D animation of simulated network topology, network devices, and link status. It can be used for visually demonstrating how terrain features, such as hills and mountains interfere with the wireless communication devices of mobile networks. Visual presentation can also be enhanced by network statistics, such as received packets, transmission quality, throughput, delay, message status, information, etc. The communication devices used in the OPNET Modeler can be visualized in 3DNV, for many different 3D objects. A library of 3D objects is available (cars, planes, ships, tanks, etc.). Fig. 5 also shows an example of communication units on virtual terrain (represented by a vehicle) visualized by 3DNV.

IV. PROPOSED DESIGN OF THE TACTICAL TRAINING SYSTEM BASED ON THE C2IS-IN-THE-LOOP SIMULATION

This research is focused on developing such a training system, which would allow realistic tactical practicing for unit commanders, C2IS operators, soldiers, etc. Training can be performed within one classroom with tactical computers equipped with appropriate C2IS software, and a simulation server equipped with simulation software. This software mimics radio communication equipment on virtual terrain, using various tactical scenarios. One of the more essential elements of developed simulation concept is battlefield digitalization using GIS cartography, which enables precise virtual terrain modeling. Throughout with all aspects of the training process, the environment would need protecting, reduced time to obtain important data, reduced costs, etc. This is possible because commanders can check mission feasibility within a simulated environment, and don't need to send real troops (units) onto real terrain to test a certain battle scenario. Because such a system is primarily intended for missions

testing and training it must involve those mechanisms which help to find proper solutions for specific scenarios, or propose such scenarios, which would fulfill commanders' expectations. Virtual nodes' movements in the simulator will behave similarly to those on real terrain. Real C2IS equipment can realistically observe effects, when communication fails. The online analysis mechanism can predict critical areas where units have lost communication, and also areas with good communication viability. Furthermore, of interest is the analysis of those conditions where an enemy disturbs communications using jammers.

The concept of the proposed training system is shown in the Fig. 4. The connections between blocks indicate data flows. C2 users representing units commanders use tactical notebooks (with C2IS), connected to the OPNET/SITL based simulation server. This connection is achieved using Ethernet links over a Hub, as shown on Figure1. Then in such a setup, all real TCP/IP based applications (VoIP phone, e-mail FTP, C2IS, etc.) will communicate with each other using a C2 user over a simulation computer. Radio equipment, which communicates over virtual terrain, is modeled in this OPNET/SITL simulation environment. This model involves various propagation models to simulate the influences of, obstacles, vegetation, dispersion, fading, etc., on a communication process. The OPNET Modeler supports different cartographic formats for virtual terrain modeling, in this case using cartography in the DTED format. This concept, where a real system is included in the simulation loop, is called SITL. Scenario engine represents a training system user interface and performs simulation control management. A C2 engine cares about the synchronization of C2IS units' geographic positions, and the positions of the tactical radio equipment on the virtual terrain.

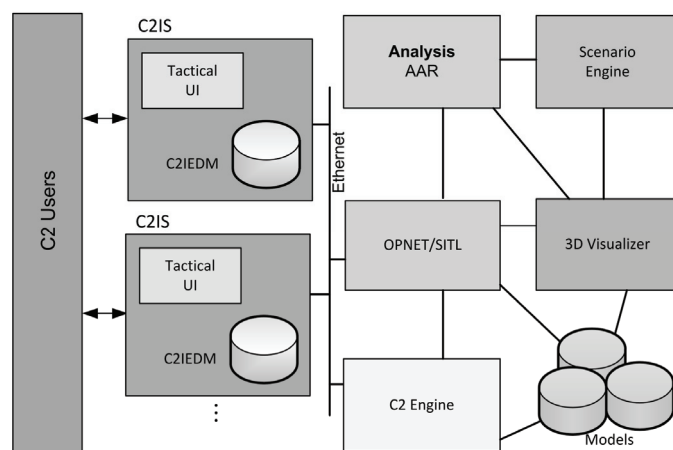


Fig. 4. Bird's eye view architecture of the proposed training systems' architecture

