Integrating ns-3 Model Construction, Description, Preprocessing, Execution, and Visualization

Workshop on ns-3 WNS3 2013

Cannes, France March 5, 2013

Peter D. Barnes, Jr,

Betty B. Abelev, Eddy Banks, James M. Brase

David R. Jefferson, Sergei Nikolaev, Steve Smith, Ron A. Soltz

Lawrence Livermore National Laboratory

LLNL-PRES-622874

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Simulating Large Networks

- dB $\rightarrow$ 20k node model
- First attempt: direct export to C++
  - Multi-MB source file
  - 10's minutes to compile
- Export to XML intermediate
  - Compile-once executable
  - Seconds to parse and instantiate model

Describing a Model is Hard

- Topology, addresses
- Channels: bandwidth, latency, error rates, …
  - Environmental: noise, interference, multi-path
- Framing, access control, devices
- Packet-level protocols, congestion control, queuing discipline, buffer sizes
- Routing!
- Traffic generators/consumers (applications)
- Measurements: parameters, statistical reductions, recording intervals
- Parallelization, checkpoint/restart, dynamic load balancing
- Parameter studies

Tension Between Framework-Agnostic (Generic) vs. -Specific

- Usable by multiple frameworks
- Larger potential user/developer base
- Less tailored to any one framework
- Difficulty mapping concepts
- Implementation requires broad knowledge
- Cross-community communication issues

- Tailored to one target
- Use familiar terms
- Smaller set of use-cases
- Tighter community buy-in
- Leverage existing code base
- Smaller user/developer community
- Models not portable between frameworks

Generic ⟷ Specific Dimensions

- Concepts
  - Explicit: "NodeContainer"
  - Implicit: nodes on this CSMA
  - Tracing and output specs
- Terms
  - "NodeContainer", vs. "Network […]"
- Models
  - Does shortest path routing mean
    - OpenFlow?
    - OSPF?
    - BGP-nsc? -dce?
    - Native BGP?
    - nix-vector?
    - GOD-routing

Abstracting Models from Simulators Has Wide-Ranging Benefits

- Specificity
  - Model description not obscured (or less obscured) by implementation details
- Portability
  - Here's my model, run it in your simulator
  - Explore new model elements with limited availability
- Comparison of simulation frameworks
  - Portable performance benchmark models
  - Cross-validation of results

Non-Simulation Benefits

- Enable multiple visualization options
  - Write visualizer once, use with many simulators
- Portable model generators
  - Graphs, RocketFuel, CAIDA, …
  - Generate standard model file readable by all simulators
  - (Instead of porting the generator to all simulators)
- Standardized parallelization tools
  - Partitioning, weighting

Various Approaches to Model Specification

- Source code
  - ns, ns-2, ns-3, ROSSNet
- Private text formats
  - ~INI file: SSFNet, REAL, …
  - XML: NEDL/NSTL, EMANE, NetDMF/XDMF
  - Other: QualNet
- Private languages
  - OmNet++ NED
- Proprietary, binary
  - OpNet

Prior Work Abundant – Notable Features – I

- Disclaimer: errors are my own
- OpNet
  - GUI-driven, proprietary binary file format
- SSFNet
  - Extensible grammar,
  - Elements of inheritance, composability and reuse
- OmNet++
  - NED-grammar compiles to C++,
  - Run-time configurable elements
  - Visualizer annotations included

Prior Work
Notable Features – II

- eMANE
  - Well-defined XML schemas
    <name, value> pairs
    Limited inheritance for alternate parameter values
- NetDMF/XDMF
  - Automatic conversion between light data (directly in XML) and heavy data (external dB, HDF5)
  - <name, value> pairs
  - Need translators to each target environment (simulation, emulation)
- ns-3
  - NEDL/NSTL – parametrized and templated models, predefined by instructor
  - ns3xml – moderately detailed grammar, somewhat rigid implementation, mixes visualization with model

Desirable Feature Highlights – Grammar

- (See the paper for a more complete list)
- Complete
  - Capture entire model in a unified grammar, in a single file
  - Including measurement points and reductions
- Validated
  - Against the fully specified grammar
- Canonical
  - Transform to canonical form, enables model comparison/differencing

Desirable Feature Highlights – Implementation

- Leverage common libraries to ease parser construction
- Modular grammar
  - Ease creation of XSD and parser for new model elements
  - <name, value> generics for elements without XSD
- Support external configurations
  - Protocol/device configuration files
  - Virtual machines

