U.S. Army Research, Development and Engineering Command

High Performance Network Modeling in the US Army Mobile Network Modeling Institute (MNMI)

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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COMBINE
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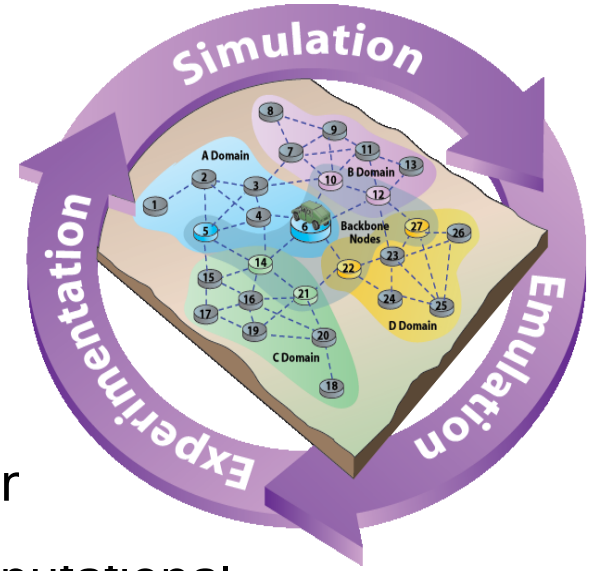
Institute Objectives

Develop multi-disciplinary expertise/software that transforms the way DoD models-simulates-emulates-tests mobile networks

Objectives

- Develop and apply HPC software for the analysis of MANETs in complex environments
- Develop an enabling interdisciplinary computing environment that links models throughout the Simulation, Emulation, and Experimentation cycle
- Leverage the powerful synergistic relationship between simulation, emulation, and experimentatior
- Expand DoD workforce that is cross-trained in computational software and network science skills
- Deliver/support software and train the DoD HPC user community, and significantly extend it to key NCW transformation programs



Key Technical Barriers

Modeling the Full Protocol Stack. Realistic simulation and emulation of the network requires looking at every layer of the protocol stack, from the physical, to the medium-access-control, network, information, and application layers.

RF Propagation and Terrain Effects Dynamic networking must account for RF propagation performance, yet there is insufficient fidelity to model large-scale mobile networks with realistic propagation effects in difficult propagation environments (i.e. urban, foliage, mountainous terrain) and under adverse conditions (i.e. interference, jamming).

Command and Control Traffic and Command Hierarchies: Traffic models for the network must be accounted for and be directly related to the command and control systems and command hierarchies.

Modeling Scope: These models must address the full capability of the LandWarNet including its multiple tiers (terrestrial, airborne, space), its key layers (transport, services, applications, platforms), and its interactions with the Global Information Grid.

Real-Time Operation: High-fidelity and scalable modeling must run in real-time to enable hardware-in-the-loop and emulations that are key to minimizing the risks inherent in fielding complex NCW technologies

'SEE' Concept

Simulation

Use theory to define:

