Adaptive Planning for Test and Training Networks

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ABSTRACT

A central requirement in test and training events is that the Test Support Network (TSN) provide sufficient coverage and bandwidth to ensure:

- Personnel and platforms participating in the event can be monitored
- All traffic needed to monitor the participants, both live and constructive, is delivered to the Exercise Control (ExCon) in a timely manner for accurate computation of Real Time Casualty Assessment (RTCA)
- The energy requirements of the various transmitters and other mobile equipment deployed as part of the TSN do not exceed battery capacity during the course of the Operational Test (OT). Tower locations have a direct impact on the power required for satisfactory network service quality.

For a successful test or training event, the access points or towers of the TSN must be located such that they can meet the preceding requirements. On most ranges, towers are an expensive asset to deploy and monitor during the test, and as such they must be managed optimally - using more towers than needed will drive up the cost of the event and having insufficient coverage may raise concerns on the validity of the data collected during the test. The primary goals of the Integrated Planning of Tactical, Test Support, and Tactical Engagement Network (IPT3N) tool, is to provide an automated capability for planning and optimizing range network laydowns to meet specified coverage, bandwidth, and power consumption requirements.

This paper will describe a use case driving the development of continuous planning for range networks and the algorithms used to improve coverage and bandwidth. Test planning challenges and how they can be overcome by support technologies like IPT3N are discussed. Data from a TSN deployment using The ATEC Player and Event Tracking System (TAPETS) towers from a synthetic scenario is used to illustrate the benefits of IPT3N.

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1. INTRODUCTION

This paper focuses on test network planning for military live, operational unit testing. Regardless of the system or military tactic under test, the test network must support the creation of a realistic operational test environment which includes all entities necessary to achieve the test objectives. In many cases these entities will include both threat and friendly vehicles and dismounted troops. The scale of these tests may range from a few vehicles to a full military Battalion (including 800 to 1200 friendly players, both vehicles and personnel), and a similar number of threat players for a typical operational test. In addition to players in the direct fire battle, there are players which may impact the battle with indirect fire from both guns and in some cases fixed and rotary wing aircraft.

In order to record the locations, movement and impact of each military object in the test scenario, the test network must maintain connectivity with these objects and provide adequate bandwidth to support object updates as they move about the test battlespace. Further, the network must also record the initiation (sensing), execution (target selection) and impact (damage assessment) of each military engagement in the test. These engagements, often called the Real Time Causality Assessment (RTCA) process, have their own bandwidth and connectivity requirements on the test network.

The goal of this paper is to provide the reader with insights into the planning necessary to create a robust network structure for Operational Test (OT) support. The next section provides a description of the RTCA process and the necessary functionality that must be supported by the test network to provide a full operational test environment. Section 3 describes a new tool, Integrated Planning of Tactical, Test Support, and Tactical Engagement Network (IPT3N), for setting up test networks taking into consideration the terrain, movement of test forces, and test network interference with other indigenous RF networks. Section 4 provides a use case and results together with IPT3N planning diagrams for an Operational Test Use Cases.

2. REAL TIME CAUSALITY ASSESSMENT

To assess the success of an event of Brigade/Battalion testing of Army Tactics and Techniques, the accurate location and time sensitive status (e.g., vital or damaged) of players, the combat interaction among players and corresponding impacts are required to be delivered to the Exercise Control (ExCon) for both real-time training control and After Action Review (AAR). RTCA, as the major data source for force engagement and its impact on players, occurs when live players in a test environment engage each other in a battle test scenario. The functionalities and procedures of RTCA specifically designed for each event significantly affect the outcome of the testing/training event. The real-time battle environment is created when live players select battlefield targets and engage them with simulated weapons fire. This process normally uses a tagging system. Often a low energy laser is bore-sighted with the firer's weapon, and a potential target has a laser sensor or tag attached to it. The firer illuminates the target and both players send a "tagged" message to a Weapons Effects Server (WES). The WES, using performance data from the weapon and the target, adjudicates the damage and sends a status message to both firer and target.

While simple in concept, the RTCA process is quite complicated to implement in a full battalion field test environment. The above description assumes a live firer and a live target. However in the Live-Virtual-Constructive

(LVC) environment of a full battalion test, many of the players must be virtual. So engagements between live and virtual entities must also be represented.