Desirable Feature Highlights – User Interaction

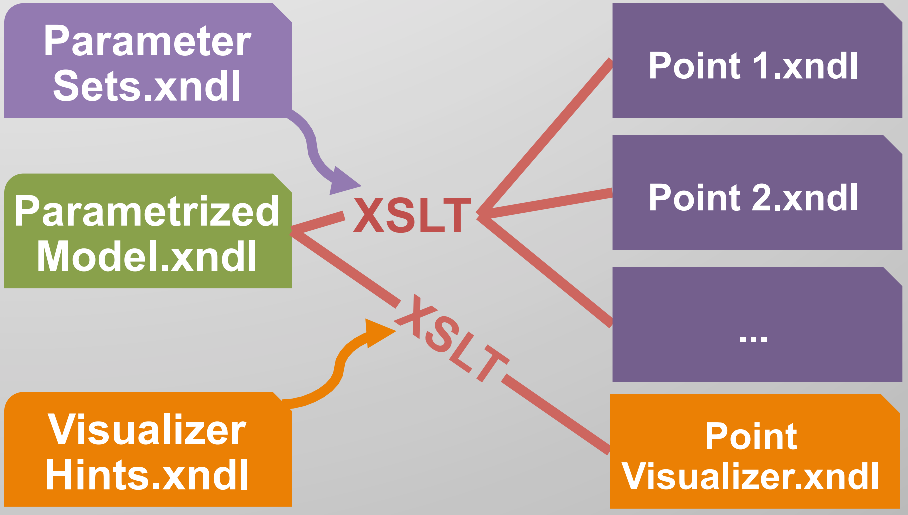
- Recognizable grammar, human and machine readable
- Composable/hierarchical/parameterized
  - Reuse: models can be incorporated as sub-elements in larger models
  - With parameter substitution (base addresses,…)
- Specialization
  - Explicit control of generic $\rightarrow$ specific

XML Network Description Language (XNDL) Design Goals

- XML, with complete XSD grammar
- Familiar networking terms
- Compact
- Simplify with reuse
- Separate model from meta-data
- Simulator-agnostic tools
- Use XSLT to transform

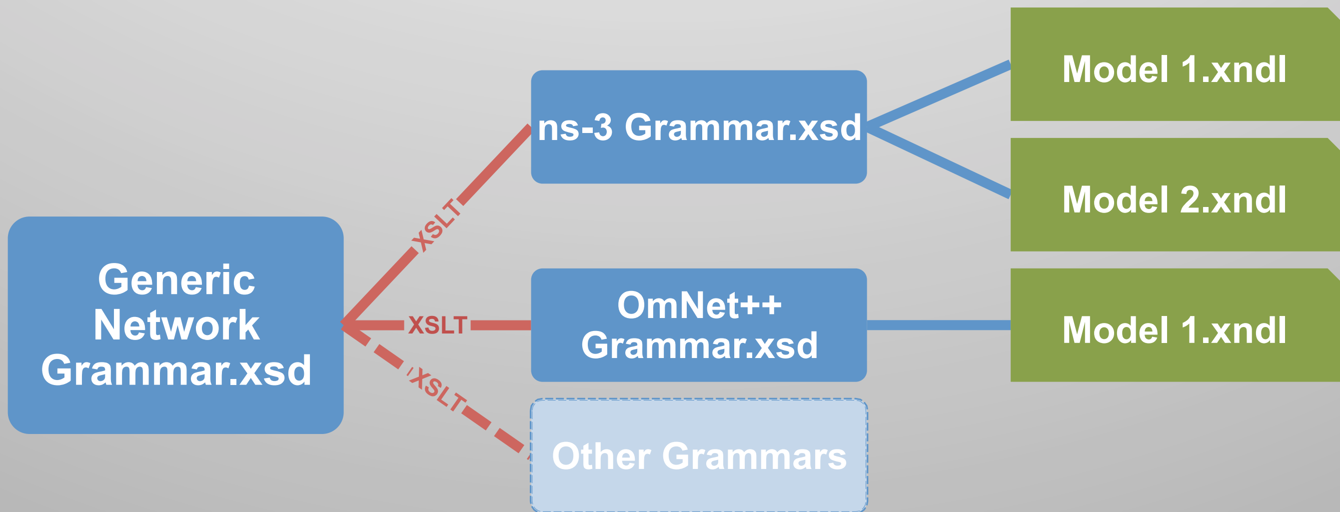
Examples: Parameter Study, Visualizer

- Start with fully-specified model
- Use XSLT to apply specific parameters, generating test points
- Mix-in visualizer hints

