

# A HARDWARE-IN-THE-LOOP (HWIL) NETWORK SIMULATOR FOR ANALYSIS AND EVALUATION OF LARGE-SCALE MILITARY WIRELESS COMMUNICATION SYSTEMS

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## ABSTRACT

*In this paper, we describe the architecture of a hardware-in-the-loop (HWIL) network simulation based testbed developed by L-3 CSW and illustrate its benefits towards effective and cost efficient design, implementation, and qualification of military wireless networks. The HWIL Network Simulator solves the challenges of large-scale network analysis and evaluation by providing network designers and testers a controlled, repeatable process for measuring operational performance characteristics of deployable networking software and hardware components. The HWIL Network Simulator system exercises, or stresses the logic and functionality of networking systems as they would be in actual military use. The HWIL Network Simulator system also comprehensively instruments (logs) both the stressing stimuli and the networking system's response to induced stressing stimuli. The simulator has been used in the evaluation process of L-3's distributive proactive network management service "Inter-Platform Communications Manger" (IPCM) and qualification of its military wireless ad-hoc networking systems such as MR-TCDL. The simulator was able to discover critical memory access errors in the IPCM code that would have not been discovered by hardware emulators, yet would have seriously compromised a full scale flight test and deployment success. In addition, the HWIL network simulator was essential to finding other significant problems during analysis, which we shall discuss in this paper.*

## I. INTRODUCTION

Network Centric Warfare (NCW) is revolutionizing combat tactics in the 21<sup>st</sup> century battle space. NCW technology provides the war-fighter highly effective tools to quickly neutralize and defeat enemy forces. Next generation military ad hoc wireless communication systems are a key component of NCW technology. L-3 CSW is in the process of building next generation communication systems hardware and software, namely the MR-TCDL (Multi-Role Tactical Common Data Link) router and the Inter-Platform Communications Manager (IPCM) software. MR-TCDL is a Wireless, IP-based, Mobile Ad-hoc Networking System that provides high bandwidth capacity over very long ranges. IPCM is a network control services suite, which is embedded in the MR-TCDL router and provides automated, proactive, ad-hoc wireless network and physical layer management. IPCM acts as a cross-layer network-centric control service. It is designed to optimize the physical and network interconnections based upon many discriminators, such as distance between nodes, QoS, traffic profiles, radio frequencies, power, data rates, and platform/terrain blockages. IPCM runs in a distributive manner, where nodes join the network to become part of a collective network intelligence. A MR-TCDL / IPCM network elects Peer Group Leader (PGL) nodes and functions as an intelligent ad-hoc cluster of nodes. IPCM is designed to provide dynamic real-time responses to changes in the RF media and the associated network layers. This in turn optimizes the interconnections and maintains a stable physical layer and network connectivity.

Testing and evaluation of these and similar large-scale military ad-hoc wireless communication technologies is an expensive process in terms of both cost and time. Specifically, large scale testing of the MR-TCDL router and IPCM software on a physical testbed requires many expensive embedded hardware routers emulators , data link emulator systems and actual router hardware units.

Physical testbeds with data link emulators are best suited for unit and functional and component level testing. Such testbeds have complex scalability issues and usually lack high-fidelity physical layers. These factors limit the capability of testbeds to exercise or stress ad-hoc wireless communications systems in realistic large-scale operational topologies. Physical testbeds also have a disadvantage due to the cost of hardware components. This cost is proportional to the number of router nodes to be tested simultaneously. For large scale testing, physical testbeds quickly become cost prohibitive. Moreover, in the case of IPCM and MR-TCDL technologies, the T&E process required flight-test validation which posed further unique challenges. Performance evaluation using flight-test methods becomes impractical and costly when testing large-scale networks. Besides logistical problems and high cost, flight tests are difficult to instrument and inherently problematic to repeat in an identical manner.