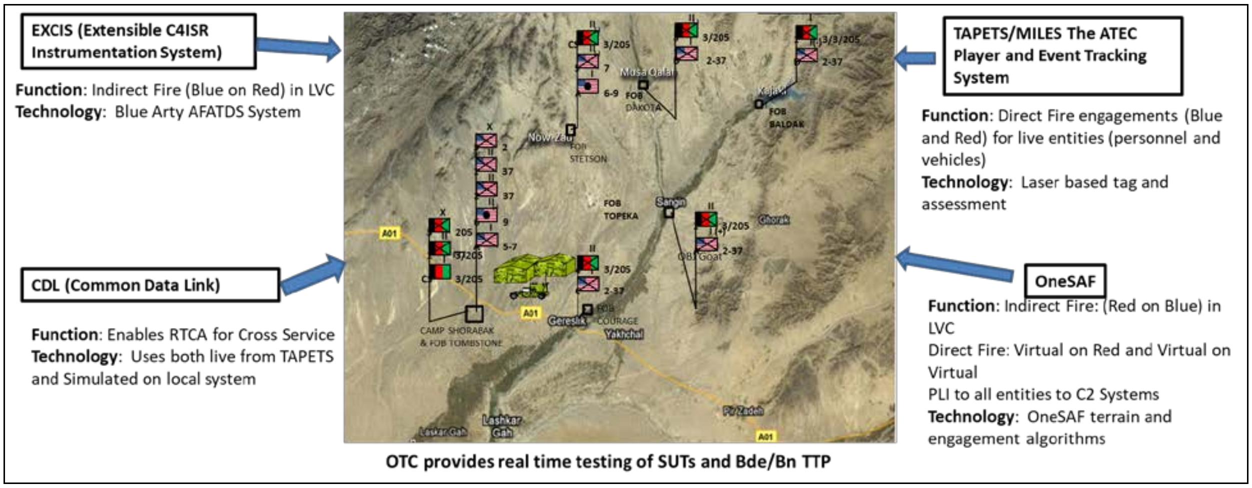

Figure 1: OTC RTCA Environment for Operational Testing

Figure 1 shows the functional architecture necessary to perform live tactical testing, to include RTCA, in a full Army/Threat operational environment. The ATEC Player and Event Tracking System (TAPETS), which provides the communication network pieces of the system, is used to track the live vehicle and foot soldier players and determine interactions with live player engagements with the Multiple Integrated Laser Engagement System (MILES). Extensible C4ISR Instrumentation System (EXCIS), another piece of the architecture, simulates Army Command and Control system's viewing of the battlefield's indirect fire systems (artillery and other indirect fire systems are often virtual entities). The entire force under test (consisting of both friendly/threat vehicles and personnel) is represented in One Semi-Automated Forces (OneSAF). Not only does OneSAF maintain the position of each entity in the test environment, it also creates and adjudicates RTCA engagement functions among entities. The Common Data Link (CDL) serves as a focal point for moving data from EXCIS, OneSAF and MILES interactions on the test network through the TAPETS towers. The architecture is further extended to incorporate the constructive/simulated entities including the constructive TAPETS towers and constructive friendly/threat vehicles and personnel. The EXCIS, OneSAF, and CLD treat all live and constructive entities equally, so that Virtual-Virtual and Virtual-Live Engagements, force maneuver, position tracking and status monitoring of all live and constructive entities are supported.

All of the preceding elements put a significant load on the TSN. Consequently, the success of a specific testing/training event and any subsequent After Action Review (AAR) relies on the TSN's ability to provide the coverage and bandwidth required to reliably transmit all the relevant data in a timely manner. Considering the diverse and dynamic factors in the training setup, such as location and day and time of the testing/training event, terrain, weather, electromagnetic compatibility, and training contents (force maneuver, force engagement), coming up with an adequate TSN lay down is a challenging task.

Currently, there are no existing tools that allow test planners to plan and dynamically re-plan TSN networks to ensure that the coverage provided by the TSN deployment is adequate as the live forces execute dynamic maneuvers during a test or training event. Further, as the Networked Systems Under Test (NSUTs) and the TSNs are designed vertically, they potentially cross-interfere with each other by simultaneously trying to access shared radio resources during a live test. To ensure a successful test event, such conflicts must be identified and mitigated prior to deploying the physical test resources. Lastly, without timely and accurate RTCA data, fair fight conditions between live and virtual forces cannot be guaranteed as 'RTCA systems integrate Live, Virtual, and Constructive (LVC) systems to enable simulated force-on-force battles … [and] must record the time-space position information and firing, damage, and casualty data for all players in the test event.' (Director, 2013).

The goal of IPT3N is to develop an integrated network planning capability that can dynamically account for force deployments and physical range characteristics, and identify potential interference between the TSN and potentially interfering transmitters, resulting in more accurate RTCA information and significant cost reductions for OTs.

To the best of our knowledge, such an integrated planning capability does not currently exist. Such a capability will find significant applicability among the test and training communities across the services. The increasing focus on next generation Network Enabled Weapons (NEWs) further underscores the need for such test planning capabilities across all services' test communities as well.

3. IPT3N ARCHITECTURE

IPT3N is an integrated simulation-based test planning framework that provides a set of semi-automated tools to plan and optimize the laydown of a TSN, and improves coverage and accuracy of data collection from NSUTs. IPT3N will enable test planners to plan and dynamically re-plan laydowns to ensure that the TSN provides adequate coverage to the ExCon & RTCA applications. This includes status monitoring, data collection and interactions between live and virtual forces. The result will be a significant improvement in the quality and quantity of data collected from OTs. This will lead to improved RTCA and lower test execution costs.

