Tutorial: Working with ns-3 on the POWDER testbed

Tom Henderson
Alicia Esquivel (Univ. of Missouri)

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ICE-T: RC: Performance Evaluation of Advanced Wireless Network Edge Infrastructure - Network Simulation & Testbeds

Motivation

- A significant amount of 5G/nextG research investment has been directed towards the construction of large-scale, virtually-accessible wireless testbeds
  - NSF **Platforms for Advanced Wireless Research (PAWR)** coordinates a $100 million public-private partnership with emerging deployments in several U.S. cities
- With industry involvement and U.S. National Science Foundation support, the **ns-3 discrete-event network simulator** is developing 5G NR and advanced 802.11 models, and use is growing in industry and government labs

What synergies may exist between these tools?

Placeholder

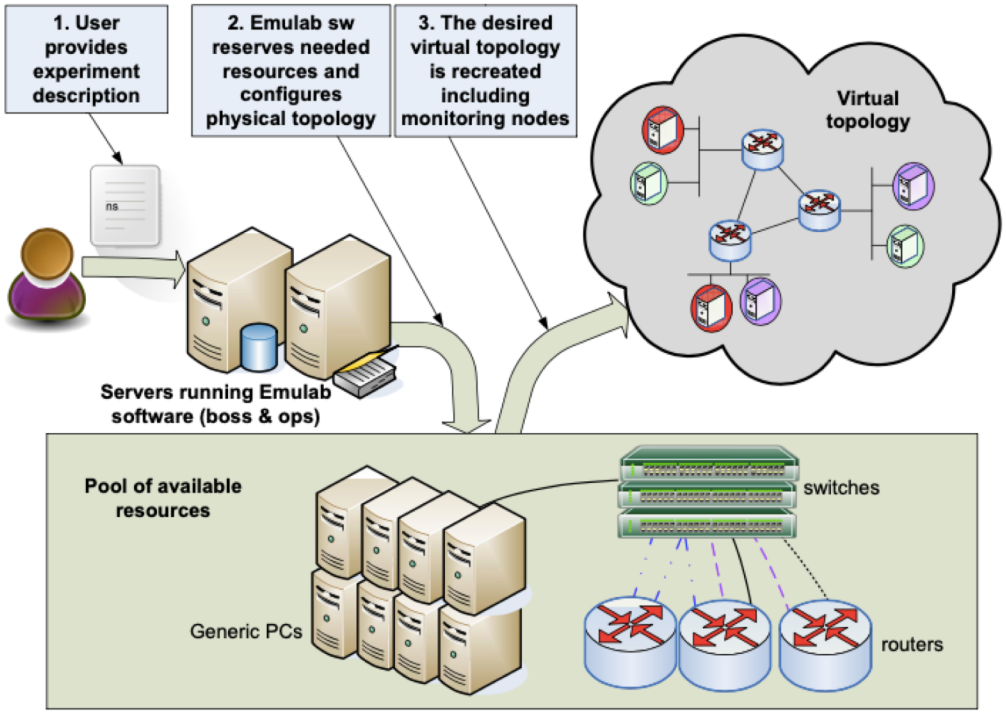
> Visit some PAWR websites

Tutorial outline

- Introduction to POWDER testbed
  - Accounts, projects, profiles, images, experiments
    - The ‘ns-3-users’ project is newly created
  - Remote access to testbed machines
  - RF emulation and over-the-air LTE experiments (srsLTE handover)
- ns-3 relationship to POWDER
  - Hybrid ns-3/POWDER experiments (Univ. of Missouri)
  - POWDER trace data for ns-3 models
  - Reproducible experiments (SCE-L4S bakeoff) and ns-3 approximations (l4s-evaluation)
  - Emulation and ns-3 model validation (e.g. TCP performance using offload engines could be characterized on a testbed)

Shared wireless testbed architecture

- Shared testbeds generally include a **collection of SDRs** or other radios, paired with **general compute nodes**, on which Linux containers co-reside, interconnected by a **backhaul network**.
- Other common components include **cloud compute**, **cloud storage,** and an **orchestration software framework** providing a Web portal to users.



