Communications Modelling and Simulation for the Development of Network-Centric C4 Systems

ABSTRACT

The advent of network-centric warfare has placed greater demands on the interconnectivity and networking between command and control, sensor, and shooter systems. The key challenges in developing the communications network for network-centric command, control, communications, and computers systems include defining the communications demands for new concepts of operations, understanding the effects of communications failure and degradation to the network, as well as verifying and validating the networked system's performance without an actual deployment. This article describes how Communications Modelling and Simulation (M&S) is applied to address these challenges. It also introduces future developments and applications for Communications M&S.

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MOTIVATION

A network-centric warfare Concept of Operations (ConOps) generates increased combat power. By networking sensors, decision-makers and shooters, there is shared awareness, increased speed of command, higher tempo of operations and a high level of self-synchronisation (Alberts, Garstka and Stein, 1999). This modern warfare has revolutionised the development of command, control, communications, and computers (C4) systems. With greater emphasis on intersystem connectivity and networking, Network-Centric C4 Systems (NCCS) were developed. These NCCS support pervasive and near real-time exchange of massive amounts of data from the battlefield and other information sources from the military enterprise (Yeoh et al., 2011).

The development of the communications network supporting NCCS faces several challenges. As communication channels are designed to be shared by multiple networked systems, it is hard to ascertain the bandwidth required and communications latency incurred to support new ConOps and systems. It is also difficult to assess the effect of communications disturbances such as link failure and degradation of the networked systems. In addition, it is costly to deploy networked systems in the actual operating environment for the Verification and Validation (V&V) of systems performance. To address these challenges, there has been an increasing application of Communications Modelling and Simulation (M&S).

Communications M&S is the application of simulation technologies to model and simulate the communications effects on networked systems. The communications effects include fading, propagation loss and bit errors, which could be caused by factors such as the environment (i.e. weather elements), terrain, network loading, and jamming. Communications M&S can also be used to emulate the communications characteristics and demands of command and control (C2) nodes, as well as their performance over the communications network. This article describes the application of Communications M&S at different stages of the system's life cycle, the challenges faced, as well as the future development and applications of this technology.

CHALLENGES IN COMMUNICATIONS NETWORK DEVELOPMENT

Figure 1 shows some of the key challenges in communications network development and identifies a Communications M&S based approach to address them.

Difficulty in Defining Performance Parameters and Analysing Impact

In a highly interconnected and complex environment, the introduction of new NCCS could have an impact on other systems and the communications network performance. To ensure systems interoperability, the impact of integrating new systems to the existing network needs to be analysed and the required communications network performance parameters have to be defined.

During the front-end planning stage of the system's life cycle, Communications M&S can help operations and network planners assess the performance of the network in support of the new ConOps. The future deployment scenario will be modelled in a virtual environment and the communications traffic profile will be simulated. The simulation results can be used to identify network constraints and potential bottlenecks, as well as to determine the network performance parameters.