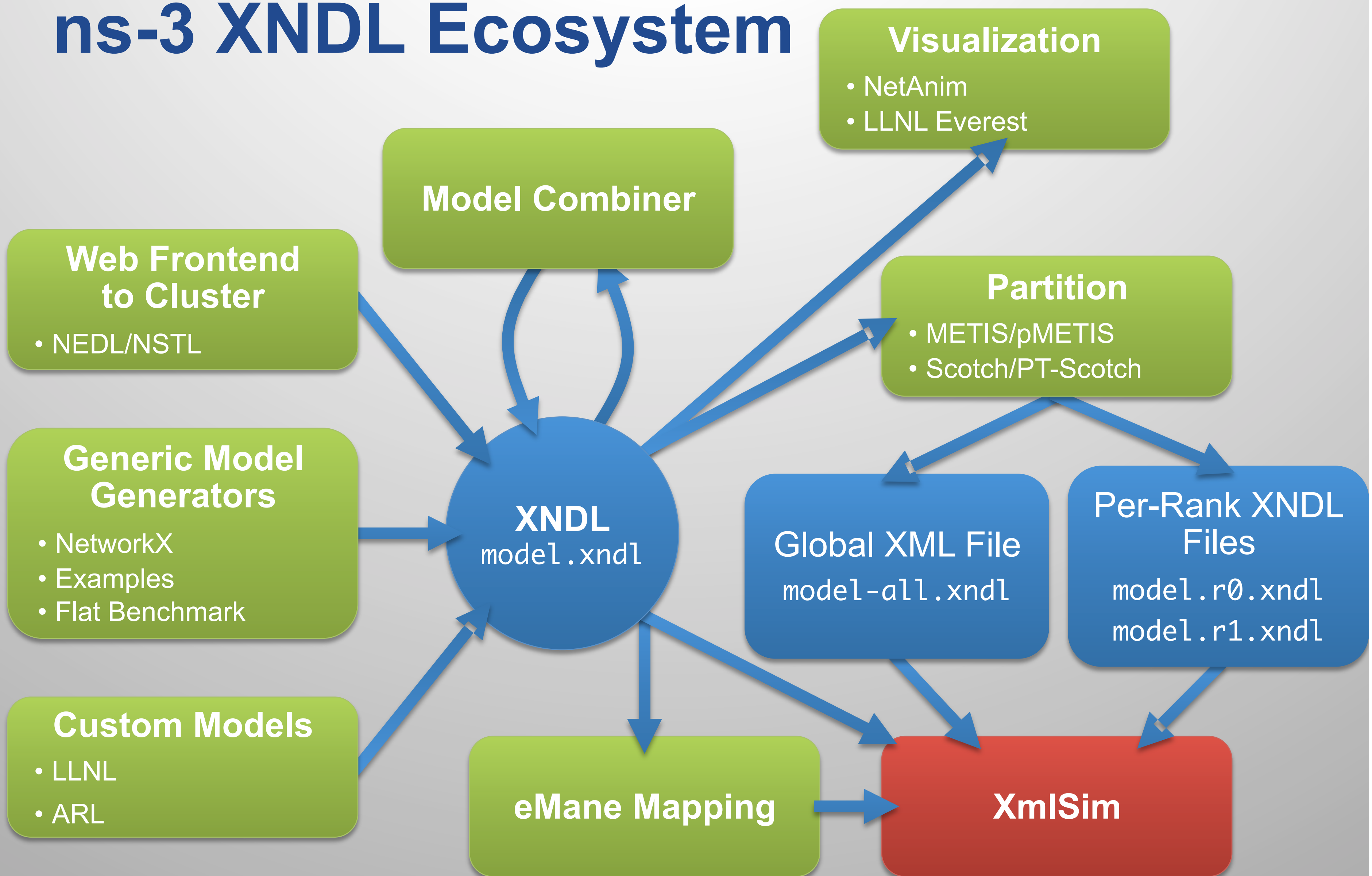


Model Portability

- Use XSLT to transform between generic and specific grammars
  - Element interpretation explicit, under modeler's control



ns-3 XNDL Ecosystem



Compile Once XmlSim (entire ns-3 source file)

```
#include "ns3.h"

int main(int argc, char **argv) {
   std::string xmlFileName;

   CommandLine cmd;
   cmd.AddValue ("xmlFileName", "Path to XML file", xmlFileName);
   cmd.Parse (argc, argv);

   XMLSimulation simulation (xmlFileName);

   simulation.Run();
   simulation.Report(std::cout);

   return 0;
}
```