This motivated us to look at alternate options for conducting large scale testing of our technology. One prominent option was hardware-in-the-loop based simulation, which leverages state-of-the-art modeling and simulation technologies to develop *realistic* environments with hardware- and software-in-the-loop interfaces for real world applications and networks. Such an environment provides a viable approach for end-to-end performance prediction of net-centric operations in an efficient, yet scalable manner. For instance, the combination of *operational* applications with models of the underlying networks offers a promising solution to assess the impact of network dynamics on the performance of *actual applications* that are already being used by the military. The network models mimic the behavior of the underlying networks and provide analysts with a *configurable* environment to conduct repeatable experiments with the traffic profile exactly as it might be generated from the corresponding applications themselves. Similarly, integrating a small *physical* network test bed with a much larger *simulated* network allows an analyst to incorporate realistic physical effects while simultaneously scaling the study to networks much larger than those that are physically accessible to the analyst.

Based on this concept, we developed a Hardware-in-the loop (HWIL) network simulation toolkit that helped address issues faced in physical testbeds for large scale testing of our technology. The Communication Network Effects Simulator (CNES) system was purposefully designed to employ the more cost effective hybrid HWIL Simulation approach. This method uses inexpensive Commercial Off the Shelf (COTS) sever

systems running QualNet-based simulation software combined with a small number of actual router systems (and/or hardware emulators) to achieve a far greater node count; in much more practical manner than hardware emulation testbeds at a significantly lower cost. In this paper we describe this simulation-based testbed, and provide details on how this setup helped us to overcome the numerous challenges posed by large-scale testing. The objective is to clearly demonstrate the usefulness of the HWIL simulation technology to address the needs of test and evaluation community in an efficient and inexpensive manner, and outline our experiences which will benefit T&E groups who face challenges similar to what we faced.

In Section II, we describe the architecture of the CNES HWIL toolkit and present the methodology and benefits of applying the toolkit to the problem of large scale T&E. In Section III, we describe in detail how the toolkit was applied during T&E of the IPCM software and MR-TCDL router and how it helped us solve critical issues faced in the testing and development of MR-TCDL and IPCM technologies. Finally we conclude in Section IV and discuss future work to further enhance this HWIL framework.

## II. THE CNES HWIL TOOLKIT

### CNES Architecture

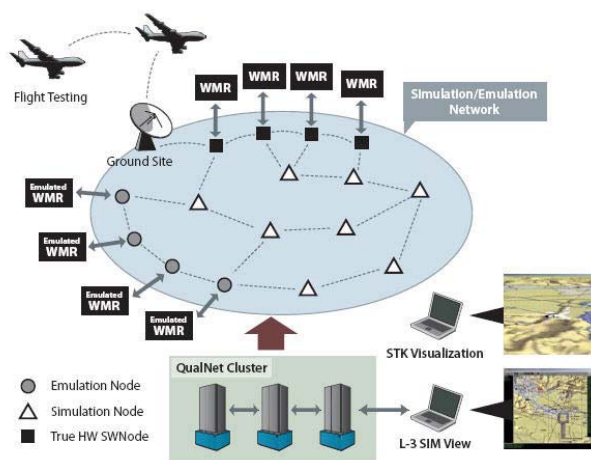
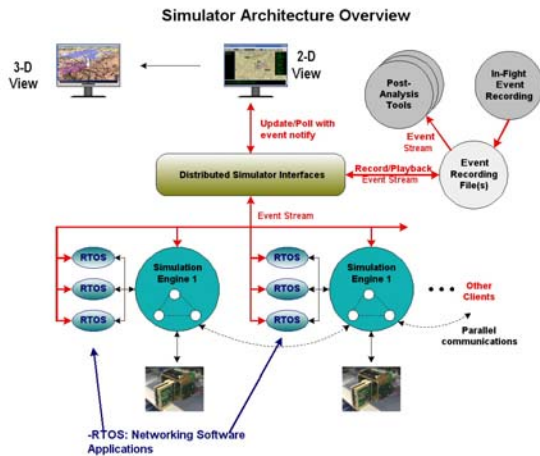


Figure 1: Overview of Testbed using CNES

Figure 1 provides an architectural overview of CNES HWIL toolkit-based testbed. It consists of physical hardware called as Wideband Mobile Routers (WMRs), on which the IPCM and MR-TCDL technologies are implemented, along with emulated nodes, which are emulations of WMRs running in the simulation environment on top of a distributed computing cluster.