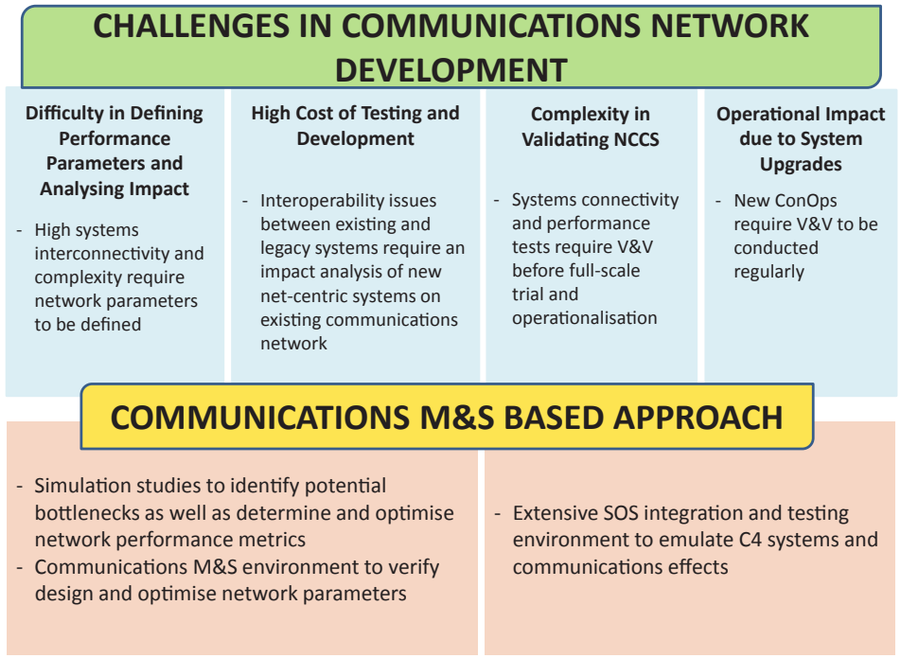

Figure 1. Challenges in communications network development (Source: RiAC Desk Reference)

High Cost of Testing and Development

Without an actual deployment during the implementation stage, it would be challenging to have an environment to facilitate iterative systems development and integration testing with other C4 systems, particularly in a system-of-systems (SoS) set-up. The Communications M&S environment can be set up to emulate C4 systems and communications network performance. Thus, users are able to make use of this virtual environment to verify the functionality and operation of the systems, and assess the communications effects and end-to-end systems performance.

Another challenge is to assess the impact that changes to the communications network parameters have on the overall system performance. Communications M&S can be used to revalidate the communications network performance whenever these parameters change.

Complexity in Validating NCCS

Systems in the NCCS have different development timelines. The Communications M&S environment can be used as a platform to verify the integration with other C4 systems which are in the development phase. This allows potential integration problems to be surfaced at an early stage. Prior to the installation on site and the subsequent operationalisation of the system, the Communications M&S environment can be used as the final validation of the NCCS.

Operational Impact due to System Upgrades

In the operations and support stage, C4 systems are often updated incrementally to support changing operational requirements. The Communications M&S environment can be used to verify the changes before the actual roll-out, minimising potential operational impact.

ADDRESSING CHALLENGES THROUGH COMMUNICATIONS M&S

DSTA has developed a Communications M&S environment to simulate, analyse, and emulate the communications network performance. This environment is built upon key M&S technologies such as the OPNET Modeler and the OPNET System-In-the-Loop (SITL) module. The OPNET Modeler (OPNET Technologies Inc., 2012) is a network simulation tool which allows users to design, simulate and analyse communications performance for wireless and wired networks. The SITL module (OPNET Technologies Inc., 2012) is an application and protocol testing tool which enables the emulation of the communications network performance as experienced by the actual C2 systems. In addition, the environment also comprises radio models, advanced communications models, network models and proprietary military protocols.

Communications Simulation and Analysis

Using the Communications M&S environment, DSTA has analysed the performance of networks consisting of multiple communications systems for up to 100 nodes. Simulation studies have also been conducted to analyse SoS communications performance.

Working with DSO National Laboratories and the original equipment manufacturer of the communications system, the DSTA project team has developed generic radio models and communications models of the SAF communications network to support simulation studies. For models of communications systems which are not available yet, the team modelled the system behaviour from field trials using mathematical models. The fidelity of these models can be improved when more information of the actual systems is available to enhance the accuracy of the simulation.

To conduct simulation studies, the following aspects must first be defined:

a) Scenario deployment topology (derived from ConOps requirements)

b) Node characteristics

c) C2 information exchange requirements (IER)[1]

d) Radio and communications models

e) Parameters to be analysed

A scaled-down simulation scenario is shown in Figure 2.

Statistic probes are used in the simulation runs to collect results such as end-to-end message latency and completion rate. Figure 3 shows a sample result of latency and its consolidated processing time. The simulation results are consolidated and analysed based on the end-to-end latency requirements as specified in the IER.