- Objective function
- Behavioral relationships
- Parameters
- Variables

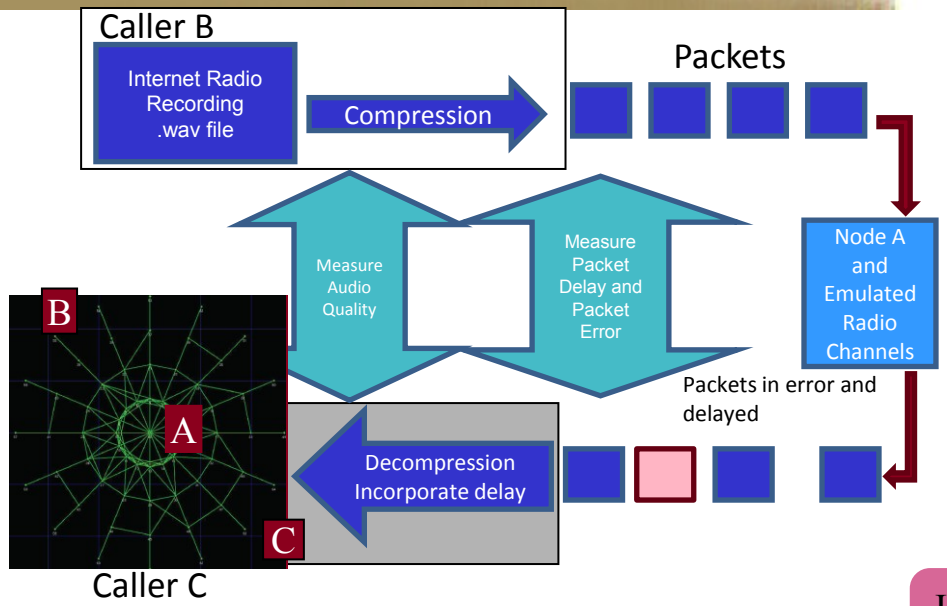
Emulation

- PC processors represent nodes
- Laboratory environment
- MANE software to model node moveme and radio access
- Actual MANET protocols run on nodes
- Applications run on nodes

Experimentation

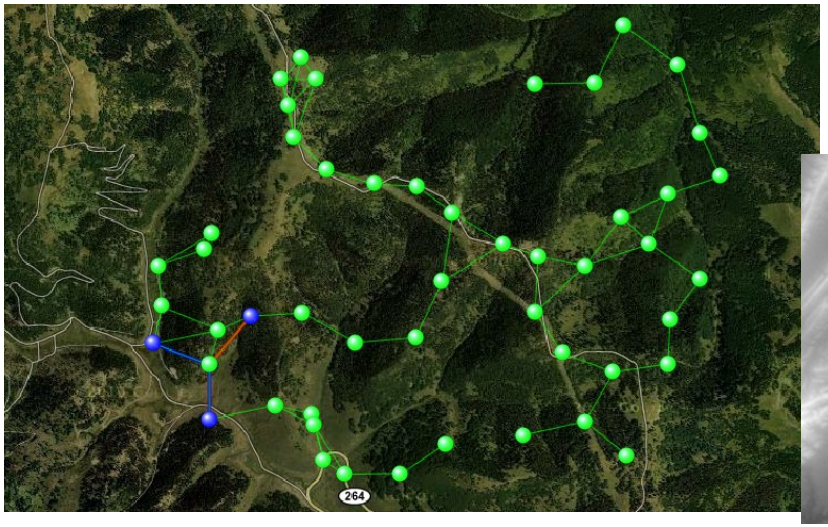
- Actual hardware in field environment
- Traffic generated from applications
- Realistic scenarios
- HPC used to augment and stimulate environment

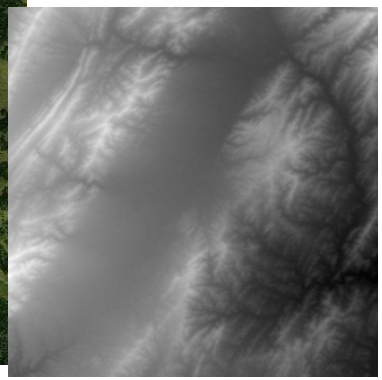
ARL Emulation Environment



Real-Time Mobile Ad-Hoc Network (MANET) provides a platform for analysis of full applications including comparison of waveforms, routing algorithms, antennae, and other radio parameters in a controllable and repeatable laboratory environment.

Human-in-the-Loop LVC experiments allowed with real-time RF propagation calculations



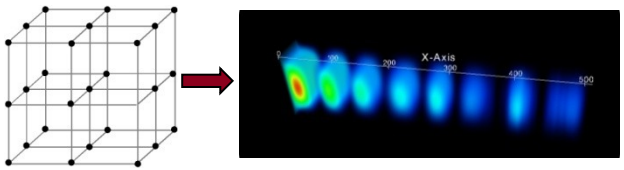


Real-Time RF Propagation Modeling

Real Time Path Loss Progress

Free Space
- Simple calculation on CPU
- Does not require digital terrain data
- Does not consider terrain
- Inaccurate if ground is not flat

Pre 2010

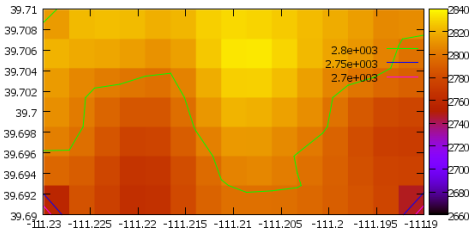


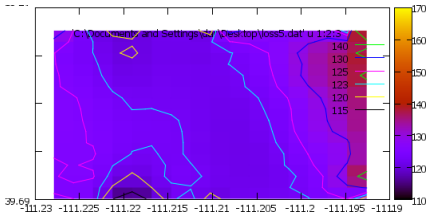
TLM simulation models propagation of energy through space (the grid)