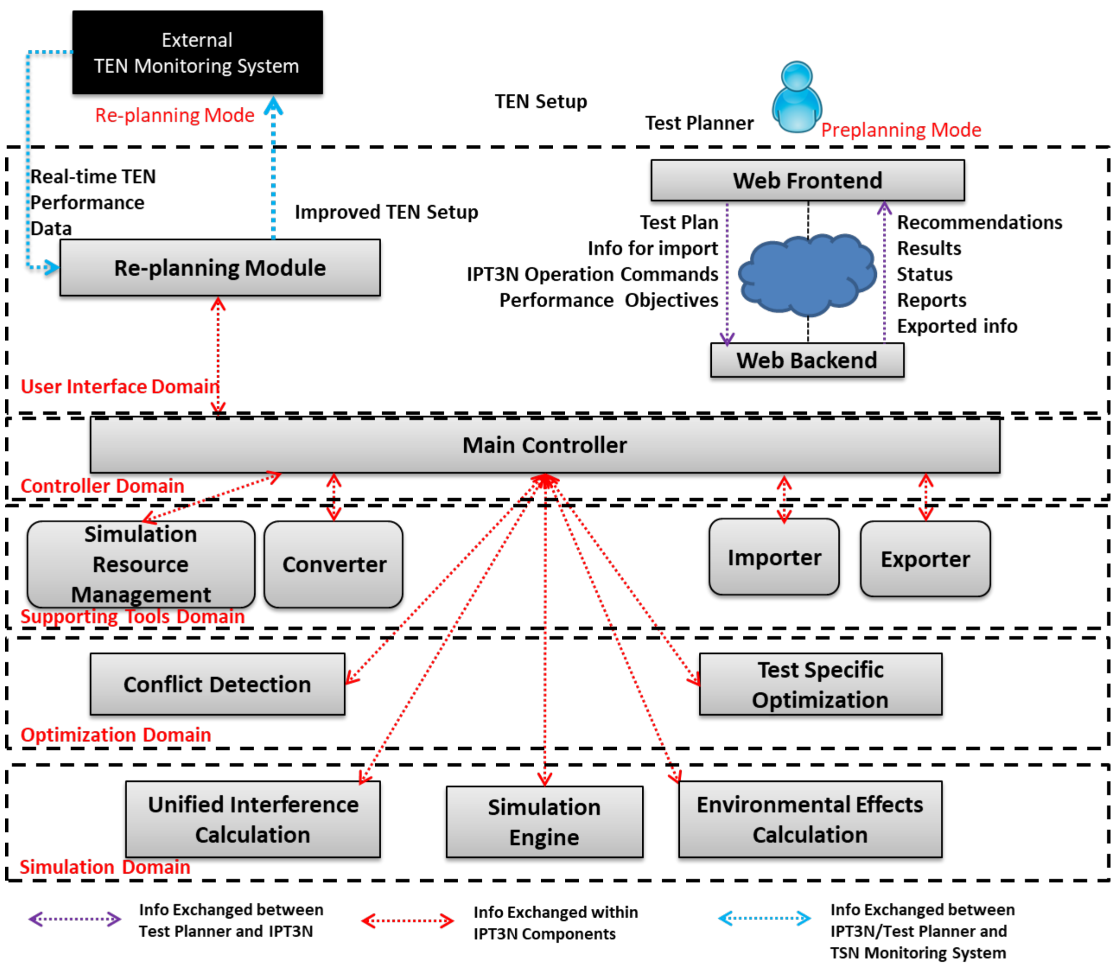

Figure 2: IPT3N Architecture

Figure 2 provides an overview of the IPT3N architecture and its primary components. The overall architecture of IPT3N is separated into domains. Each domain is comprised of one or more components which provide services of similar nature. In each component one or more modules are included, depending on the complexity of the service provided by the component. In IPT3N five main domains (enclosed in black dashed boxes) are defined: User Interface (UI) domain, Optimization domain, Simulation domain, Supporting Tools domain, and Controller domain.

User Interface Domain

This domain contains the Web UI and the Interface to a TSN Monitoring System. Test planners can use the Web UI to interact with the other components of the IPT3N in the preplanning mode. The Web UI's front-end will be used by the test planner to input the network plan of the NSUT and to perform the TSN planning, optimization and analysis operations. The Web UI's back-end will handle the requests and interact with the other IPT3N components indirectly through the main controller and will render the response from those components to the test planner. With live TSN deployed in the test range, planners can use the Interface to TSN Monitoring System in the re-planning mode to interact with third party test operation and management software.

Optimization Domain

This domain contains the Conflict Detection and Test Specific Optimization components. IPT3N will perform optimizations and analysis to guide the test planner towards the best TSN for a given NSUT. It will first identify the non-conflicting TSN technologies and then optimize the layout and configuration of the selected TSN to meet the desired performance target.

- Conflict Detection**:** The purpose of this component is to determine the non-conflicting TSN technologies for a given NSUT. First, it will check if any available frequency band supported by a candidate TSN has an overlap with the frequency band allocated to the NSUT. It will then check if the Modulation and Coding Scheme (MCS) used by the TSN and the MCS used by the NSUT can lead to significant interference when the frequency bands available to the TSN partially or fully overlap with the frequency bands specified in the NSUT network plan. Finally, it will use the Simulation Engine component in the Simulation domain to generate 2-D heat-map (Figure 3) of the signal strength of the test area at different times and different frequency bands. The Conflict Detection component evaluates the heat map and determines if any frequency band can be reused in a certain area and for a certain duration without causing significant interference to the operations of the TSN and NSUT.