XNDL
XML Preamble

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<!--Simulation XML file-->
<XNDL
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:noNamespaceSchemaLocation="XNDL.xsd"
  SchemaVersion="1.0"

  <!-- Model name -->
  Name="Campus Network v2.9"

  <!-- Anything can have a description -->
  <Description>
    This model describes ...
  </Description>

  <!-- Global attributes -->
  CsmaEnableAsciiTraceAll ="false"
  CsmaEnablePcapAll       ="false"
  P2pEnableAsciiTraceAll  ="false"
  P2pEnablePcapAll        ="false"

  <!-- Override on command line -->
  RandomSeed = …
>
```

XNDL
Ref: Inheritance/Reuse

```
<!-- CSMA channel template -->
<Subnet Name="csma"
  DataRate="100Mbps"
  Delay="1ms" >
</>

<Subnet Name="Building 1-3rd Floor"

  <!-- Reuse the "csma" parameters defined above -->
  Ref="csma"

  <!-- But change this parameter -->
  Delay="2ms"

  <!-- Add new nodes to the model -->
  Size=20

  <!-- Automatic parameter assignment where reasonable -->
  Cidr="10.12.133.64/27"

/>
```

XNDL
Ref and Index

```
<Subnet Name="Building 1–Building 2"

  <!-- Use the previously specified point-to-point parameters -->
  Ref="p2p"
>

  <!– Install P2P on nodes instantiated elsewhere -->
  <Node Ref="Building 1-3rd Floor"
    Index=3

    <!-- Explicit address assignment -->
    IPv4="192.10.1.40"
    DNS="rtr-b1-f3-00"
  />

  ...

</Subnet>
```

XNDL Applications

```
<Application Name="Admin-browser"
  Type="OnOffApplication">
  <Parameters
    DataRate=100000
    OnTime=2
    OffTime=20
  />
</Application>

<Application Name="Admin-email" ... />

<ApplicationSet Name="Admin">
  <Application name="Admin-browser" />
  <Application name="Admin-email" />
</ApplicationSet>

<Subnet Name="Front Office" />

  <!- Install these apps randomly to 80% of the nodes -->
  <ApplicationSet Ref="Admin" Percentage="80"/>