This idea about how to involve humans in the communication simulation loop concerns standard MIP C2IEDM data bases. Such data bases would be some kind of bridge between C2IS applications on real C2 equipment and modeled radio equipment in the OPNET Modeler simulator [4]. Each movement in the Sitaware user interface could be online synchronized (using a C2 engine) with virtual nodes movements within the simulator. Such approach can provide

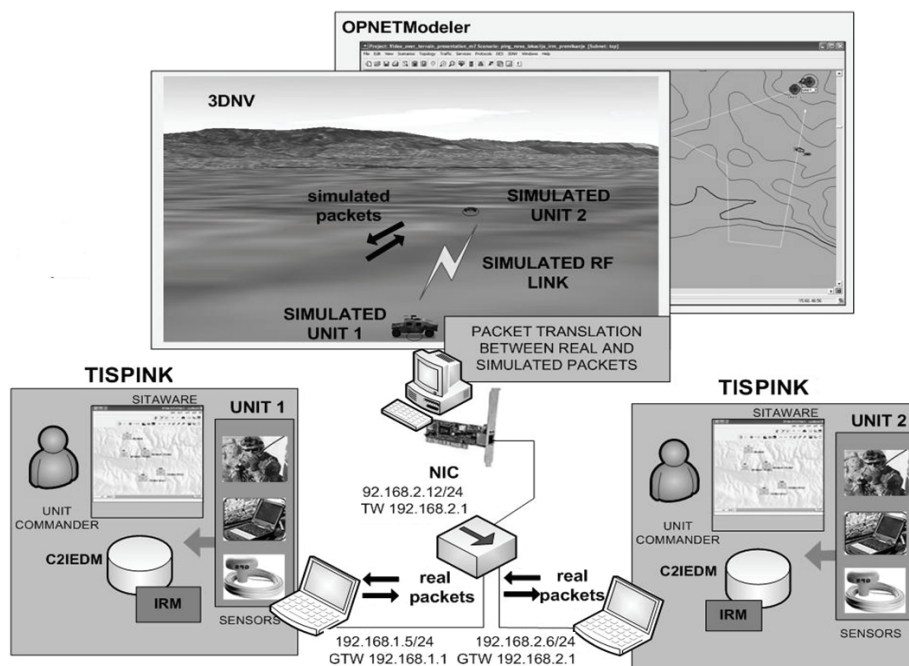


Fig. 5. Topology of test network for data transmission between real Unit 1 and Unit 2 over a simulated wireless link.

an independent system which is not limited to specific user software equipment (such as Sitaware [16, 17], as used by Slovenian armed forces). Movements of units are performed and controlled by C2 users, using a GIS user interface like Sitaware. Their actions would be stored in C2IEDM, and from there (using C2 Engine) sent further to the OPNET Modeler based simulation tool. In this way, the C2 users interactively influence node movements during a simulation process. In addition to this, a human can also be included in the simulation loop with an additional user interface, which would allow interactive changes in the operating parameters of the modeled radio equipment, such as: frequency bands, modulation types, transmitting power, etc. This concept is known as MITL (Man-In-The-Loop) [22]. Both concepts, SITL and MITL, are relatively new, and are revolutionary within the concepts of virtual reality and virtual combats, mission planning, etc. All there presented concepts together we have named C2IS-in-the-loop simulation.

Each mission or battle scenario would also be presented in 3D form on virtually modeled terrain using a 3D visualizer. All tactical movements during the training or planning process would be performed in real or near real time and simultaneously displayed on the big tactical screen. The simulation administrator could change the 3D observing perspectives for specific units. He could also observe various simulations' attributes such as: packet loss, communication visibility, units' speeds, units' geographical positions, etc. We also wanted to provide realistic visualization of virtual objects, which would include soldiers, tanks, battle plans, helicopters, medical vehicles, hammers, flying antennas, etc. An enhanced terrain model with roads, buildings, vegetation, railways, vegetation (trees) and, so could also be included in to the 3D visualization. Our proposal suggests using a 3DNV (MAK Stealth) visualizer, as described in section 3.3., which communicate with OPNET Modeler using HLA (High Level Architecture) protocols.

