CASE STUDY OF EMULATION WORKFLOW: FROM SCENARIO DEFINITION TO ROUTE ANALYSIS IN TACTICAL WIRELESS MOBILE NETWORKS

Brian Adamson[1], Ta Chen[2], Mariusz Fecko[2], Ibrahim Hokelek[2], Michael A. Kaplan[2], Sunil Samtani[2], Chintan Shah[2]

[1] Protean Research Group, Naval Research Laboratory, Washington , DC 20375

[2] Applied Research, Telcordia Technologies, Inc. Piscataway, NJ 08854

ABSTRACT

In this paper[1], we present a case study of emulation workflow in tactical wireless mobile network. The main contribution of this paper is an XML schema which has been recently developed by the Naval Research Laboratory (NRL) to support high level scenario definition for mobile network emulators in a tool independent manner. In the scenario definition phase, a high level mobility scenario defined using the NRL's XML schema is converted to WISER's run-time emulation files. Using the nodes' locations and terrain information, the RF module performs the relevant calculations and outputs a topology script that depicts node positions and link characteristics (i.e. bandwidth, BER) for all node pairs. To demonstrate emulation scenario definition workflow, Dynamic Routing Control Agent (DRCA) along with the snapshot generation tool is selected as a case study. DRCA, which is a run-time agent, monitors network topology, traffic and capacity and sets the OSPF link metrics dynamically to control routing paths. A snapshot generation tool is integrated with the WISER SDT to identify significant changes in the network. An objective is to identify a small but representative set of snapshots that capture all of the key changes in network topology over the course of a scenario. The above mentioned tools, which are integrated within the WISER SDT, are used to define and analyze DRCA scenarios for the WISER emulation system. EMANE emulation workflow is also described to demonstrate that the NRL's emulation script schema can be used to define scenarios in a tool independent manner.

INTRODUCTION

Network emulation and simulation tools have been widely used in research and development of mobile ad hoc network (MANET) architectures and protocols. These systems provide not only a cost effective infrastructure in terms of hardware resources; they also ensure efficiency in terms of human power needed to test and evaluate the network performance under various conditions before the field testing and actual deployment. A variety of network emulators and simulators (e.g., WISER [4], EMANE [2], Qualnet, ns-2, OPNET) provide a rich set of tools and models to conduct customized experiments.

Each of these platforms has different capabilities and features. Unfortunately there is not one single platform that can be used exclusively to study the network performance; hence, it is common that one might need to work with a multitude of tools. For example, we use WISER, EMANE, and OPNET for the research and development of Telcordia's Dynamic Routing Control Agent (DRCA) for various reasons. The OPNET simulator is used to study the DRCA parameters under various network conditions since OPNET has highly advanced scenario generation and performance analysis tools. Scenarios with different DRCA parameters can be conveniently generated and scheduled to run overnight. However, simulation tools typically do not run in real time and rely on simplified models rather than a real system.

WISER and EMANE platforms provide high-fidelity network modeling, exchange packets in real-time, and faithfully capture the complexity of interactions among different network entities. WISER is used for the DRCA development since it supports ground-to-ground (HNW-like) and ground-to-satellite (NCW-like) TDMA MAC algorithms and provides automated routing protocol configurations for XORP [2]. These MACs are not available for EMANE as of the writing of this paper. Moreover, WISER's packet forwarding and MAC emulation modules run in the kernel space, and hence provide significant performance improvements for emulating large sized networks. EMANE is used for the DRCA development since the open source *quagga* routing suite [6], which supports OSPFv2 with Multi Topology Routing (MTR) and OSPFv3 with MANET extensions, can be run in the EMANE testbed. These routing protocols are planned to be used in DRCA's target network environment which is currently being developed under the DTCN program.