The toolkit has a GUI based on STK[7] to help visualize the operation of the testbed.



**Figure 2: Components of CNES**

Figure 2 shows the internal components of the CNES HWIL toolkit. CNES provides high-fidelity physical layer modeling including terrain, weather, platform, and antenna models in addition to a complete suite of networking protocols. Event stream flow for complete instrumentation and logging suite are incorporated into the simulation environment. This design allows the environment to monitor all aspects of the simulation scenario in real-time, including all layers of the simulation, OSI 0-7 (high fidelity physical layer) layers, routing protocols, IPCM application code, and router firmware/hardware. All data produced by the simulation environment is time synchronized and time-stamped for correlation within post-run statistical analysis tools. A real-time graphing suite allows for all instrumented data to be visually monitored during simulation run-time.

The core hardware-in-the-loop network simulation component of the CNES toolkit is provided by the QualNet network simulator with the IP Network Emulation (IPNE) module [1]. The IPNE module is responsible for HWIL interface between the physical WMR hardware and the simulator. The simulator is run on a parallel computing cluster that ensures scalability, using nodes running high fidelity emulation level models of the protocols with high fidelity wireless environment and signal propagation effects; all with real-time execution. QualNet’s integrated physical layer modeling, combined with its high fidelity radio signal strength degradation effects provide additional capabilities that enrich the base functional testing services of the HWIL simulator. The high fidelity PHY models also provide comparative analysis for integration testing. Other critical phenomena at play that are represented in the QualNet simulation are antenna blockage due to wing

shadowing, as well as terrain and weather conditions. The successful inclusion of these factors is a key role in determining communication success between the radios. QualNet includes a high fidelity emulation-level model of the WMR developed by L-3 CSW and the CDL MAC layer, which is used to setup emulated routers in the simulation. QualNet also includes a shared code model of the actual IPCM software, which runs on top of the emulated WMR routers.

We produced translational import tools in the CNES environment which facilitated converting L-3 CSW proprietary MR-TCDL and IPCM flight test logging data into mobility data for QualNet emulated nodes. This allows the importing of flight trajectory information from flight tests into the QualNet simulation core for the purpose of real-time or post –test troubleshooting and analysis. As a general example, a “networking” flight test mission is flown and the data is recorded on the airplane and ground sites. The trajectory data from this instrumentation is then automatically imported into the QualNet-based Network Simulator environment.

### CNES based product development lifecycle

Because it is relatively inexpensive and quick to set up, the CNES toolkit can be used to validate a large variety of design constructs, from protocols to bigger picture flight-test and mission planning requirements. Beyond the initial analysis, critical tuning of the system can be used to evaluate and find optimized configurations for a final solution. As the CNES toolkit is used to validate wireless ad-hoc mobile networks during product development and flight-test phases, it can also be employed to capture system qualification, or release acceptance criteria for our government customers during final release stages. The controlled repeatable process, inherent in CNES simulator design combined with its multi-run statistical analysis capability enable the CNES toolkit to readily capture overall system performance of wireless ad-hoc networks being qualified.

The first step in this process involves determining the correct series of CONOPS qualification scenarios and the overall acceptance criteria for the multi-run analysis. In the next step, the simulator is configured to run qualification scenarios in batch processing mode. Finally, qualification scenarios are run in batch mode and the instrumentation (logged) data from these runs is used to perform results analysis against the qualification acceptance criteria. The analysis of multi-run simulation results applies classical “statistical control processes” to produce an overall acceptance “performance envelope”, which captures the wireless ad-hoc networks overall