ITM (Longley-Rice)
- Efficient GPGPU implementation (>10x faster than single core)
- Considers terrain
- Does not consider human made structures

TLM
- Very efficient GPGPU computation (60x faster than single core)
- Typically used for pico-cell modeling
- Scale as $O(n^3)$ with spatial discretization

2011

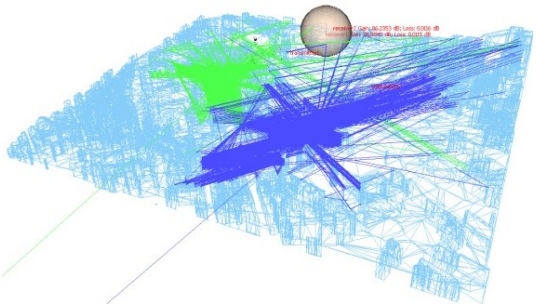




ITM path-loss calculation integrated with emulation server

Ray Tracing
- Perceived efficiency on GPGPUs
- Capable of accurately predicting propagation in urban environment
- Requires 3-D model of environment
- Computationally expensive

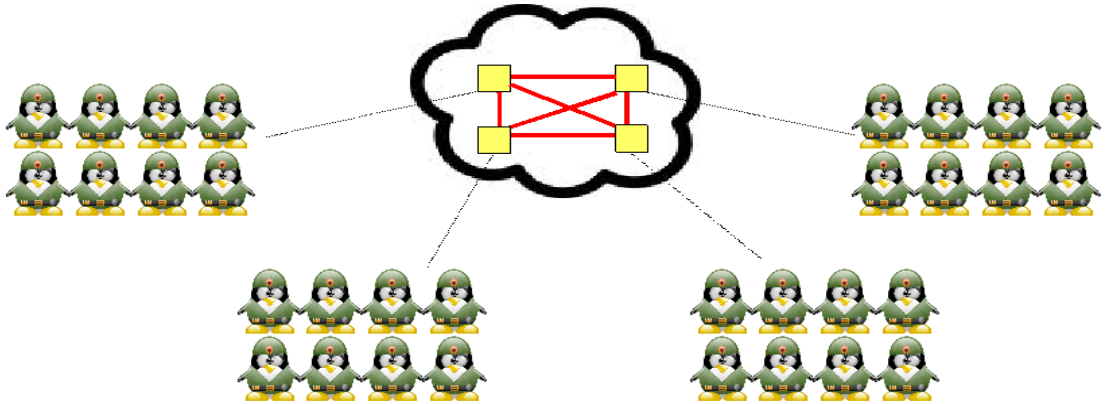
2012 and Beyond

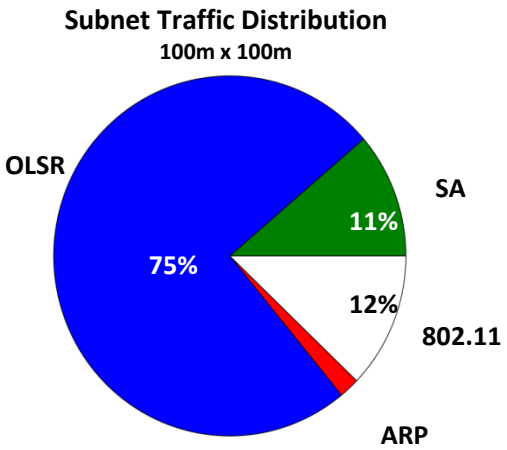


3D view of GPU accelerated ray-tracing calculation.