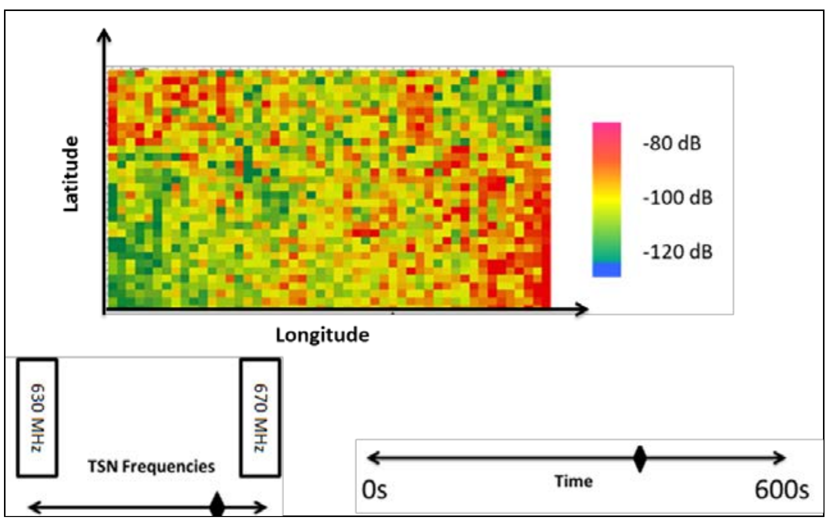

Figure 3: NSUT Heat Map Generated by Conflict Detection

- Test Specific Optimization (TSO): The purpose of the TSO component is to optimize a TSN layout for coverage and to optimize the network configuration to meet the required performance objectives. Optimization techniques specific to the TSN waveforms are employed in searching for the optimal TSN layout and the preferred parameter values for the network configuration.

Simulation Domain

The Simulation domain contains the following components: the Unified Interference Computation Module (UICM) that can calculate the interference among waveforms; the Environmental Effects Calculation Module (EECM) that evaluates the impacts from the environmental factors such as vegetation and weather; and the Simulation Engine (SE) that performs modeling and simulation and provides results to the Optimization domain.

The purpose of the UICM is to increase the fidelity of the simulation engine such that the calculation of interference across heterogeneous networks can be of sufficient accuracy. The UICM also considers non-packet-based interference, such as that from power lines, radios, TVs, etc. The purpose of the EECM is to increase the fidelity of the SE such that the impacts from the environmental effects such as vegetation and weather are taken into consideration in the modeling of signal propagation and reception.

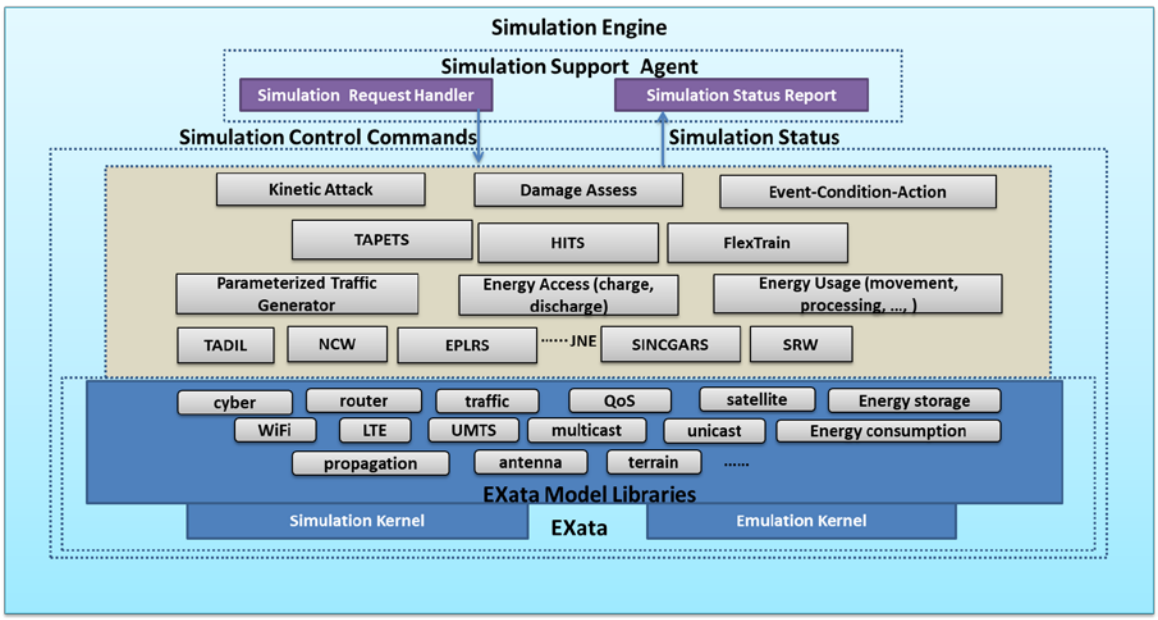

Figure 4: Simulation Engine

The Simulation Engine (Figure 4) handles the simulation requests originating from the Conflict Detection or Test Specific Optimization components, runs the simulation in the simulation core (e.g., the Joint Network Emulator (JNE)) which includes high-fidelity network models for NSUT waveforms (e.g., Soldier Radio Waveform (SRW), Mobile User Objectve System (MUOS), Link16/11, Common Data Link (CDL), Net-Centric Waveform (NCW), Highband Networking Waveform (HNW), TSN waveforms (e.g.,FlexTrain, TAPETS, LTE), the parameterized traffic generator, and battery and energy consumption models. It notifies simulation request originators when simulations are complete and makes simulation results available to them. Besides the use of high-fidelity network models, the SE utilizes additional capabilities, such as a statistics database and parallel execution, to provide accurate and detailed performance results in a timely manner.