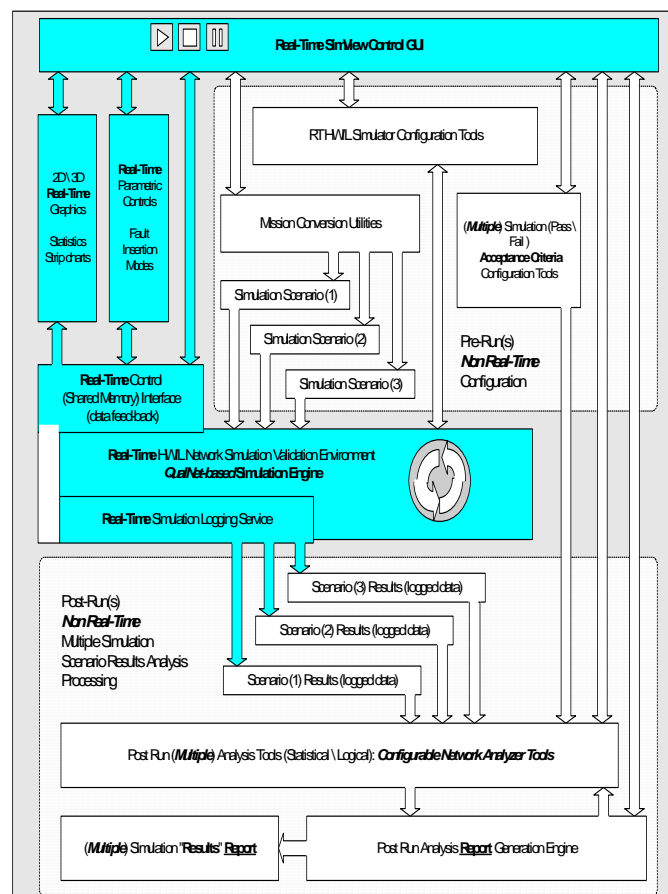
“product release” performance verification results. The product-release “performance envelope” and release acceptance criteria become the “gold-standard” baseline reference for any future upgrades to the networking system. This baseline qualification reference is an invaluable resource when system upgrades (firmware, software, hardware) require regression testing once the networking system is operationally deployed to L-3 customers. For ad-hoc wireless networking systems like MR-TCDL and IPCM, the CNES simulator system (simulator configuration), baseline qualification “performance envelopes”, and associated acceptance criteria results are the only viable cost effective methods to perform regression testing on new or enhanced features and upgrades once the networking system is deployed to L-3 government customers. Any new or enhanced feature desired after operational deployment can be added, and the whole networking system can be easily rerun in the baseline configuration with baseline qualifying scenarios. This step produces baseline performance envelopes and acceptance criteria results for the networking system with the newly added features. These results are then compared against the original baseline results to determine if the new features or upgrades introduce unintended detrimental effects on the currently working system.

This baseline regression testing of new and enhanced features provides the only practical method to mitigate the risk that these new features may pose to the stability and reliability of currently deployed networking systems. Once these new features pass prior baselines, and their own testing scenarios, then new qualification scenarios and “performance envelope” baselines can be established to serve as qualification baselines for the next version of features and upgrades.

For actual large scale wireless network systems like MR-TCDL, the CNES simulator’s distributed large scale capability, controlled repeatable process and aforementioned multi-run statistical analysis tools provide L-3 with required levels of data reduction and complexity management.

Figure 3 gives a functional flowchart of the CNES toolkit and ad-hoc wireless networking qualification process using multiple simulation scenarios. The figure shows all real-time network simulation processes in light blue, everything else is non real-time. It shows how the CNES Simulator system process multiple scenarios in batch mode, producing instrumentation-logged data sets for each scenario processed.

Figure 3 also depicts how these multi-run data sets are evaluated against acceptance criteria with configurable CNES integrated network analysis tools during post-run analysis. The simulation environment design shown in Figure 3 provides the CNES network simulator with powerful diagnostics and qualification capabilities. These allow the CNES toolkit to be flexible and adaptable enough to fulfill many required roles in support of network system development, and complete product lifecycle support.