NS-3 Performance Testing Scenario

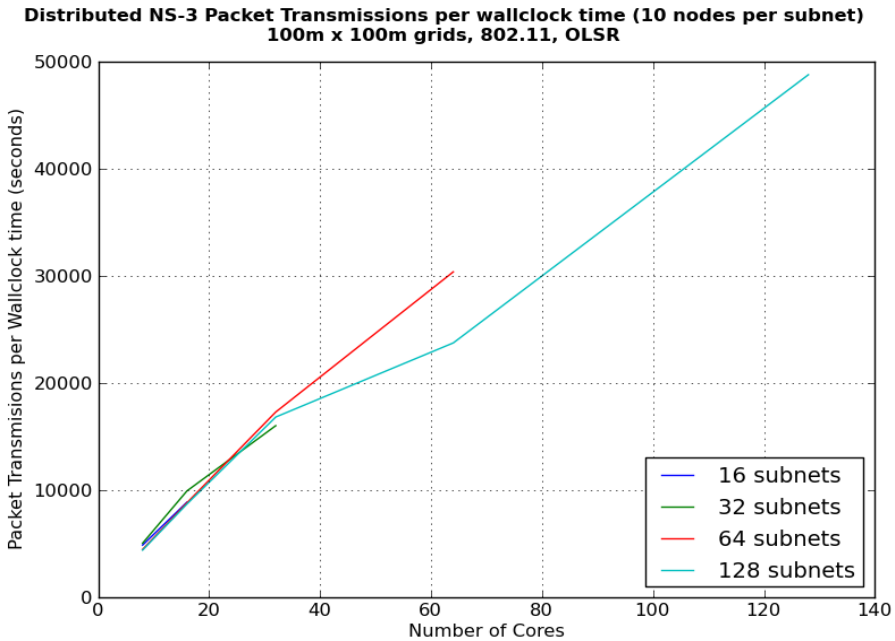
- Balance of realism and performance
  - "*Reality is complex and dynamic*" vs. "*High Performance can be unrealistic*"
- Split network into federates (1 federate per core)
  - Optimizing inter-federate latency and limiting inter-federate communication
- A "Subnet" is a collection of nodes on the same channel (802.11 or CSMA)
  - Typically a team or squad that has similar mobility profile
  - Single router in subnet that connects to WAN
- "Router-in-the-sky" that connects subnets via Point-to-Point links
- Ad-hoc 802.11 networks use OLSR routing
  - Significant processing and traffic overhead
  - Situational Awareness (SA) reported by each node to subnet router
- Random walk within bounded area