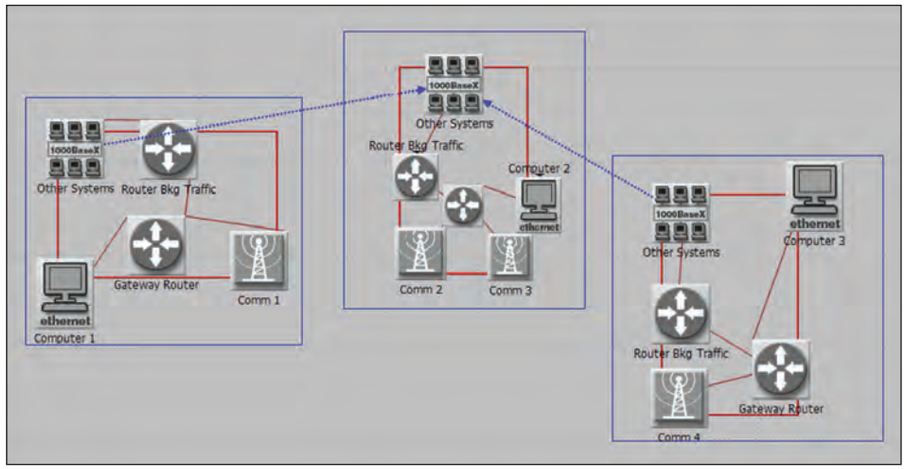

Figure 2. Communications network simulation environment using OPNET Modeler

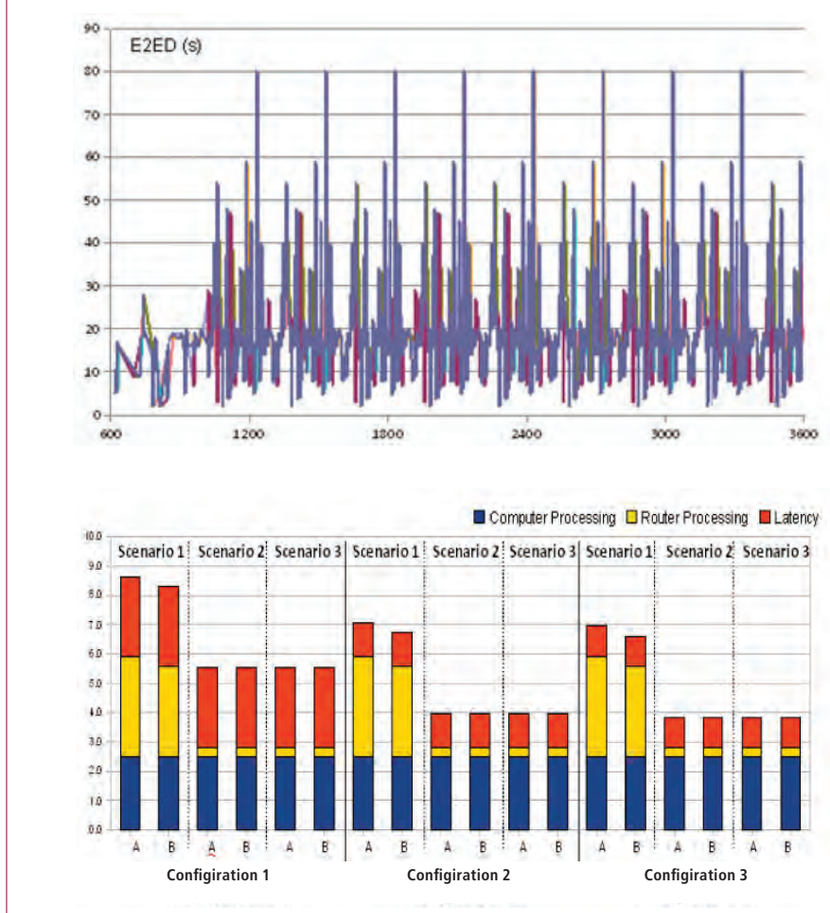

Figure 3. Simulation results

For more accurate simulations, actual traffic profiles can be collected from exercises and imported into the Communications M&S environment. The team explored an innovative method to use data collected from a traffic monitoring tool – the OPNET Application Management solution. The collected data was imported as traffic profiles and network topology for simulation studies. The traffic statistics captured by this tool can also be used for future system testing and throughout the development life cycle. This innovative method (Chua, Sivagami and Boo, 2011) was presented at the OPNETWORK 2011 Conference[2].