**Figure 3: Functional view of product qualification using CNES**

This purposefully designed-in flexibility of the CNES toolkit enables it to provide the complex management of large-scale qualification processes. It accomplished this by automatically producing data reports and performing data reduction to generate overall “performance envelopes” of the large-scale wireless ad-hoc networking system under test. This same multi-run processing provides support for extremely powerful diagnostics and debugging tools built into CNES toolkit.

These capabilities allow networking development engineers, test and evaluation engineers, and field

engineers to use the simulator system like a sophisticated piece of test equipment, such as a combined “HP 1600C” logic analyzer, network analyzer and software debugger. In this mode of operation the CNES toolkit is used to detect problems using automatic acceptance criteria testing, trap and isolate complex problems, and drill down into code, hardware, and system functionality to completely understand the problem area and fix it. The CNES simulator tool kit provides many powerful advantages, because once a solution has been implemented, it can be rapidly tested and checked for unintended detrimental effects (i.e.. The solution can be tested to verify that it not only fixes the problem, but that it does not create other problems. This helps to ensure that it is therefore an acceptable solution). The CNES toolkit diagnostics include event triggers and trapping mechanisms integrated into code debuggers to trap problems in the firmware and code on a per line basis. Diagnostics also include configurable parametric and “Monte Carlo” type analyses, along with programmed configurable fault insertion analysis.

Figure 4 gives a generic example of a statistical control chart of a single networking performance metric obtained by a multi-run of 20 different scenario runs. This provides a graphical representation of the analysis done in the post run analyzer tools in Figure 3. As an example, qualification testing may requires different types of targeted operational CONOPS scenarios to exercise and stress ad-hoc wireless networking systems exactly like they would be once deployed in the field. Qualification testing requires that scenarios be constructed that validate all of the required functionality. For complex systems, it is unlikely that any single scenario can achieve this goal. As a result, it is very important that testing be performed on a sufficiently varied set of scenarios that reliable validation can be performed.

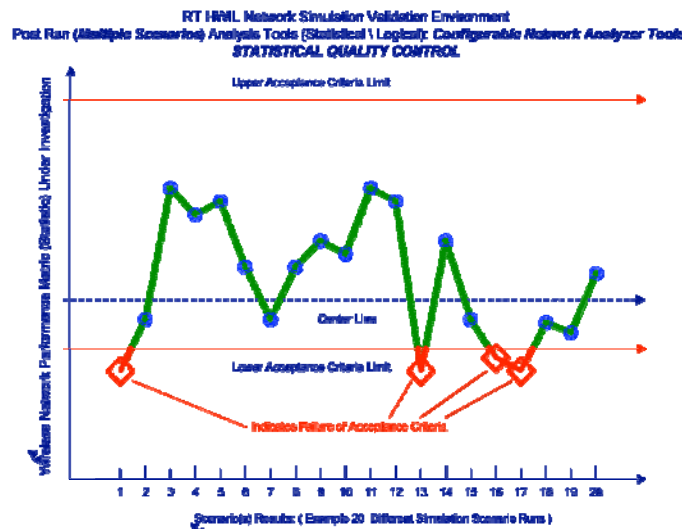


Figure 4: Statistical Quality Control using CNES

In the example of Figure 4, the performance metric(s) obtained via automatic multiple scenario processing failed to achieve the specified acceptance tolerance for lower limit criteria in simulation runs 1,13,16, and 17.

The acceptance data results depicted in this statistical control chart would typically be evaluated along with a complete series of acceptance data results sets to produce an operational-level performance envelope for the wireless ad-hoc networking system under test.

### III. CNES ROLE IN IPCM AND MR-TCDL TESTING

All of the aforementioned diagnostics capabilities were employed in support of the MR-TCDL flight-test program. In the pre-flight phase the simulator detected and resolved many critical problems which mitigated technical and schedule risk for the MR-TCDL program. During the flight-test series the CNES toolkit’s ability to readily import actual mission data into QualNet scenarios and apply these same diagnostics and troubleshooting features to actual mission recorded data, provided invaluable support for the MR-TCDL flight test team and helped ensure the success of the initial flight test series. In this section, we describe how the CNES toolkit was used to detect and fix issues with the MR-TCDL and IPCM technologies.