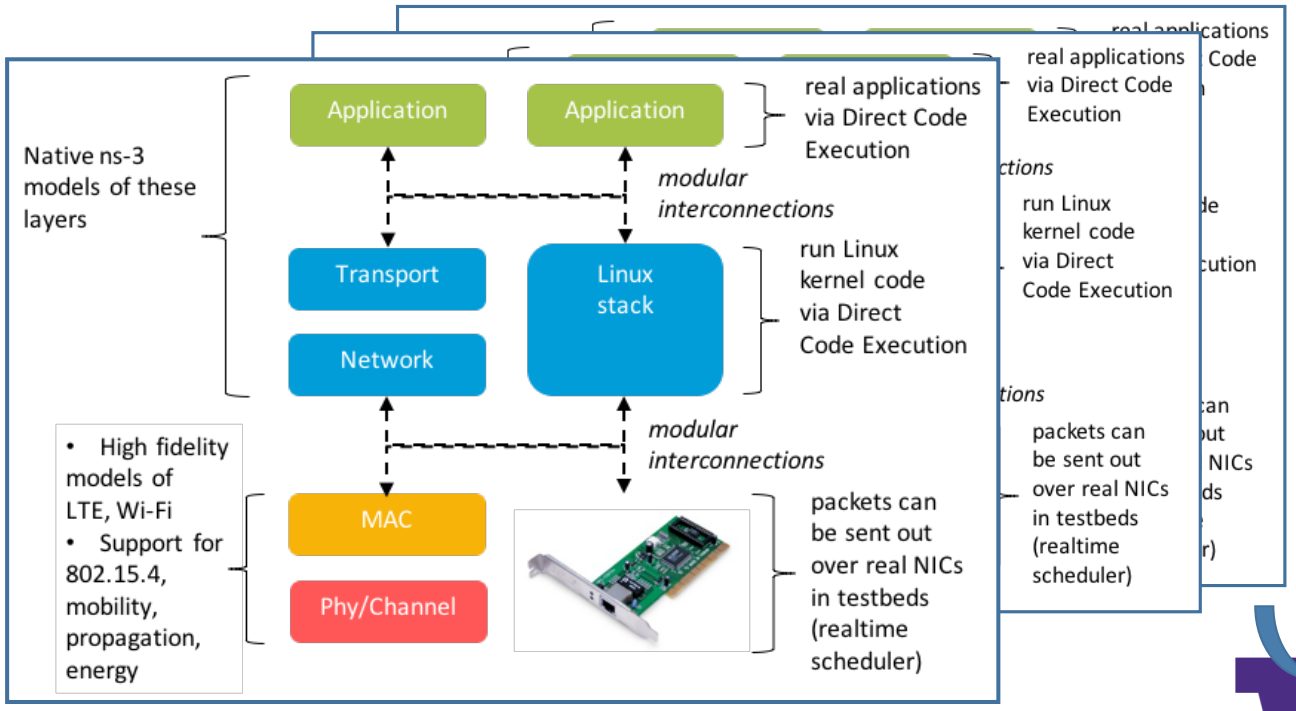
Depiction of Univ. of Utah EMULAB system, one framework from which POWDER derives

Figure source: Christos Siaterlis et al., On the Use of Emulab Testbeds for Scientifically Rigorous Experiments

ns-3 overview

> An open source, **packet-level network simulator** oriented towards network research, featuring a **high-performance core** enabling **parallelization across a cluster** (for large scenarios), **ability to run real code**, and **interaction with testbeds**