Supporting Tools Domain

This domain consists of the Converter, Simulation Resource Management, Importer and Exporter components. Both the Converter and Simulation Resource Management components enhance the IPT3N capabilities provided by the components in the Optimization domain and the Simulation domain. The Converter generates the JNE compliant configurations that can be executed by the Simulation Engine. The Simulation Resource Management component monitors and coordinates the use of the simulation resources (i.e., computers, processors, memory, etc.). The Simulation Resource Management and the Simulation Engine work closely to provide rapid simulation results to assist in the analysis and optimization activities in the Optimization domain. The Importer helps the test planner to utilize mission planning information from other tools which can be in various formats and translates the information into IPT3N specific formats. For example, platform movement information stored as a OneSAF log can be imported and used in IPT3N.Similarly, the Exporter helps the test planner translate the mission plan recommended by IPT3N into formats used by other tools. For example, the layout of the TAPETS tower can be exported as configuration files used on live radios in the field.

Controller Domain

This domain consists of the Main Controller, which is the command processing and message switching center of IPT3N. It provides the login and authentication service so that only authenticated users can use the IPT3N service. It also manages and maintains a state machine for mission planning tasks submitted from test planners. It processes the requests, operation commands, or information obtained via the Web UI and the Third-party Interface. It also translates them into IPT3N internal messages and sends the messages to the proper components for further processing. It accepts the responses from the other components and forwards them to the web backend and the Third-Party Interface for further processing.

4. EXAMPLE IPT3N USE CASE

In this section, we use a synthetic test event scenario termed StarPeak to demonstrate the capabilities of IPT3N to create TSN laydowns that consider both connectivity and bandwidth to support the RTCA test environment. Given the information of the primary communication networks (e.g., spectrum, transmission power) used by the participants in the test event, and the area of test activities (e.g., movement trajectory, terrain), IPT3N will be used to:

- Determine TSN's spectrum and laydown (i.e., the required towers and their locations and settings)
- Evaluate the resulting coverage and RTCA performance
- Identify potential interference impacts on the primary communication networks (e.g., time, location, and magnitude of any interference)

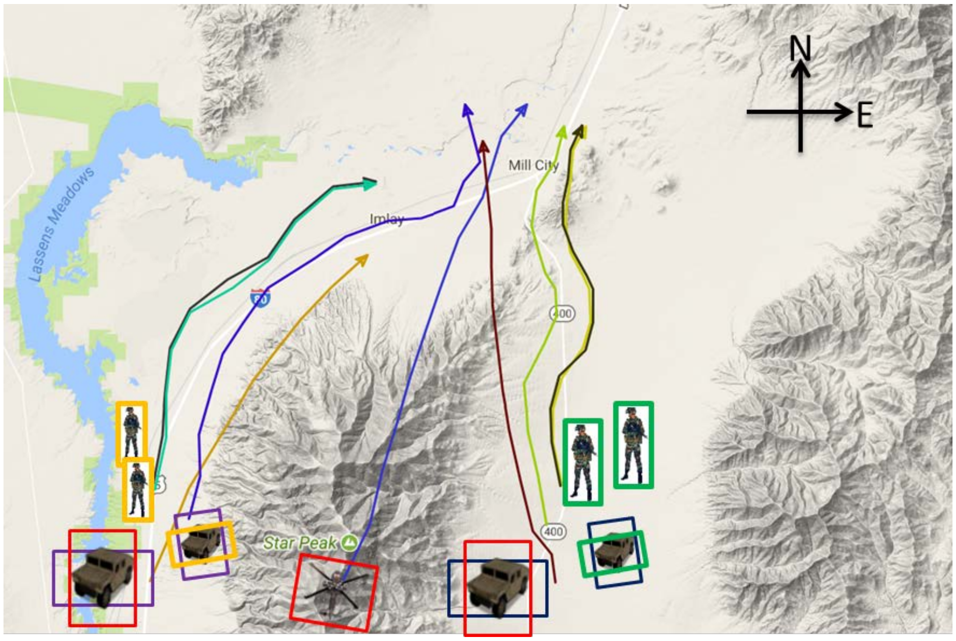

Figure 5: Western and Eastern Forces Traverse Around StarPeak

The StarPeak scenario consists of western and eastern forces traversing along two sides of the StarPeak mountain range, as shown in Figure 5. We reiterate that this this test event scenario was created to highlight IPT3N capabilities and does not reflect operationally representative information or data. This test event uses the WNW and SRW tactical waveforms as the primary communication network and the test planner needs to use the TAPETS technology to establish a TSN to support this event. The StarPeak scenario includes many aspects of a real life test event such as uneven terrain, overlap of radio coverage, tactical waveforms, mobility, etc.

The StarPeak scenario is comprised of the following elements:

- **Units:** The units that make up the scenario are shown in Figure 6 and consist of western ground forces (ground units 1, 4, 6, 7) and eastern ground forces (ground units 3, 5, 8, 9) which need to traverse around the StarPeak mountain range via western and eastern routes before meeting at the end of the range to continue their mission. The helicopter unit (airborne unit 2) moves along the central route for air support, and serves as a bridge for the two ground forces in terms of communication.
- **Primary communication network:** The primary communication networks used by the units consist of 3 WNW subnets (purple, red and blue) and 2 SRW subnets (yellow and green), which are used by the western forces, eastern forces and the helicopter. The spectrum is artificially configured such that the WNW and SRW subnets occupy the entirety of the TAPETS spectrum as shown in Figure 6.
- **Area of training activities**: Figure 7 shows the area of the test activities. The arrows represent the mobility paths of the units as the scenario progresses.
- **Test Network:** The test network will use the TAPETS technology. The towers need to be placed over the StarPeak terrain to provide the best coverage for the western and eastern units while avoiding any potential negative impacts on the primary communication networks.