Mobile network emulation scenarios have many common features. For example, each scenario has to define network properties such as number of nodes, area boundaries, terrain; node and link properties such as vehicle type, speed, role on the scenario, radio capabilities and antenna settings, IP address configuration. Defining nodes' locations and their mobility patterns over the course of emulation is an essential part of the scenario definition for MANET. Finally, each emulation scenario has to define application traffic types (e.g., UDP, TCP, VoIP, etc.) and their characteristics (e.g., duration, rate, inter-arrival times, etc.). Although there are many common properties, each emulation tool has its own scenario definition format. The user has to spend considerable time to replicate the scenario under test for different platforms, especially in case of complex scenarios. The ability to define scenarios in a tool independent manner is highly desirable in the networking community.

In this paper we present a generalized Emulation script schema, which has been recently developed by NRL [1]. The scenarios defined according to this schema can be translated to multiple emulation systems with the appropriate tools. The system independent, common scenario definition allows the user to utilize the same scenario in different systems. This

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14. ABSTRACT

In this paper, we present a case study of emulation workflow in tactical wireless mobile network. The main contribution of this paper is an XML schema which has been recently developed by the Naval Research Laboratory (NRL) to support high level scenario definition for mobile network emulators in a tool independent manner. In the scenario definition phase, a high level mobility scenario defined using the NRL's XML schema is converted to WISER's run-time emulation files. Using the nodes? locations and terrain information, the RF module performs the relevant calculations and outputs a topology script that depicts node positions and link characteristics (i.e. bandwidth, BER) for all node pairs. To demonstrate emulation scenario definition workflow, Dynamic Routing Control Agent (DRCA) along with the snapshot generation tool is selected as a case study. DRCA, which is a run-time agent, monitors network topology, traffic and capacity and sets the OSPF link metrics dynamically to control routing paths. A snapshot generation tool is integrated with the WISER SDT to identify significant changes in the network. An objective is to identify a small but representative set of snapshots that capture all of the key changes in network topology over the course of a scenario. The above mentioned tools, which are integrated within the WISER SDT, are used to define and analyze DRCA scenarios for the WISER emulation system. EMANE emulation workflow is also described to demonstrate that the NRL?s emulation script schema can be used to define scenarios in a tool independent manner.

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would also enable the networking community to define benchmark scenarios. The scenarios defined according to the NRL Emulation script schema are converted to the WISER run-time emulation files. The standalone version of DRCA along with the snapshot generation tool is used as a scenario definition workflow case study.

NRL EMULATION SCRIPT SCHEMA

The Emulation script schema is an XML schema that supports elements to define certain mobile node characteristics (e.g. location, velocity, orientation, etc.) and parameters of other functional modules and changes to those characteristics or parameters over the course of mobile network modeling experiment. This schema adopts a modular approach to the definition of mobile network modeling scenarios. A couple of categories of document types comprise this modular approach: "Planning Documents" and "Emulation Script Documents". Figure 1 illustrates this modular approach of planning documents that can be created to separately describe different aspects of the scenario and script documents that are the resulting composite of the separate planning components. The Emulation script documents contain time-ordered events that tightly script (i.e., dynamically update) emulation module properties (e.g., node location/motion and others). The planning documents allow aspects of the scenario to be preplanned in a more tenable, natural fashion. For example, a "MotionPlan" document type is an example of a planning document that lets a user describe the intended motion plans for mobile nodes in the scenario in a somewhat natural fashion (e.g., start at a certain location, move to first waypoint, then another, etc.). Additional planning document types such as "NetworkPlan" and "CommunicationPlan" types convey network system and node configuration and communication events, respectively. The blue portions of Figure 1 correspond to the components of the planning and experiment orchestration process that can be somewhat independent of the target mobile network modeling system. The red portions are those components that need to have specific knowledge of the target system. The template file provides an input to the system configuration process that can be used to control parameters of how the specific modeling system is to be set up or used. The generation of the system configuration file(s) is a synthesis of the generic planning documents and this template. The "EmulationDirectory" document provides a mapping of the generic scenario elements (e.g., nodes and their interfaces) to the instantiations of emulation system components (e.g., EMANE Network Emulation Modules (NEMs), ns-2 simulation agents, etc.) that represent those elements. The "EmulationDirectory" document then provides a reference to map scripted scenario configuration events to specific run-time events or commands for the specific modeling system(s) in use. Similarly, run-time control events are generated as a synthesis of the scripts that result from the processing of planning documents and the specific system configuration that was created. The purple coloring of the "EmulationDirectory" document and "Event Generator" functional module illustrates their incorporation of both the blue generic scenario description and red system-specific configuration information. The Emulation script XML schema enables the use of existing and emerging XML content manipulation tools to perform operations on scripts. This includes filtering of events within scripts, potential merging of scripts, and manipulations that might parametrically alter a script. This schema is also designed to allow for conversion to and from other file formats as needed. This ability to provide translation compatibility with other formats can make this schema useful for specifying and/or scripting scenarios outside of strictly emulation purposes, including use with tools for discrete event network simulation (e.g. ns-2, OPNET, etc.) or for analytical programs. The structure of the schema attempts to be sufficiently general to contain XML elements that allow inclusion of events that can initialize or update characteristics of any modules within the emulation system. This generalized capability will allow users to construct scripts that can describe alterations to arbitrary aspects of the emulation over time (provided that the run-time framework supports interpretation of these events and control of those aspects). To demonstrate that the proposed schema can be used in a tool independent manner, we will present the workflow for two emulation systems: EMANE and WISER.