Analysis and an After Action Review (AAR) provides a basis for evaluating missions' (scenarios), implementation effectiveness as a whole scenario, as well as for individual participants. Evaluation of specific missions/scenarios could be done similarly to those done in our R&D project (Modeling of the command and control information systems - C2IS), where a so-called 'expert system for automatic analysis of simulation results' was developed [18]. Also included is the possibility for scenario visualization and scenario replaying, such as implemented in the previously mentioned project [19].

V. SIMULATION EXPERIMENTS

This section, presents a simple example of real time simulation of a tactical communication system using real C2IS software and hardware equipment in the simulation loop. This example can be used as proof of the concepts described in the previous section.

A. Simulation setup

The real-sim-real type of SITL simulation is used where real C2IS equipment communicates through a modeled wireless environment. Fig. 1 shows the basic connections between tactical units and the simulator. This is shown in more detail in Fig. 5, which shows the setup of our test simulation scenario. Here, two real TISPINK tactical units are connected to the hub. Each of these TISPINK units define has defined an IP addresses, gateway, etc. The hub is also connected to the physical interface (NIC) of the computer, where an OPNET Modeler simulation tool is installed. This computer must also be set up for proper IP addresses, gateways, disabled firewalls, etc. It is important that each of the tactical units is from a different subnet. In other cases, they will communicate directly across the hub and not over the OPNET simulator.

The tactical radio equipment was modeled in a simulated environment, on virtual terrain, as shown in Fig. 5. Here tactical radios are labeled as simulated units (Unit 1 and Unit 2). Externally connected real tactical equipment serve as traffic sources and sinks. Modified real packets of TISPINK application run through the simulation, where the SITL gateway translates real packets into simulation packets, and vice versa. Simulation packets carry real packets payloads, with additional data needed in simulation process. Simulated communication equipment acts as real equipment in all considerations (query buffers, responses on lost packets, etc.). In simulations computer must be enough processing power to process incoming traffic in real time. In other case in such simulation system will be involved additional communication delays caused by processing delays. Our previous researches, where 2500 kbps live video stream is transmitted through simulated virtual 802.11g connection on virtual terrain, shown that moderate powerful simulation computer (Intel® Core™2 Quad Q6600, 2.4Gz, 4Gbyte RAM) is strong enough for such simulations [40]. In the case of tactical radio networks, described in our simulation case, typical communication speeds are around 9600 bps. This mean, that same simulation computer can easy process at least 260 tactical radio links simultaneously.

In the OPNET Modeler, the model of a tactical radio was created, suitable for simulations in near real-time. It consists of three devices: SITL gateway (node_2), SITL link, and wireless router as a tactical radio model (node_1). SITL gateway translates packets between simulated and real communication equipment. It can be configured as a filter that defines which packets from which network interface card would be imported or exported via this SITL gateway. Using the wireless router, the tactical radio's attributes can be defined such as the transmitter's power, receiver's sensitivity, channel frequency, types of modulations, types of antenna, etc. This example used TISPINK applications (Sitaware and IRM replication mechanism) installed on tactical computers of units Unit 1 and Unit 2. Unit 1 plays the role of the Brigade and Unit 2 represents the Battalion. Using the IRM user interface, "peer-to-peer" contract between units Unit 1 and Unit 2 were defined. Traffic between these units was caused manually by sending and requesting management or the operational bulks in the IRM replication mechanism. The topology shown in Fig. 5 was used in this simulation case. Unit 1 is a fixed node and Unit 2 is the mobile unit, which moves along a predefined trajectory. The speed of unit's movement is 60km/h. The radio equipment of both units' acts as wireless 802.11g devices with channel capacity of 54Mbps. Virtual terrain is defined by using a DTED Level 2 elevation map with 30m resolution. TIREM was chosen for the propagation model.