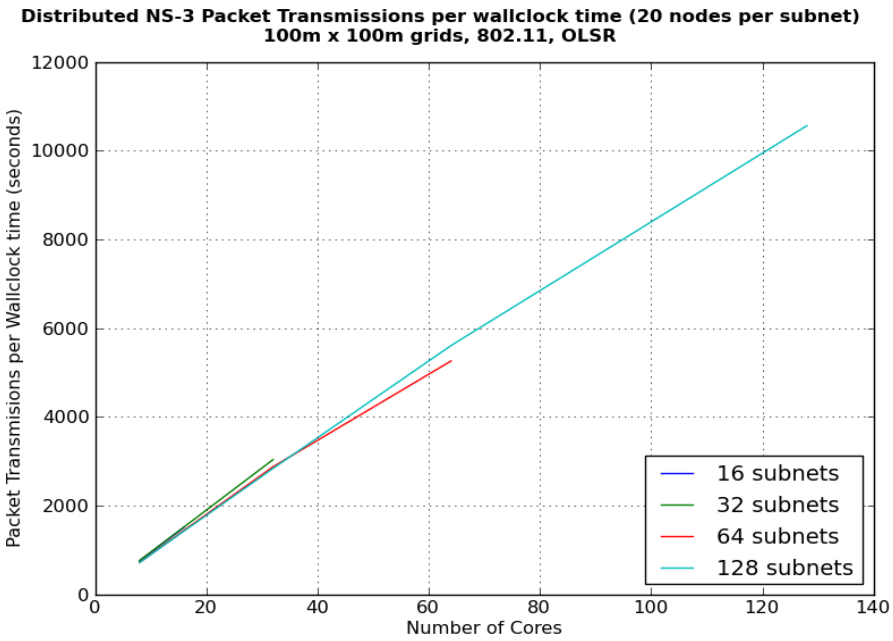




Simulator Performance with OLSR

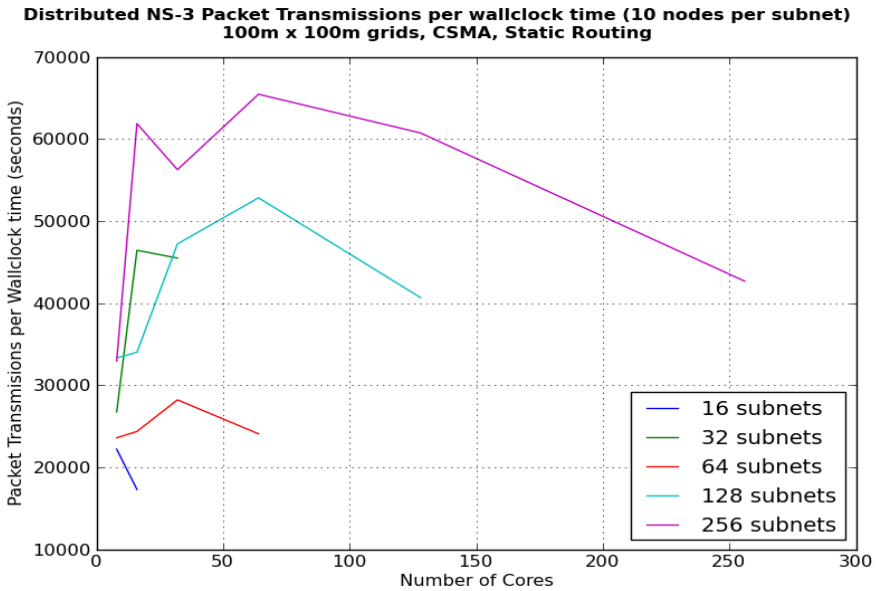
- Packet event rate (per wall-clock time) shows linear scaling versus number of cores
- Promising results assuming that wireless networks can be broken into independent federates