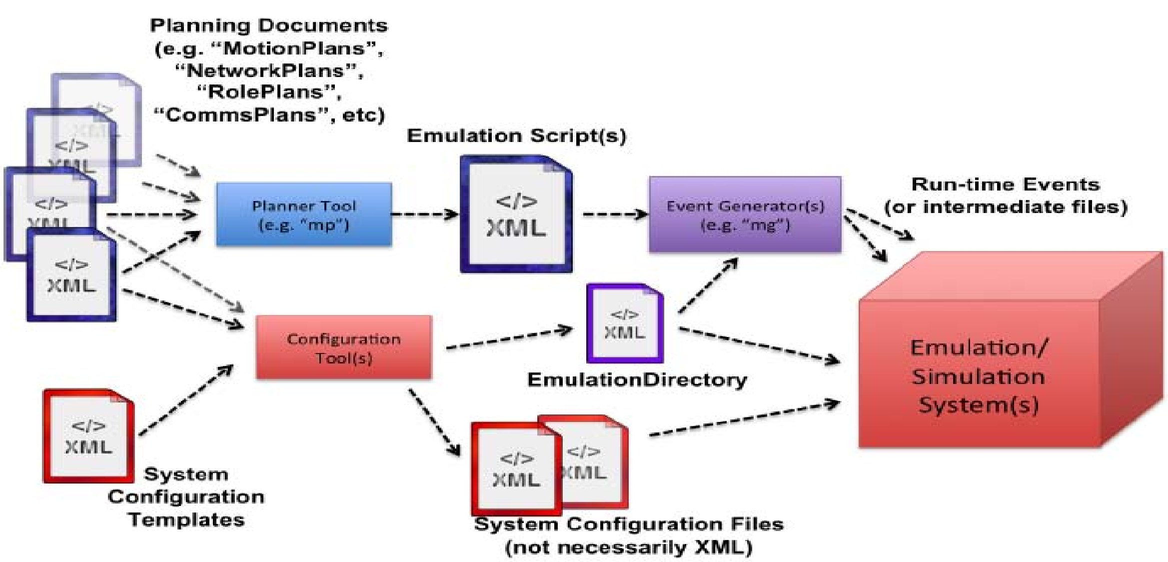

Figure 1 Emulation Planning and Scripting Work Flow

EMULATION WORKFLOW FOR EMANE

A rich set of tools as depicted in Figure 2 has been developed by NRL to generate and manipulate the EMANE scenarios based on the Emulation script schema. These tools are displayed in blue in Figure 2. The motion plan (*mp*) tool converts the MotionPlan document into an intermediate EmulationScript document which includes location and motion events. The *enp* tool gets NetworkPlans, EmaneTemplate, and EmulationsScript (generated by *mp*) documents as input and generates the final EmulationScript and EmulationDirectory files, and the EMANE "platform.xml" configuration file. The next step is to use motion generator (*mg*) tool to generate an EMANE EEL (emulation event log) file with location events (and possibly some network configuration and/or interface parameter events). The graph builder (*gb*) tool takes the EEL file as input and optionally a terrain data file to calculate and add "pathLoss" events to the given EEL file. Finally, an EMANE experiment can be run with the given configuration files and the EEL file. It should be noted that utilities are available that can convert to and from different mobility file formats like SDT, MMF, EEL and ns-2 setdest. This allows the output of the workflow chain to be used for different systems.