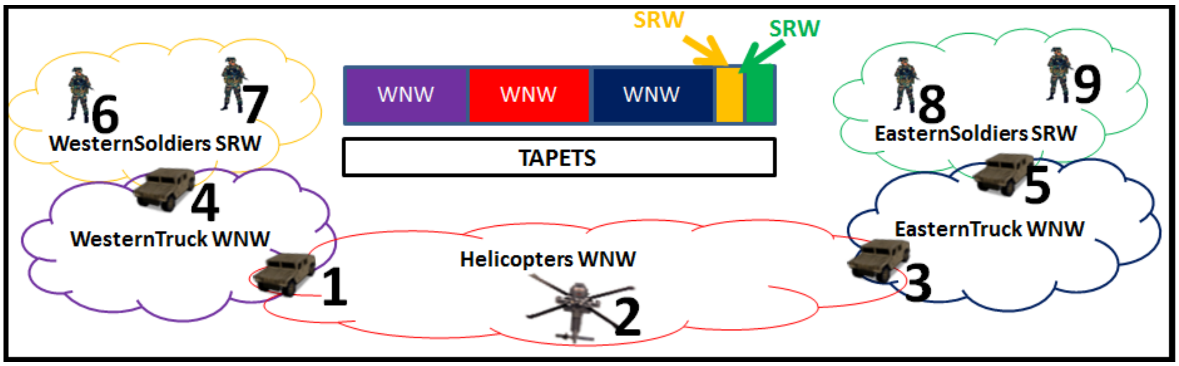

Figure 6: Subnets and Spectrum Allocation of Primary Communication Network

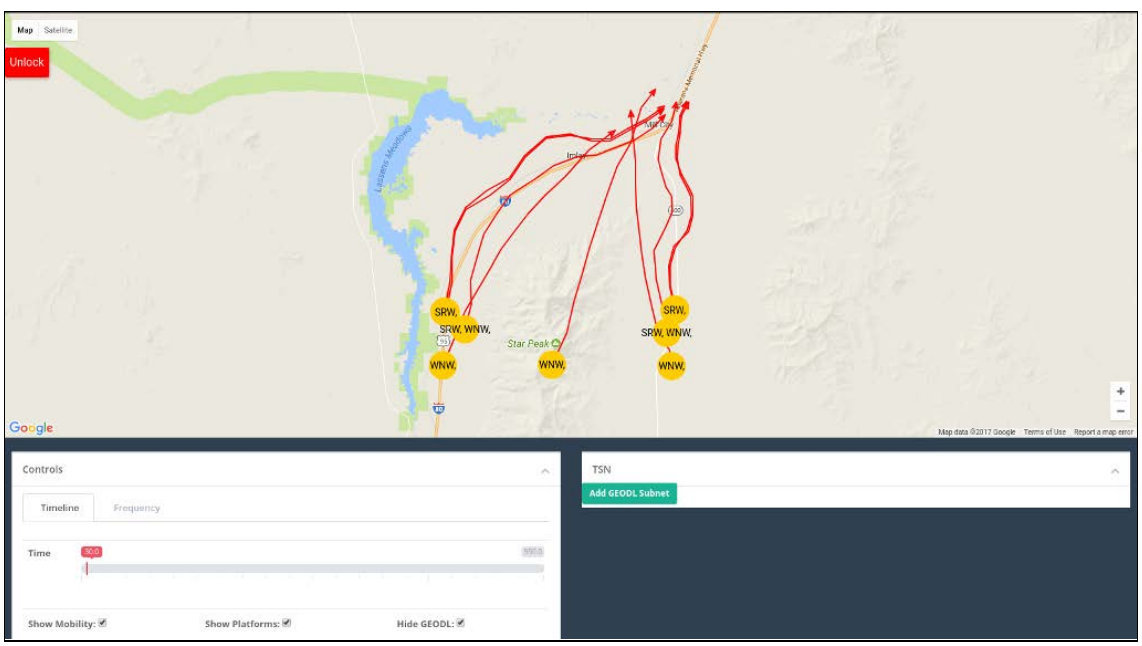

Figure 7: StarPeak Scenario Visualized in IPT3N GUI

Figure 7 shows the visualization of the StarPeak scenario in the IPT3N GUI. The solid circles represent the platforms that make up the existing network which includes the SRW and WNW subnets. IPT3N overlays the platforms and their mobility paths onto Google map with a time slider to visualize the scenario progress over time.

Determine Spectrum for Test Network

The first step the test planer will take is to use IPT3N to determine how the spectrum is occupied over space and time. To do this, the test planner will make use of the heat map feature of IPT3N. A heat map displays the energy at a particular frequency overlaid onto the terrain. IPT3N generates the heat map by using the Simulation Engine to capture the effects of terrain, weather, vegetation, and mobility on the potential signal quality of radio transmissions. As mentioned in Section 3, the Simulation Engine makes use of UICM to accurately calculate the interference across heterogeneous networks as well as non-packet-based interference due to power lines, radios, TVs etc. The Simulation Engine also makes use of the EECM to accurately calculate the signal attenuation due to environmental factors, such as terrain, weather and vegetation. To generate the heat map, the energy levels at each location over time for each frequency band are calculated and recorded by simulation; the recorded energy levels are used to generate the heat map.