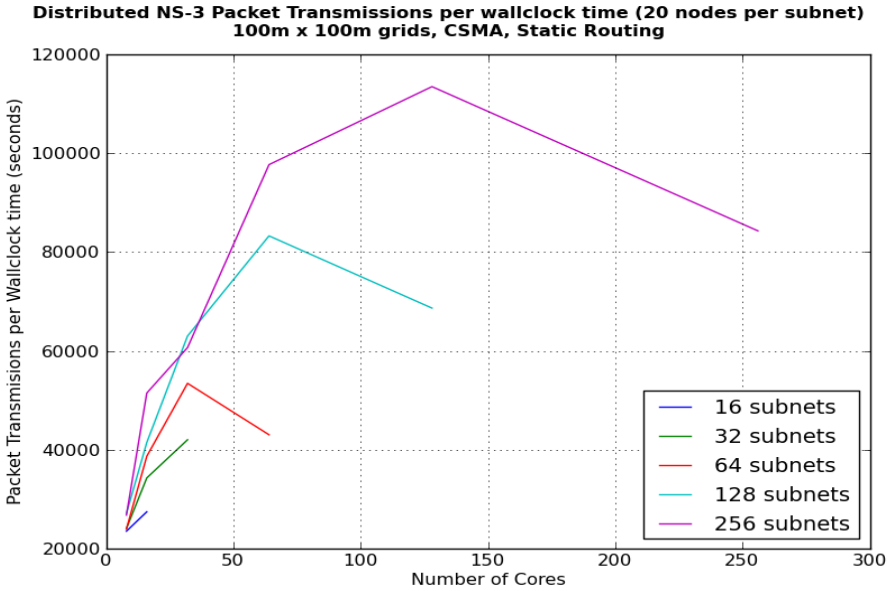




Simulator Performance without OLSR

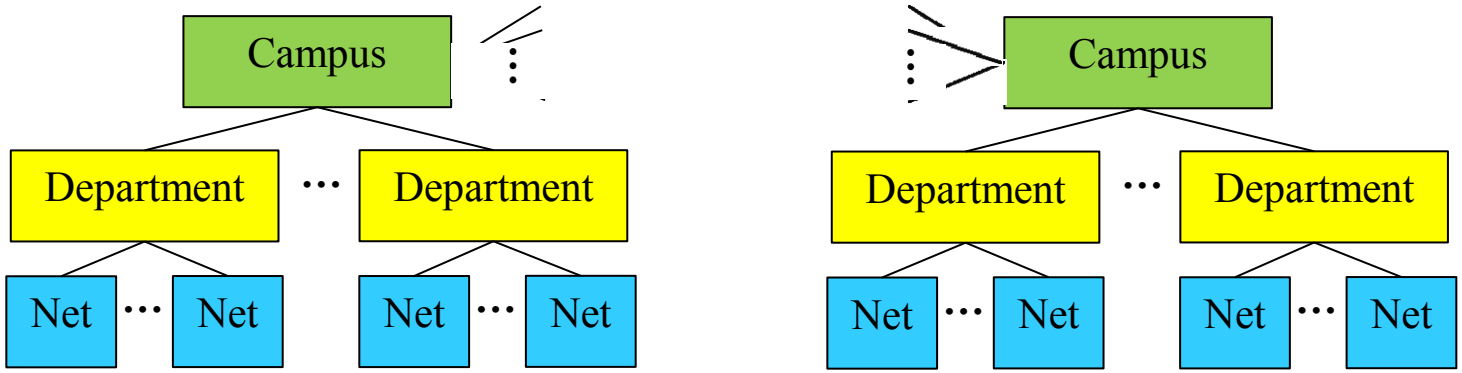
- Drop-off observed in scaling of CSMA/static routing
  - Much less work done per federate
  - Workload per grant time not enough to offset increasing time for federate synchronization [MPI_AllGather()]
- Expect to see this for large enough core counts with larger workloads (OLSR)





NS-3 Scaling Tests

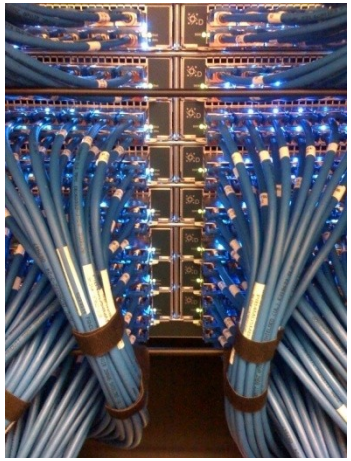
- MNMI goal is to enable scaling of MANET simulations on the order of 10^5 nodes while maintaining high fidelity protocol, traffic, and propagation models.
- Simple scaling tests with NS-3 were conducted to understand effects of distributed scheduler and MPI interconnect latencies.
  - Simple Point-to-Point and CSMA "campus" networks



- UDP packet transfer within and among campuses (campus = federate)
- Only 40% of hosts were communicating during simulation
  - 1% of those were communicating across federate boundaries
- IPv6 with static routing

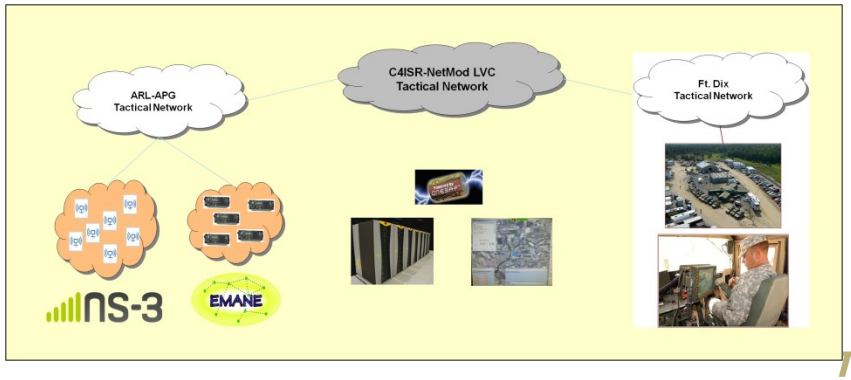
NS-3 Scaling Results

- Achieved best results limiting each compute node to a single federate
  - Each compute node has 8 cores and 18G of usable memory
- Largest run:
  - Each federate used 1 core and 17.5G on a compute node
  - 176 federates (176 compute nodes)
  - **360,448,000** simulated nodes
  - **413,704.52** packet receive events per second [wall-clock]