#### Pre-Testing Stage

Prior to test flights featuring real aircraft, we connect real WMR / MR-TCDL prototypes to an emulated fleet of aircraft in QualNet. The pretest-flight validation process, in system design and development phases, is

intended to reduce the risk of system or network failure during system testing and actual flight test acceptance phases. With real hardware and actual algorithms integrated into the simulation process, protocol service verification takes place throughout various stages of product development, not just at the final step. QualNet-based simulation is critical to understanding and refining the performance of IPCM, network protocols and other network services.

The following summarizes a typical pre-flight test emulation-based validation process for a next generation device such as the L-3 WMR router:

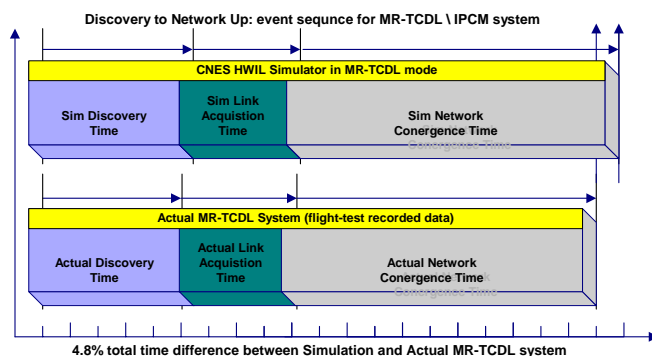
- Determine the wireless networking equipment configurations. Identify hardware, software, and platforms. Determine the relevant flight test scenarios. Identify key performance metrics.
- Define required performance metrics and acceptance criteria for simulated flight tests. Define the emulation test scenarios that will run concurrent to actual flight tests
- Perform flight test simulations and collect instrumented simulation run data, i.e., network, IPCM, and physical layer statistics
- Perform results analysis on simulation run data, and compare against desired acceptance criteria (i.e. apply standard “statistical control process” quality assurance methods).

### Real-time validation and troubleshooting using CNES during live testing

Once the emulation-based analysis is performed using the CNES toolkit, flight tests involving deployable hardware and software are conducted. Once the test flights are underway, CNES plays a critical role in the actual testing via real-time validation and troubleshooting. Real-time validation and troubleshooting involves monitoring live test results and comparing with expected results obtained during the pre-tests. At any point during the test, if there appears to be a mismatch, the CNES toolkit is instrumented to run the simulation in real-time. It uses the actual flight trajectories flown during live testing to drive the motion of the emulated nodes. The effects of any bug or glitches in the hardware and software being tested that are the cause of the mismatch can thus be reproduced in the CNES toolkit, and the repeatable nature of the HWIL simulator testing allows the designer to discover the bug or glitch. The designer can then fix it instantaneously for verification, and update the test hardware with the fixes for the next round of tests.

Working together, the pre-test and real-time validation

methods using the CNES HWIL toolkit form a comprehensive (layered and cross-checked) approach to reducing technical failure risks prior to scheduled flight tests.



**Figure 5: Comparison between CNES simulated and actual flight test results**

Figure 5 shows the measured tolerance between simulated CNES IPCM and MR-TCDL "Discovery to Network Up" sequence timing versus the actual MR-TCDL "Discovery to Network Up" sequence timing observed during flight tests. Our observations indicate that the CNES toolkit was able to reproduce phenomena that occurred in the physical testbed during the actual flights with remarkable accuracy.