</Subnet>
```

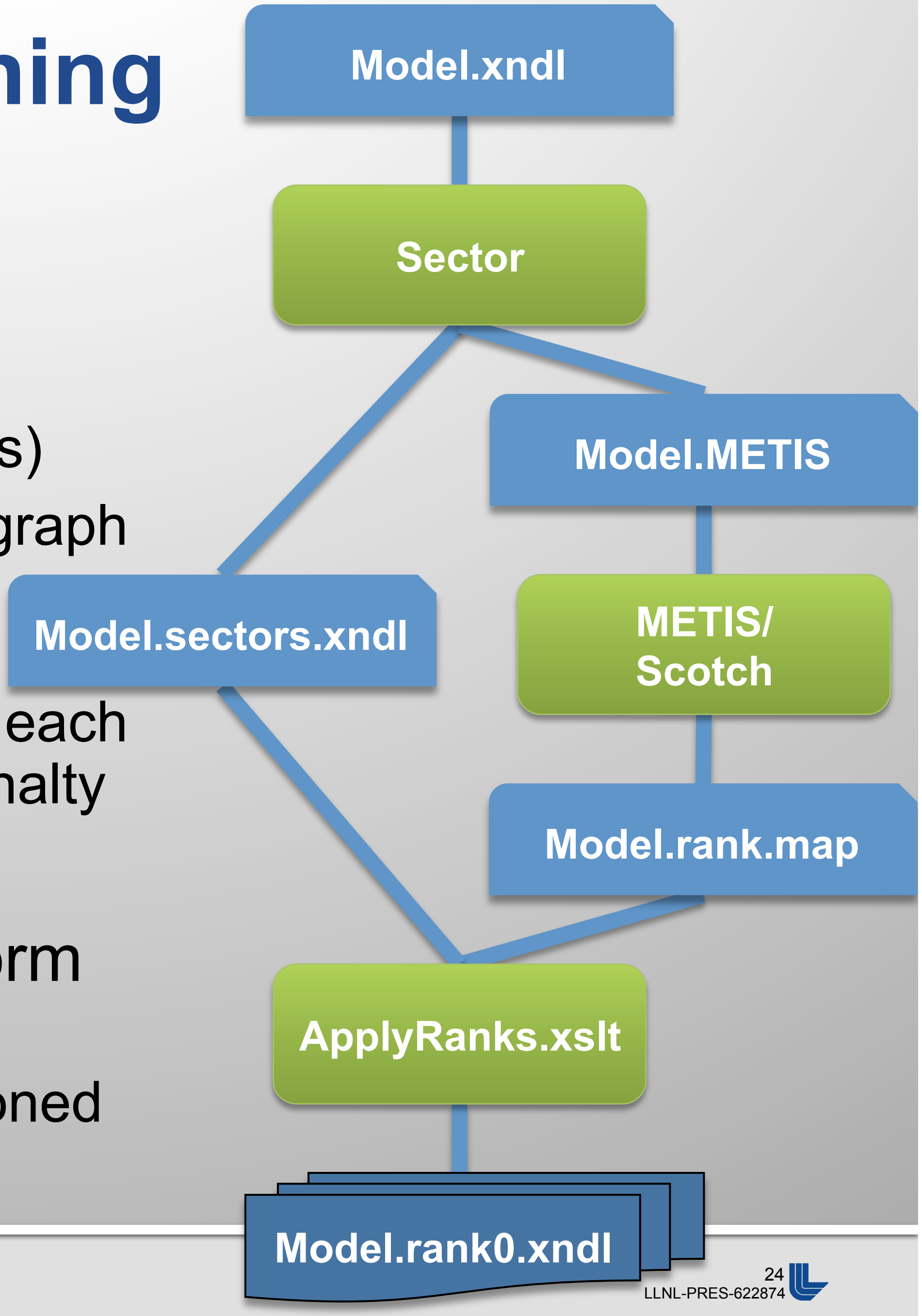
XNDL
Generic Applications

```
<Application Name="GenericOnOffTest”
  Type="GenericApp">
  <Parameters

    <!-- ns-3 TypeId -->
    Type="ns3::OnOffApplication"

    <!-- Base class parameters -->
    Start="2.0" Stop="20.0">

    <!-- Name, value attritbutes -->
    <Attribute Name="DataRate"   Value="500bps"/>
    <Attribute Name="PacketSize" Value="50"/>
    <Attribute Name="Remote"     Value="03-06-0a:01:03:0f:50:00"/>
</Application>
```

- Uses ns-3 Type and Attribute systems
  - Create the object from a factory, obtaining the c’tor from `TypeId::LookupByName ()`
  - Configure attributes from <name, value> pairs
  - ➢ Assumes (as does ns-3) that attributes are representable as strings

Automatic Partitioning Process

- Sector tool
  - Labels unpartitionable regions (*e.g.* CSMA channels)
  - Generates weighted sector graph
- METIS (or Scotch)
  - Selects rank assignment for each sector, minimizing global penalty function
- ApplyRanks XSLT transform
  - Apply METIS assignments, generating (per-rank) partitioned model file(s)



Automatic Partitioning Advantages

- Sector labeling performed once
- Simplifies exploration of different partitioners, weighting
  - Rerun partitioning step with different arguments
- ApplyRanks can produce
  - A single .xndl model file
  - An .xndl file per rank, or group of ranks (expected to improve parallel I/O for very large models)
- XSLT preprocess step to improve parallel performance
  - Replace 2-node CSMA with P2P (correcting bitrate for duplex → simplex)
  - Refactor high-centrality routers as partitionable cliques

Limitations

- Is one .xndl the complete model? – NO!
- Some things obviously should be included by reference:
  - VM images
  - Models with well-established (real-world) external configuration schemes
    - Quagga BGP, …
- Gray areas
  - Phenomenological probability distributions

Still To-Do

- Complete coverage of ns-3 models
  - Wireless
  - Position, mobility
  - Buildings, antenna
  - Support Tracing and output
- Output .xndl at `Simulator::Run ()`
- Support for NetAnim uses

Lawrence Livermore National Laboratory