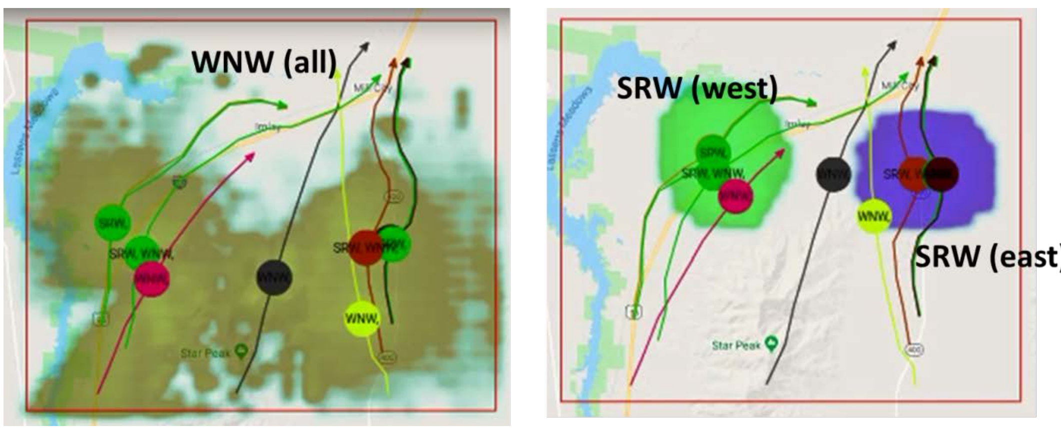

Figure 8: Heat Maps for WNW (Left) and SRW (Right) Subnets

Figure 8 shows the heat map snapshots for the WNW and SRW subnets as the western and eastern units traverse along the StarPeak mountain range. From the figure on the left, we can see that the WNW signals spreads across both sides of the mountain. However, the figure on the right shows that the SRW signals from either side of the mountain do not crossover. Therefore, the test planner can conclude that the spectrum used by SRW can be reused by TAPETS because the StarPeak mountain range blocks the signals from either SRW subnet from leaking to the other side. This means that when the TAPETS towers are placed on either side of the mountain range, the western TAPETS towers can use the eastern SRW spectrum, and the reverse for the eastern TAPETS towers.

Determine Test Network Laydown

IPT3N supports both spatial and temporal spectrum visual analysis which allows the test planner to easily determine how the test network laydown impacts the primary communication network used in the test event. Once the test planner determines the best spectrum allocation for the TAPETS towers, the next step is to determine the best location and settings for those towers. To do this, the test planner places tower markers (blue ^) onto the terrain map and sets the tower's TX power. The number of towers to be placed will depend on the real world resource limitations and the inherent tradeoff between coverage and cost. As the test planner places or moves the towers, the resulting heat map, or coverage map, will be automatically generated through a preliminary simulation study. The test planner will use the coverage maps to to make sure that the tower locations and configured TX powers are properly set so that the TAPETS signal does not leak over to the other side of the mountain range (as this will cause interference with SRW due to spectrum reuse) while providing the best coverage to the units.

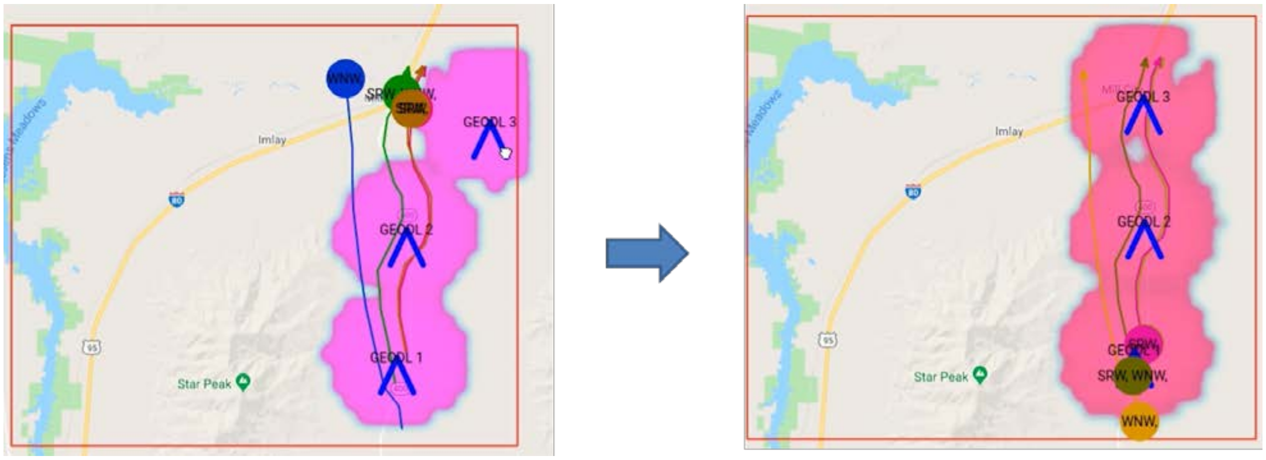

Figure 9: Heat Map for Coverage of Placed Towers (Blue ^) for First (Left) and Second (Right) Iterations