The CNES toolkit has allowed L-3 CSW to solve many issues faced during the T&E of the MR-TCDL routers and the IPCM software that runs on those routers. Most of these issues discovered can be either classified as bugs and glitches in the software/hardware or as deficiencies in the design of the technology. Both kinds of issues were successfully resolved when discovered using the CNES toolkit. We outline a few critical issues that were discovered and solved using the CNES toolkit. Early detection of these issues using the toolkit avoided significant deficiencies in overall system performance, prevented dramatically increased costs, and helped us avoid significant schedule slip to resolve these deficiencies which would have otherwise been found during the later stages of product development.

### Issues fixed during pre-testing with CNES

1. *Detection and resolution of Closed Loop Power Control (CLPC) problems of MR-TCDL Directional (CDL) Data Links and IPCM SNMP control:*

Pretesting using the CNES toolkit helped us completely resolve a series of Data Link Controller / IPCM prior to

the actual flight test. Detailed simulations predicted that the Line of Sight (LOS) Data Links would fail after 18 nautical miles of LOS range between the nodes due to link control errors. Unit and DVT tests could not have detected these CLPC range limitation defects since they lacked physical layer and transmission propagation models, therefore this issue would have been discovered during the beginning and of the actual flight test and would have cost several weeks of delays, which would have been unacceptable to the L-3 CSW MR-TCDL program and its customers.

## *2. Diagnoses of IPCM application code Memory Violation \ Access issues on WMR Power PC processor causing unstable IPCM behavior and system crashes:*

Prior to initial flight test, the CNES toolset proved invaluable to the development and testing of the IPCM code base. During this phase of testing, the CNES toolset identified and provided solutions for at least ten (10) key memory violation/access issues on the MRT-CDL Power PC processor. The CNES toolset ensured the success of the MRT-CDL system development. MR-TCDL / (IPCM) system would have failed to be flight-worthy for its initial tests or flight tests. The IPCM code base would not have passed tests in the hardware emulator system, nor would it have performed in any of the parking-lot and radar-range test series. Without detecting and repairing these issues the whole MR-TCDL program was at risk of technical and schedule failure.

## **Issues fixed using real-time validation and troubleshooting with CNES**

1. Real-time validation and testing with CNES helped assure that Directional (CDL) Data Links met their respective maximum propagation range targets. These issues were with actual Data Link control algorithms; Rx sensitivity levels and Tx power were resolved during initial flight test series.

2. The CNES toolset was essential in the resolution of issues with the Discovery mechanism in the MR-TCDL system. For the MR-TCDL ad hoc wireless system, if Discovery process between the MR-TCDL routers does not work, then the network will never form, rendering the whole communication system useless. The CNES toolset used actual flight trajectory data in the simulator to verify that the Discovery Omni Antenna on the Bombardier Global Express XRS (BizJet) had LOS access during times in the actual flight test when Discovery was attempted but failed to actually work.

Analysis of the scenario using the CNES toolkit confirmed that the Discovery Omni on the BizJet had clear access to the Fixed-STE ground site when it was failing to make Discovery connections. These experiments helped isolate the real causes for the Discovery waveform failure, which were Doppler effects, low power, and waveform problems. Actual flight-logged trajectory data imported into the CNES framework was used to detect that the internal navigation system on Bombardier GE XRS (BizJet) was reporting heading data 90 degrees out of phase during the actual test flight. This data told the IPCM algorithms and the Data Link Controller that the aircraft was flying sideways, causing both IPCM and DLC to perform in erratic modes of operation. By importing logged trajectories into the CNES toolkit and analyzing the reported INS data during the simulation scenario, critical diagnostics information was provided to flight test technical team, which helped them resolve the electronic issues in the MR-TCDL system. This heading problem if unresolved would have prevented any successful Discovery processes or Data Link establishment during MR-TCDL flight tests.

3. Actual flight-logged trajectory data was imported into the CNES environment to detect high levels of spurious noise in the INS velocity and waypoint data on both Bombardier GE XRS (BizJet) and WB-57 NASA aircraft. The noise component on this data caused the predictive Network \ Physical Layer algorithms in IPCM to not work properly during test flights. Detection of severe INS Noise in the flight recorded trajectory data lead to system level troubleshooting that eventually found a manufacturing flaw of an electrolytic capacitor being mounted backwards on a CCA. This was charging up and breaking down and discharging through the bus signals across the different LRUs in the MR-TCDL system. This provided critical understanding of noise issues on the bus between the MR-TCDL and RF systems, and without using the simulator to detect and isolate this noise issue, the MR-TCDL flight test would have lost several days of flight time, and would have been at serious risk for overall technical failure.