A. Simulation results

Two different scenarios were created for the OPNET simulation tool. In the first scenario, the units Unit 1 and Unit 2 are stationary and between them radio visibility is assured all the time. In the second scenario, Unit 2 is mobile along a defined trajectory and Unit 1 is stationary. In both scenarios,

the network traffic is generated by sending and requesting operational and management bulks. In the first scenario, where radio visibility is assured, there are no communication problems during the replication process. From the simulation results (Fig. 6), it can be seeing that radio visibility between units in the first scenario existed all the time. The receiver power at the Unit 1 tactical unit is almost the same all the time, and is above the receiver's threshold, which is -12.5dB.

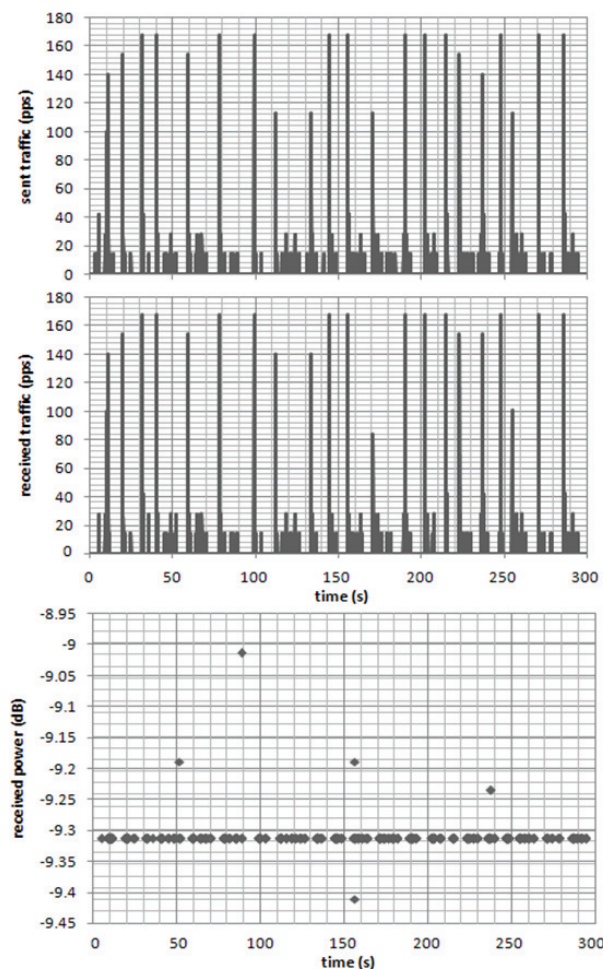


Fig. 6. The first graph shows the sent traffic of the tactical Unit 2, the second graph shows the received network traffic by the tactical Unit 1, and the third graph shows the received power of the Unit 1.

The second scenario repeated the simulation when the Unit 2 was moving along a predefined trajectory. From the Unit 2, we sent and requested operational and management bulks, but at some intervals, there were no responses from the Unit 1 in the cases when a connection was lost. At this point, when connection had been re-established, replications of all data changes during lost connection were accomplished. In these cases, a large amount of replication traffic appeared. This is visible in Fig. 7, which shows the sent traffic from the Unit 2 unit and the received traffic of the Unit 1. There were certain intervals within the range 50 and 150 seconds, where radio visibility between units was unavailable. The graphs in Fig. 8 show the estimated values for received power and signal-to-noise ratio (SNR), of the Unit 1. These can only be estimated in those cases where connections between units are established.