Once a satisfactory laydown has been determined, a full simulation study will be performed for a detailed performance evaluation to determine metrics such as coverage and throughput over time. Figure 9 shows the heat map for the laydown created during the first iteration (left figure) and the second iteration (right figure) to provide coverage for the eastern units. The first iteration does not provide adequate coverage due to the units moving out of range of the towers as the scenario progresses due to the improper location of the north most tower. The resulting coverage of the units over time is shown in Figure 10 (red line). The coverage drops precipitously to zero almost halfway through the scenario. Using the coverage map, for the second iteration the test planner moves the north most tower to the west to better provide coverage to the unit as they move along the paths represented by the arrows. This increases the coverage of the units as the scenario progresses, as shown in Figure 10 (blue line). This process demonstrates how IPT3N can be used iteratively to determine the best test network laydown for good RTCA performance for a test event.

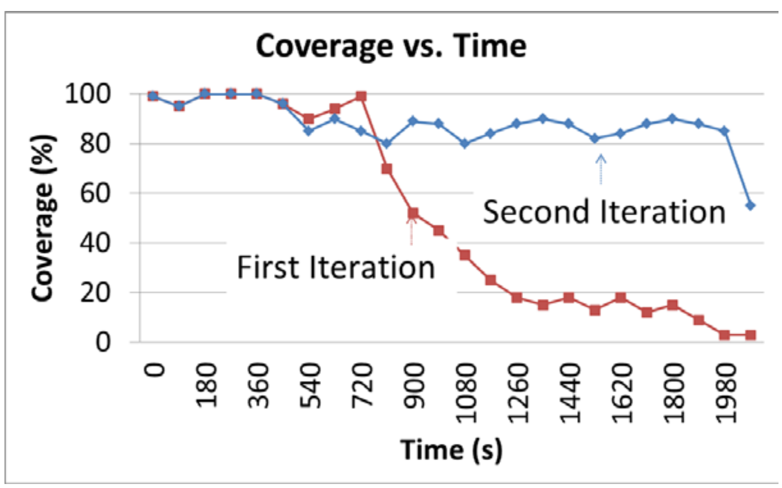

Figure 10: Coverage vs Time of Resulting Tower Placements for First and Second Iterations

Interference between Primary Communication Networks and Test Network

As mentioned earlier, for this scenario the entire spectrum used by the TAPETS network is occupied by SRW and WNW subnets of the primary communication network. The test planner used IPT3N to recognize that the SRW spectrum can be reused across time and space by leveraging the mountain range to block the interfering signals. To see the side effects of this spectrum reuse, the test planner can use IPT3N to view the interference map for the subnets that occupy the same spectrum. This overlap is calculated through a process similar to the one used to calculate the heat map data and is displayed in a similar manner, as shown in Figure 11. In Figure 11, the interference between the eastern TAPETS and western SRW subnets are shown in orange while the heat map for eastern TAPETS and western SRW are shown in violet and purple, respectively. This information allows the test planner to determine the potential interference impacts on the primary communication networks due to the test network and how to best adjust the test network laydown to minimize these effects, such as by changing tower locations and/or adjusting TX powers.

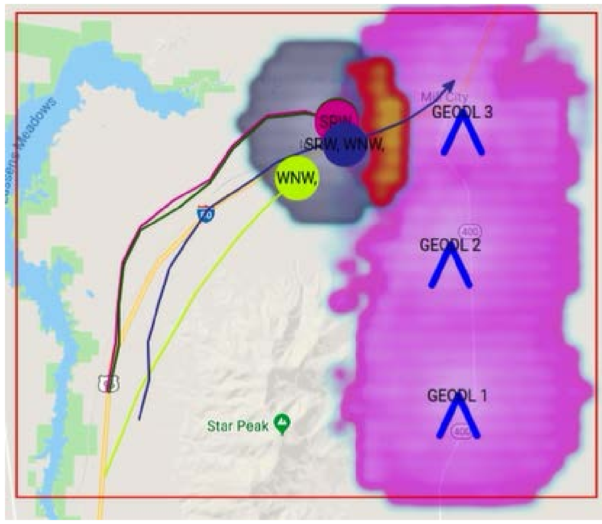

Figure 11: Interference (Orange) between Eastern TAPETS (Violet) and Western SRW (Purple)

5. CONCLUSION

In this paper, we described how RTCA traffic is a necessary function that must be supported by the test network to provide a full operational test environment. We also described how a new tool, IPT3N, may be used for setting up test networks and described a detailed example use case of how a test planner can use IPT3N to create a test network to support a test or training event where there are spectrum conflicts between the test network and indigenous RF networks. In the example use case we have shown how the IPT3N GUI can visualize the scenario which includes the area of training activities, such as the terrain and unit mobility, as well as the spectrum allocation across time and space via a heat map. We have shown how the test planner can use IPT3N to determine if the terrain characteristics can be leveraged to reuse the spectrum for the test network to provide sufficient coverage for RTCA traffic performance while avoiding significant interference impacts on the native RF networks. We currently plan to extend the IPT3N capabilities to support general communication networks for both tactical and enterprise usages.

6. ACKNOWLEDGEMENTS

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