4. Actual flight-logged trajectory data imported into the CNES Toolset was used to cross check access to ground sites during flight test in the Nellis AFB range area (Angles Peak area). During the flight test, it was expected that the MR-TCDL / IPCM, multi-access antenna systems could see the Fixed-STE ground site at Angles Peak, but their access “connectivity” was not as expected. Running the recorded flight data through the CNES toolkit, demonstrated that the aircraft geometry, and the mounting of the roll-stabilized multi-access

antenna and the terrain blockage did present signal blockage regions that prevented the system from working. This post flight diagnostic prevented the Test flight team from needlessly trying to trouble shoot problems that really did not exist with the system. The real-time validation and troubleshooting capability allowed us to rapidly convert actual MR-TCDL flight data into a QualNet based scenario in a matter of minutes and then run it in the simulator system to verify issues or performance characteristics seen in during the actual flight test: In some cases this was at a near real-time (within hours) response, since we provided analysis to the team while they were still flying that day.

#### IV. CONCLUSION AND FUTURE WORK

In conclusion, HWIL simulation has been demonstrated to play a key role throughout the product development and qualification testing phases by:

- Mitigating failure risk by iteratively employing HWIL simulation based validation during all phases of a wireless networking system's lifecycle.
- Using simulation-based validation processes to establish a realistic networking system "performance envelope" (numerical data based) prior to initial flight demonstrations. A known "performance envelope" reduces failure risk, and can provide a valuable outline of expected test results
- Performing critical closed-loop analysis between simulation predicted trials, and actual test performance metrics by comparing actual test results, against targeted simulated scenarios
- Using observed data sets to derive test-based scenarios to build a CONOPS scenario simulation reference library. In other words, earlier simulation based testing efforts are used to spawn a different series of organic CONOPS missions.

The L-3 CNES HWIL network simulation toolkit provides the ability to rapidly test a networking system under a wide variety of operational conditions. It reduces an enormous and complex problem space into a reasonable problem space via the data reduction and programmable analysis in the post run analysis tool kit. The simulator then provides the architecture and tools to rapidly diagnose, understand, and resolve problems once they are detected. Our experiences during pre-test and real-time validation using CNES indicate that the HWIL simulation framework accurately represents the test environment and the technology, and results obtained from the CNES framework were very close to what were obtained during actual flight tests. A system development approach employing HWIL network simulation can thus serve as a cost effective, repeatable, controlled systematic validation process to ensure the

performance, reliability, and quality of next-generation network-centric warfare systems.

In future versions of the CNES toolkit we anticipate employing translational algorithms in a real-time mode with live telemetry feeds, which will enable us to track a flight test in the simulation with only several seconds of delay. This will enable real-time on-the-fly evaluation and analysis of the trajectories and network topologies. This could be accomplished at the airfield, test facility, or on one of the platforms in the network (for example: a wide body 707 type aircraft with the network simulator in racks). The system will take SATCOM back channel telemetry data back into the simulator in real-time. These translation tools where further leveraged can form the basis for automated data mining and analysis tools: The intent here is to create search and keying algorithms that will be abstracted and fulfill dual use. These will be used to analyze raw flight data as well as be used to analyze the same types of data produced by the network simulation. As an example, any logged IPCM messages will be recorded in the same manner in the simulator as in the real flight test with the algorithms used to parse, filter, key and analyze the same for both real flight test IPCM instrumentation (logging) data and IPCM instrumentation (logging) data within the network simulator environment. This algorithm paradigm will also be utilized for the analysis of routing protocols, physical layer information and for unique application traffic for both real and simulated domains.

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