EMULATION WORKFLOW FOR WISER WITH SCENARIO ANALYSIS TOOLS

In this section we demonstrate how the Emulation Script schema can be used for defining a WISER scenario. Figure 3 shows an overview of the emulation workflow which consists of four steps: scenario definition, RF analysis, snapshot generation, and route analysis. These steps are integrated into Scenario Definition Tool (SDT) of WISER which provides high-fidelity network modeling, exchanges packets in real-time, supports a flexible open source router platform (XORP), and offers TDMA-based wireless MAC emulation capabilities for different types of links, waveforms, radio devices. Our objective is to define scenarios for DRCA testing using the NRL's tool independent emulation script schema and analyze and refine the scenarios before running them in the real emulation system.

In the scenario definition phase, two files are input to the WISER SDT, a motion plan document and a WISER template file. The NRL motion plan document is used to define the nodes's initial locations and mobility patterns. WISER assigns network configuration in an automated way and RF properties like fading, shadow loss, path loss model, bit error ratio (BER), etc are defined from the SDT on a scenario wide basis. Hence, the "NetworkPlan" and "CommunicationPlan" documents in Figure 1 are not used in this case. The WISER template file corresponds to the System Configuration Template and contains information specific to the SDT such as node type, satellite capability, interface type, etc. The *MpToSdt* tool is analogous to the "mp" tool shown in Figure 2. It converts a high level mobility scenario defined by the NRL's Motion plan to WISER's input file which includes the nodes' initial locations and their movements using the waypoint primitives. Using the nodes' locations, terrain information, and the RF parameters, the RF module performs the relevant calculations and outputs an emulation scenario script that depicts node positions and link characteristics (i.e. bandwidth, BER) for all node pairs over the course of emulation. This script includes a time ordered emulation scenario that can be played on the GUI or run on the emulation test bed. DRCA along with the snapshot generation tool is selected as the emulation case study. The standalone version of DRCA is integrated with the WISER SDT to analyze the scenarios in terms of routing and link utilizations. A snapshot generation tool is integrated with the WISER SDT to identify a small but representative set of snapshots that capture all of the key changes in network topology over the course of a scenario. These steps will be described in detail in the following subsections.