Communications Emulation

The Communications M&S environment allows multiple live and virtual systems to be connected to form an emulated NCCS. This scalable environment enables communications network performance testing before field trials or operationalisation.

In addition, the Communications M&S environment helps to validate existing and new military doctrines and communications architectures. Communications effects such as link failures, network jamming and attenuation due to terrain can be introduced to emulate the expected operational environment.

A scaled-down SITL set-up is shown in Figure 4, where two live C2 nodes are deployed with four emulated C2 nodes and communications nodes.

IMPLEMENTATION CHALLENGES

The implementation of Communications M&S in NCCS development faces several challenges.

Adoption of Communications M&S

While Communications M&S is used increasingly for NCCS projects, it is not a mandatory requirement. The need for Communications M&S may arise only at a later stage of the project. However, a late introduction of Communications M&S to the project may result in higher costs and schedule delays. Furthermore, to apply Communications M&S across the various stages of the system's life cycle, the development of new simulation models and the communications network must be carried out in tandem. Thus, NCCS projects should plan for the use of Communications M&S as early as possible in the system's life cycle, with sufficient time and budget allocated.

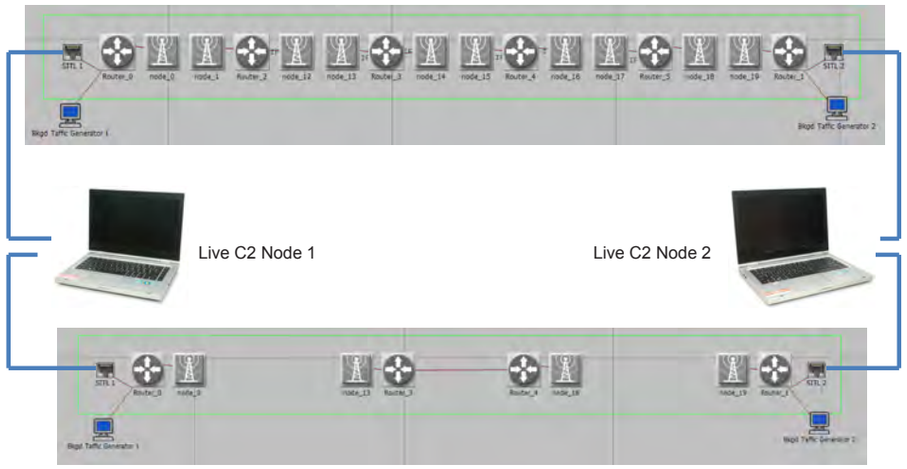

Figure 4. SITL setup

Compatibility and Interoperability

Communications models are developed by different vendors who may use different modelling methodologies. Models using proprietary protocols and interface messages may not be able to interact with one another in the Communications M&S environment. To address this issue, the scenarios can be divided into phases using different protocols. These phases are then simulated separately. The results will be analysed and consolidated to determine the overall communications network performance.

Complexity and Fidelity

During the early stages of development, the actual system protocols, performance or demand may not be available. To apply Communications M&S at this stage, an abstracted model to simulate results based on field trials can be developed to deliver meaningful results.

For scenarios where communications emulators are integrated with live C4 systems, high fidelity and complex models will require time to compute and therefore may not meet the real-time requirements. In such cases, the trade-off between fidelity, complexity and computation time must be considered.

FUTURE INNOVATIONS

Communications M&S Framework

The simulation and training systems for the SAF are developed using the Joint M&S Environment for Wargaming and Experimentation Labs (JEWEL) framework. This framework enables composable simulations to be generated and allows interoperability across simulation systems.

Moving ahead, there is a need to develop a Communications M&S model framework which is aligned to JEWEL. This enables future communications models to integrate with platforms, sensors and weapon simulation models, so as to increase the realism of current wargaming, training and operational analysis simulators with communications effects included. To ensure interoperability of proprietary protocols, the framework will be used as a guide for model development.

Communications Planning and Analysis System

To promote the use of communications planning and analysis tools in the SAF and DSTA, the Communications Planning and Analysis System (CPAS) will be developed as part of a common repository.