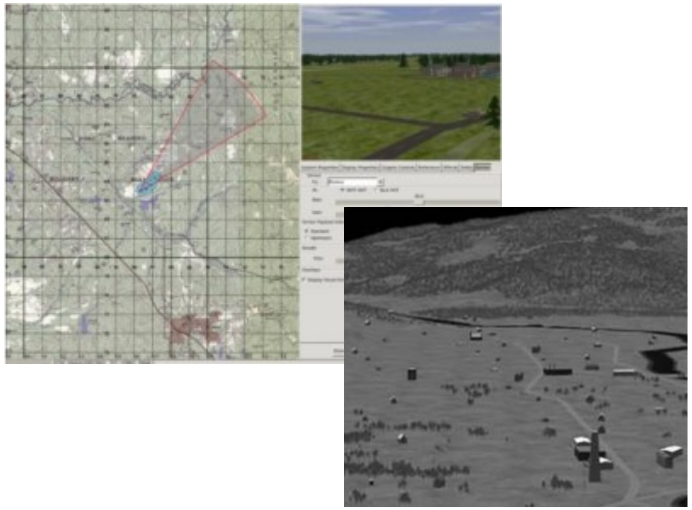
NS-3 in Experimentation

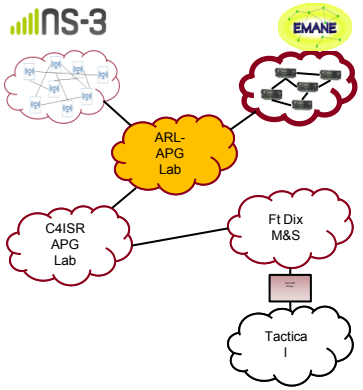
- C4ISR-Network Modernization holds annual events to test emerging tactical network technologies and their suitability for Army deployment
  - Live (20-40) and virtual (3k-10k) entities deployed at Ft. Dix, NJ conducting missions
  - Live vehicles and dismounted soldiers have access to range facilities
  - Infrastructure provided to measure network performance and connectivity
  - Virtual assets constructed in OneSAF environment interact with live assets
- Gateways connect [and optionally translate] operational messaging between live and virtual entities
- Brigade and Battalion TOCs with live C2 systems

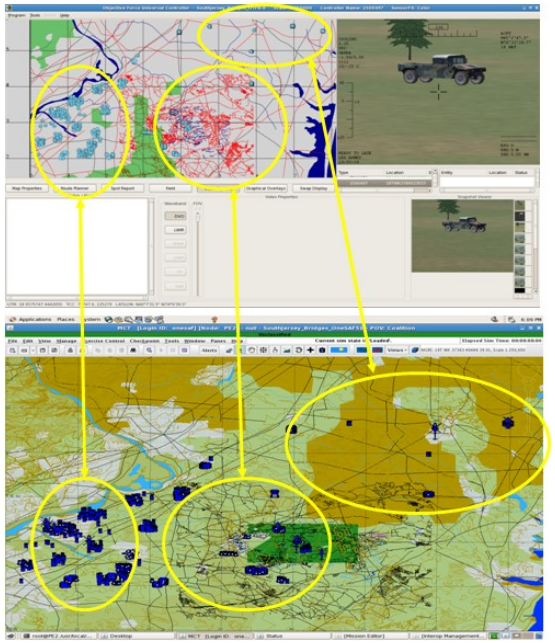


NS3 in Experimentation

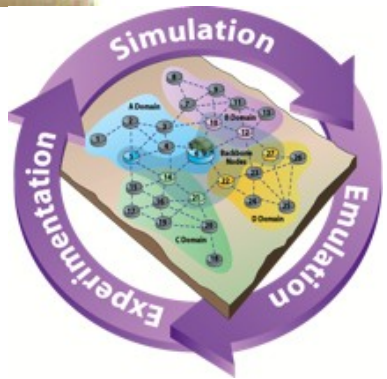
- Real-time Distributed scheduler developed for NS-3
  - Combination of real-time (best-effort) and distributed schedulers
  - MPI communication is simplified
    - Timing is only synchronized on start
    - Only packets are exchanged (w/ delay tolerance)
- DIS interface to other M&S tools
  - Forces and ISR Modeling







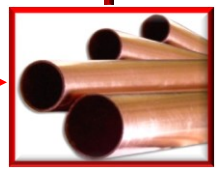
Network Interdisciplinary Computing Environment (aka "the plumbing")



Existing and New Tools

Scenario Generator

Scenario Conversion



Network Simulator
(Open Source and/or Commercial)

Visualization and Analysis

Emulation

Experiment / Testing

Existing and New Tools

NetDAAF

XML Based Interface Definitions