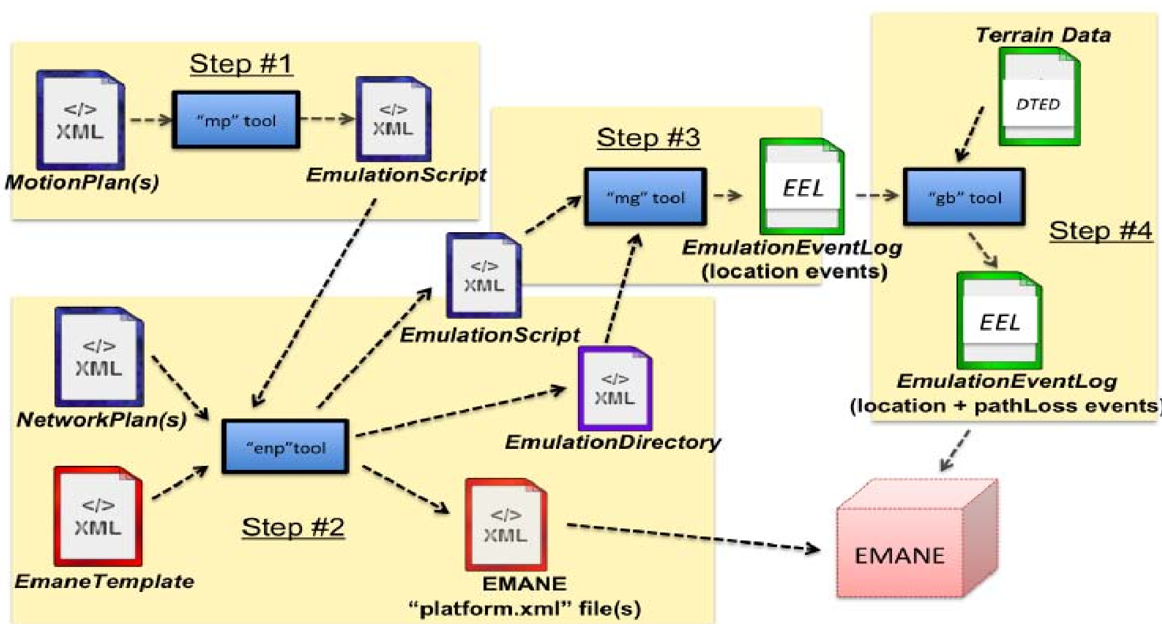

Figure 2 Emulation Workflow for EMANE

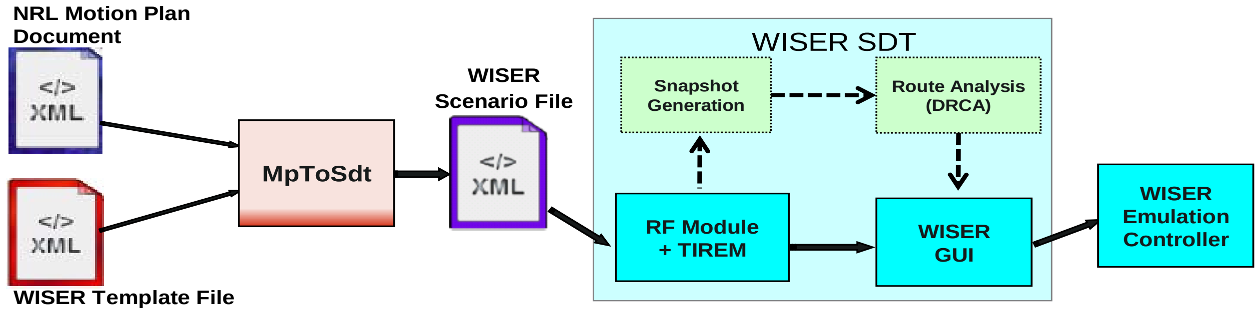

Figure 3 Emulation Case Study Workflow for WISER using NRL Motion Plan

SCENARIO DEFINITION USING NRL MOTION PLAN

As described earlier in the paper, the MotionPlan document lets the user describe the intended motion patterns for nodes in a natural fashion. This is achieved by specifying complex motion as a concatenation of primary motion primitives. The tools can then convert these complex motion primitives to the time ordered representation required for run time motion generation. Furthermore, sequences of motion primitives can be encapsulated as named motion patterns and those patterns can be re-used by reference to specify, possibly repetitive, node motion or as part of more complex pattern definition. In the simple MotionPlan example in Figure 4, a *loop* pattern is defined that consists of a triangle of three waypoints. The *node01* motion plan is specified with an initial location and pause of 120.0 seconds followed by the triangle loop pattern with an undefined number of repeats, but limited to duration of 600.0 seconds. After the 600.0 seconds of time spent in the loop, the node traverses to a specified waypoint and begins another 120.0 second pause. After this pause, *node01* finally enters into a 30 meter radius circle motion pattern for an indefinite time. The primary motion primitives include waypoint, vector, location, circle, pause, loiter and randpoint. The motion primitives also have a duration attribute that can be set to specify time limits for each primitive to pace the execution of the concatenated set of motion primitives. The *location* primitive specifies immediate re-location (i.e., teleportation) to specified coordinates. The *waypoint* primitive specifies a destination towards which the node should move at specified velocity. The *vector* primitive specifies a direction, given in azimuth and optional elevation angles at which the node should move at specified velocity. The *circle* primitive is used specify motion along the perimeter of a circle of a specified radius about a center location at a given velocity. The *circle* also has an optional *revs* element that indicates the maximum number (or fractional number) of circle revolutions to complete before motion is completed. The *loiter* primitive is provided to specify a circular (hovering or loitering) motion that is relative to another embedded motion primitive or pattern. The *randpoint* primitive can be used to generate randomly selected node waypoints or locations. Each time a *randpoint* primitive is processed it may generate a random waypoint or location within the bounding location box, time, and speed. The *pause* primitive element is provided to specify intervals of immobility from the completion of a prior motion primitive or pattern before beginning transition to a subsequent motion primitive or pattern. The *pattern* primitive identifies (by name) a motion sequence that was previously-defined using the “PatternDefinition” element. The *pattern* element also has an optional repeat attribute that can be used to indicate how many times the motion sequence should repeat before proceeding to any subsequent motion.