The CPAS comprises an IER repository, communications models, terrain data, radio models and a user-friendly interface. It is used to support the simulation and analysis of communications network performance for various operational scenarios.

A scenario generator in the CPAS enables users to design the network topology and tap into the repository for relevant models,

without the need for prior knowledge of OPNET programming. Simulation results will be presented in a visually comprehensive manner through charts, graphs and trends. Thus, CPAS will improve the effectiveness of the planning processes for communications network development.

Communications M&S for Signal Specialist Training

An application of Communications M&S for signal specialist training will also be developed. In this case, the trainer can simulate an operational scenario and communications disturbance using the Communications M&S environment. The simulated scenario will require the signal specialist trainees to respond to the various communications disturbances. This training capability allows signal specialists to develop and evolve C4 military doctrines as well.

C4I Test and Integration Framework

The SAF is developing a C4I Test and Integration Framework for SoS. This framework will include aspects such as the testing and integration of SoS as well as the test methodology and processes. Communications M&S is envisaged to play a significant role in the testing and integration of SoS, and will be used by ConOps developers and planners to perform V&V, as well as interoperability analysis. This process will raise users' confidence that the interoperability requirements for C2 systems to communicate across the SoS can be met.

BENEFITS

The Communications M&S has brought about many benefits to the SAF in the development of NCCS.

For the SAF, the Communications M&S capability has enabled the development and validation of new operational concepts. It also enabled signal specialists to test and select optimal communications solutions for various operational scenarios. Simulation studies have improved user awareness of the limitations of new and legacy communications systems in different operational concepts. Results from these simulations have been used to recommend improvements in areas such as deployment configuration and resource allocation, communications system configurations, and information exchange between nodes.

Communications M&S has enabled DSTA acquisition teams to design and validate new communications architecture and protocols early in the acquisition phase. It has also supported iterative testing for the SoS, as well as the conduct of V&V before operationalisation.

The Communications M&S has also enabled DSTA C2 system development teams to validate the performance of C2 systems in a communications network during development. From the Communications M&S findings, C2 teams have changed their interface design specifications early in the development phase to meet the performance requirements, thus avoiding the high costs of changing specifications after implementation.

Communications M&S will play a larger role in NCCS development ahead. The Communications M&S Framework, a communications planning and analysis system, the virtual environment and the C4I Test and Integration Framework, will address the challenges faced in implementing Communications M&S today.

CONCLUSION

The adoption of Communications M&S in the design, development and implementation of NCCS proved to be beneficial in the various stages of a system's life cycle. While the challenges in implementing Communications M&S are not trivial, more emphasis should be placed on the use of Communications M&S for such developments to ensure its early adoption. Developers and users of NCCS can look forward to greater Communications M&S capabilities and applications in future developments and potential innovations.

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ENDNOTES

[1] C2 IER defines the data message, size, frequency, priority and mode of transmission between nodes in the simulation scenarios.

[2] OPNETWORK is an annual industry conference conducted by OPNET for users of OPNET solutions. At the conference, the users share their innovations and knowledge of application performance management, network engineering and communications M&S.

BIOGRAPHY

Sivagami Ananthanarayanan is an Engineer (C4I Development) responsible for the development of the Communications M&S environment. She is involved in multiple communications network performance analyses. She also works on the exploration of Disruption Tolerant Network technologies for the Army, which includes simulation studies. Sivagami obtained a Bachelor of Engineering (Computer Engineering) degree with Honours in 2007 and a Master of Science (Communications Engineering) degree in 2012 from the National University of Singapore (NUS).

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Anthony Chua Yong Pheng is a Senior Principal Engineer (C4I Development). He leads numerous initiatives to analyse the communications network performance in different scenarios. Through the various studies, he recommends configuration changes to improve the communications network performance for the SAF. He also spearheaded the development of the Communications M&S environment. Anthony obtained a Bachelor of Engineering (Electrical Engineering) degree from NUS and a Master of Science (Electrical Engineering) degree with Distinction from the Naval Postgraduate School, USA in 1986 and 1994 respectively.