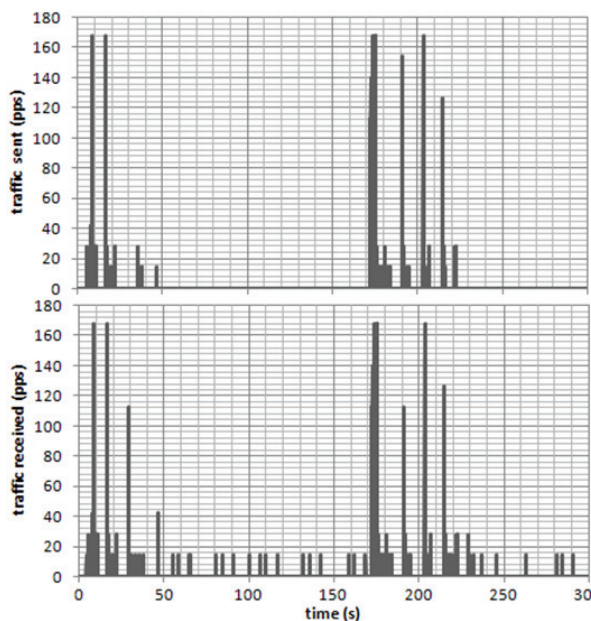


Fig. 7: Sent and received network traffic between tactical Unit 1 and Unit 2 for the second scenario.

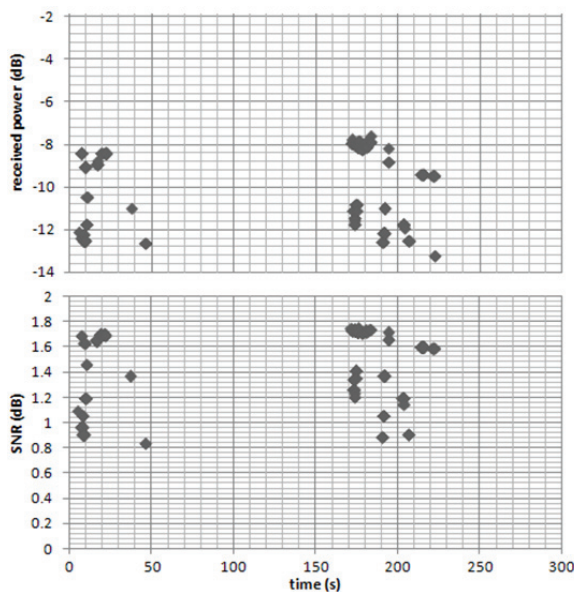


Fig. 8: Received power and signal-to-noise ratio (SNR) parameter for the Unit 1 (right).

VI. CONCLUSION

A real time simulation of tactical networks is a novelty in the area of tactical network simulations. This paper presents the main concept and methodology of a tactical training system, which incorporates SITL, MITL and C2IS within the simulation loop. It is named the C2IS-in-the-loop simulation concept. Such a simulation system enables the training of C2IS personnel and also helps in the planning process when predicting how tactical networks will act on real, terrain during real tactical situations. It can be seen, as to what happens if tactical units move along a virtual terrain and lose radio contact. It can be observed, for such cases, that real C2IS applications response on real tactical equipment in the

sense of traffic delay, losing connections, utilization, etc. Such kinds of results offer substantial help to the tactical mission planners and operators when evaluating tactical networks under real circumstances. This also allows operators and planners to optimize tactical mission plans in such a way that simulation results are consider as much as possible. It can be also used for testing the effectiveness of different network topologies and protocol types, and for optimizing the traffic amounts defined by IRM contracts. Such kinds of simulations are also suitable for the evaluation of new radio equipment before purchase. It is also possible to evaluate communication parameters such as the necessary bandwidths of radio devices, power levels, antenna gains, etc. Tests can also be carried-out using the new C2IS software, without the need for a real tactical radio communication infrastructure.

The simulation experiment presented in this paper proves that the proposed C2IS-in-the-loop concept can be implemented using an OPNET Modeler and additional modules, such are SITL, TMM, and 3DNV (MÄK Stealth). But for an entire and full functionally tactical training system additional modules must be developed such as:

- An analysis module with an expert system, for online network performance evaluation, and an After Action Review module,
- A scenario engine which represents a training system user interface and performs simulation control management,
- A C2 engine which cares about the synchronization of C2IS units' geographic positions, and the positions of the tactical radio equipment on the virtual terrain.

Future research would support the development of a full functional real time training system for the Slovenian Army's needs. It can be expected, for all the presented reasons, a wider use of such training systems and simulators soon.

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