The WISER SDT input file only allows node motion in the form of waypoints. The *MpToSdt* tool therefore implements these complex motion patterns as a set of concatenated waypoints. This approach shows that even if the target system does not support a particular feature defined by the Emulation script schema, the system specific tools can be designed in such a way as to result in the intended scenarios.

```
<MotionPlan>
   <PatternDefinition name=”loop”>
      <waypoint>
         <destination> lat1, lon1, alt1</>
         <velocity>12.0</>
      </waypoint>
      <waypoint>
         <destination> lat2, lon2, alt2</>
         <velocity>12.0</>
      </waypoint>
      <waypoint>
         <destination> lat3, lon3, alt3</>
         <velocity>12.0</>
      </waypoint>
      <waypoint>
         <destination> lat1, lon1, alt1</>
         <velocity>12.0</>
      </waypoint>
   </PatternDefinition>
   <Node name=”node01”>
     <location> lat0,lon0,alt0</location>
     <pause>120.0</pause>
     <pattern repeat=”-1” duration=”600.0”>loop</pattern>
       <waypoint>
          <destination>lat4,lon4,alt4</>
          <velocity>20.0</>
      </waypoint>
      <pause>120.0</>
      <circle>
           <center>lat5,lon5,alt5</>
           <radius>30.0</>
           <velocity>15.0</>
      </circle>
   </Node>
</MotionPlan>
```

Fig 4 Motion Plan Example

RF ANALYSIS

With the NRL Motion Plan and WISER template files merged in the above, the scenario is next fed through the RF module to compute a realistic physical layer representation. To determine ground-to-ground connectivity, the RF module computes the Symbol Energy to Noise Density Ratio (E_s/N_o) for all node pairs per a configurable time interval [5]. The E_s/N_o is then used as an index for table-lookup into target radio specifications, providing the expected symbol coding and modulation rates applied. An additional look-up calculation then converts the coding and modulation rates to yield typical bandwidth and bit-error-ratio under these conditions.

The E_s/N_o calculation requires its own set of inputs extracted from the WISER scenario file. First, path loss between all node pairs is computed using antennae settings and instantaneous node positions. Path loss models include terrain data (i.e. TIREM) or theoretical models such as exponent-based propagation with a configurable Path Loss Exponent (PLE) parameter. Next, shadowing effects are applied using constant or log-normally distributed models. Finally, Rayleigh fading based on Effective SINR Mapping further attenuates the signal. The ground-to-satellite RF model follows a similar procedure to that of ground-to-ground RF, however it computes the Carrier to Noise Ratio (C/N_o) instead of E_s/N_o, follows free space path loss, and applies atmospheric absorption models for further accuracy.

SNAPSHOT GENERATION

In this stage, the scenario time line is sliced into multiple phases, each summarized by a snapshot that characterizes the state of the network. The term "snapshot" is used here for descriptive purposes to connote the notion of capturing the network state at a particular point in time. A snapshot generation tool is integrated with the WISER SDT to identify a small but representative set of snapshots that capture all of the key changes in network topology over the course of a scenario. Clearly, one of the tradeoffs in snapshot identification is the number of snapshots to be computed. That is, allowing more snapshots potentially increases the fidelity of capturing changes in the network state at the expense of increased computation delay when these snapshots are analyzed (e.g., route analysis by DRCA).

The snapshot identification approach has two configurable options: *(i)* create snapshots by sampling the mission timeline at a regular interval, *(ii)* apply the counts of various event classes (including node/link arrivals and departures) as the main snapshot discriminator. In the interval-based snapshot identification, the mission timeline is sampled at a regular interval. With the number of snapshots specified as a configuration parameter, the time interval is determined from the total scenario time and the number of snapshots. In Option *(ii)*, the procedure identifies a new snapshot when two conditions hold: *(i)* the number of events counted from the start of the current snapshot exceeds a given threshold, and *(ii)* the time-distance between the last event in the current snapshot and the earliest next event exceeds a given threshold.

ROUTE ANALYSIS (DRCA)

After the snapshots are generated, each snapshot is analyzed using the standalone version of DRCA [7], where the DRCA input files are obtained from the scenario definition tool. In the actual deployment of DRCA as a run-time agent, the network topology is extracted from the Link State Database (LSDB) while local DRCA agents running at every node measure the traffic and link capacity information and report this information to the Lead DRCA analyzer for new link weights' calculations. DRCA has been running in COTS router, WISER, and EMANE testbeds, and OPNET as well.

For each scenario, the DRCA GUI is used to visualize the network information and conditions at a particular snapshot. For example, the GUI shows the network topology, link capacities, routing paths, link utilizations, throughput, congested links, and more. In the analysis heuristics, DRCA dynamically computes OSPF link metrics to achieve the user specified objectives based on the *network topology*, *traffic demand* and *link capacities* and *transmission delays* of the network. The WISER emulation script instances corresponding to the snapshots are converted to the DRCA input files (e.g., topology and link capacity files). Another important scenario element for DRCA is the traffic demand matrix which contains the amount of traffic among all node pairs in the network. As described below, the traffic matrix is randomly generated and scaled up/down to obtain different network loading (light, medium, and heavily loaded networks).

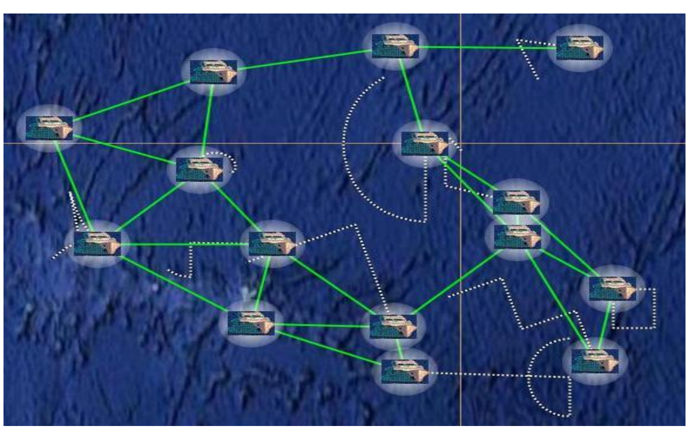

Figure 4 Initial snapshot at time=0

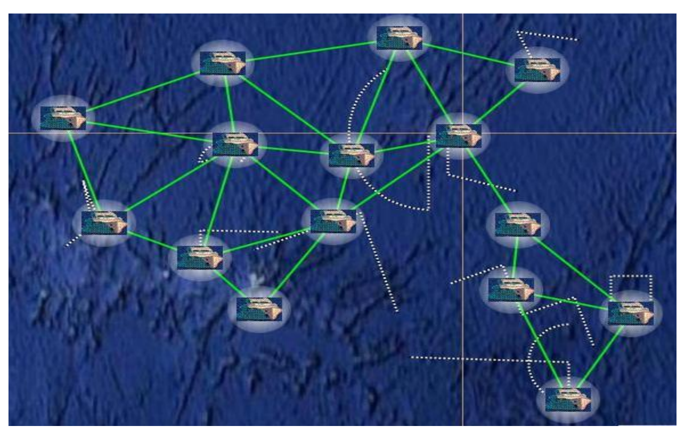

Figure 5 Third snapshot at time=197 seconds

Table 1 The network-wide packet loss percentages w/o and w/ DRCA

		T		**2T**		**3T**		**4T**	
	N	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*
PLE=2.15	**5.01**	0	0	1.34	0	6.65	3.69	14.23	13.17
PLE=2.20	**3.51**	3.15	0	23.30	15.36	37.99	34.61	47.59	46.54

EXAMPLE SCENARIOS AND RESULTS

In this section, we present numerical results to demonstrate the complete emulation scenario definition workflow for WISER. A similar workflow has been implemented for EMANE; however, due to the space limit we will not include any result here. First, a *MotionPlan* document is generated for a 15-node scenario, where each node's movement pattern can be seen in Figure 4 and Figure 5. The scenario duration is 600 seconds.

In the RF module, two different Path Loss Exponents (PLEs) of 2.15 and 2.20 are used. As Table 1 shows, the average number of neighbors (N) is 5.01 and 3.51 for the PLEs of 2.15 and 2.20, respectively. Figure 4 shows initial locations and Figure 5 shows the third snapshot at time 197 seconds, both for the PLE of 2.20. The same NRL MotionPlan document is used for both PLEs.

For each PLE scenario, the snapshot generation tool using the same parameters is run. The minimum and maximum number of events to generate a new snapshot as a percentage of the total events are 0.2 and 0.4, respectively. The minimum time difference between snapshots is set to 40 seconds. Our snapshot identification algorithm uses the counts of link arrival and departure events. The snapshot generation tool yields 4 snapshots for the scenario with the PLE of 2.15 while 5 snapshots for the scenario with the PLE of 2.20 (excluding the initial snapshots). The snapshot times for the PLE of 2.15 are 71, 121, 197, and 338 seconds. For the traffic generation, each node randomly selects 4 destinations and generates Constant Bit Rate (CBR) traffic (i.e., 60 sessions) to their selected destinations. For example, in Table 1, *T* corresponds to a traffic rate of one unit per second between each source and destination pair and *2T* corresponds to 2 units per second, and so on.

Table 1 shows the network-wide traffic loss percentages averaged over all snapshots for each PLE scenario. Although there are other results available in the DRCA GUI (e.g., the link utilization ratios, traffic loading, etc.), the network-wide loss percentages are selected as an example. The parameter PLE in the RF module has significant impacts on the network density (i.e., average number of neighbors) and hence the network-wide traffic loss percentages. For example, the traffic demand matrix of *T* yields no traffic loss for the case with the PLE of 2.15 while it causes 3.15% traffic loss for the PLE of 2.20 using the default link weights (i.e., hop counts for the w/o DRCA case). The same observation is valid for all the other traffic demand matrices in Table 1. The traffic loading level has significant effects on the DRCA optimization performance such that, for the heavily loaded networks (*4T* for the PLE of 2.15 and *3T* and *4T* for the PLE of 2.20), the DRCA throughput improvements are minimal since there is less likely to have underutilized alternative paths for rerouting in the highly loaded networks. In other words, no alternative paths with sufficient link capacities exist since all link capacities are almost fully utilized for the heavily loaded networks. For the lightly and medium loaded networks (*T*, *2T*, and *3T* for the PLE of 2.15 and *T* and *2T* for the PLE of 2.20), the DRCA provides significant performance improvements (from about %34 less traffic loss to no loss at all). This confirms that DRCA can provide better resource utilizations for the operational MANET networks since they are usually lightly and medium loaded but some of their links gets congested due to sudden changes in traffic demand and link capacities. These example scenarios and results demonstrated that the proposed emulation scenario definition workflow can be effectively used to define and analyze the DRCA scenarios for the WISER emulation platform.

CONCLUSION[2]

In this paper, we presented a new XML schema developed by the Naval Research Laboratory to support high level scenario definition for mobile network emulators in a tool independent manner. The scenario definition emulation workflows for EMANE and WISER platforms along with the supporting tools are described. As a scenario definition case study, DRCA along with the snapshot generation tool is integrated with the WISER SDT. The scenarios generated using the NRL schema are converted to the WISER emulation scripts and analyzed by the snapshot generation and DRCA tools. The proposed emulation script schema along with the supporting tools can be effectively used to define benchmark scenarios for the networking community.

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