Runs on a single machine



or partitioned across a cluster

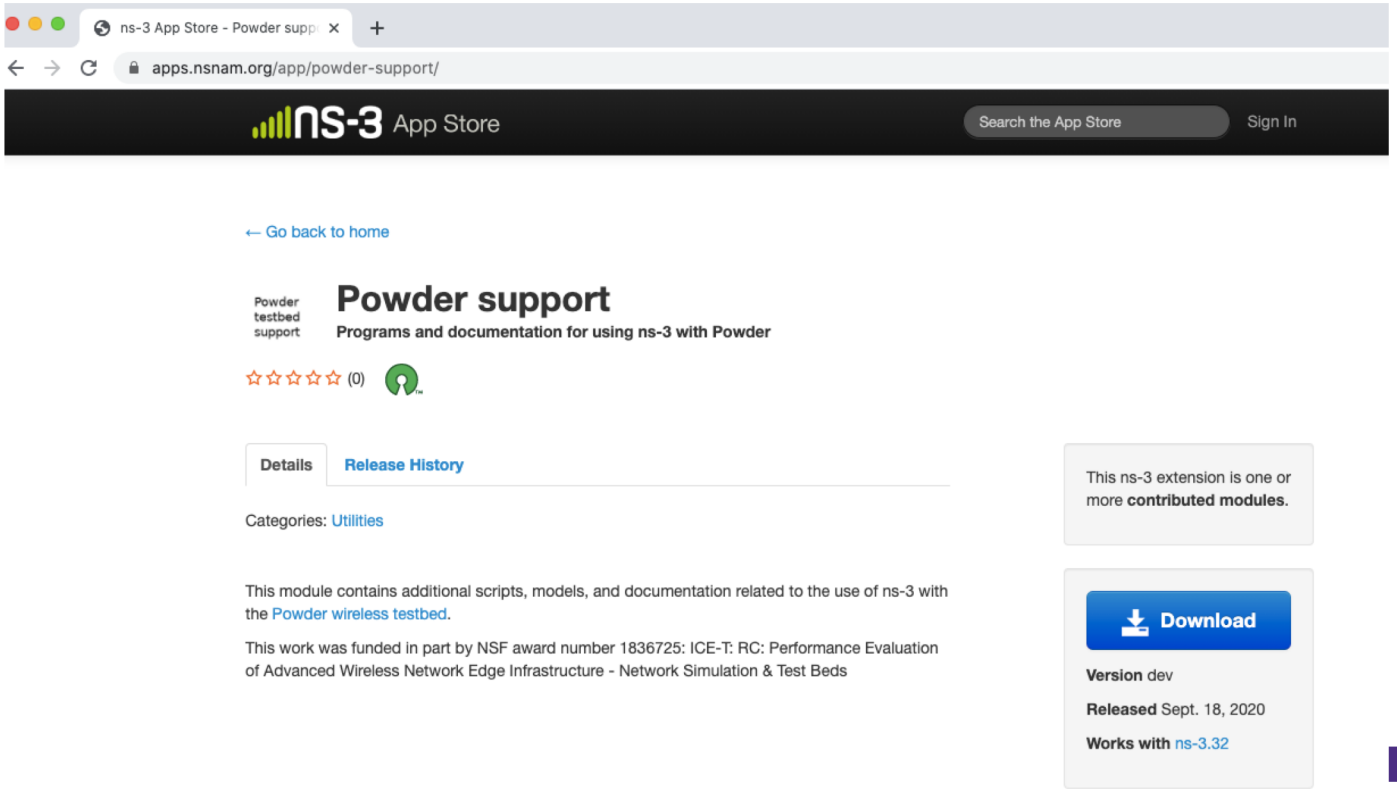
Current level of integration

A user who wanted to use PAWR and ns-3 (either for the same project, or for different research projects) would currently experience the following challenges:

- configuration APIs for devices and simulation models are completely different
- terminology is different
- scripting languages are different
- output data formats are different
- experiment control (orchestration) frameworks have been developed independently
- no documentation available on how to use one tool in the context of the other

Powder-support app on ns-3 App Store

- https://apps.nsnam.org
  - Documentation and example code (under development)



Outline

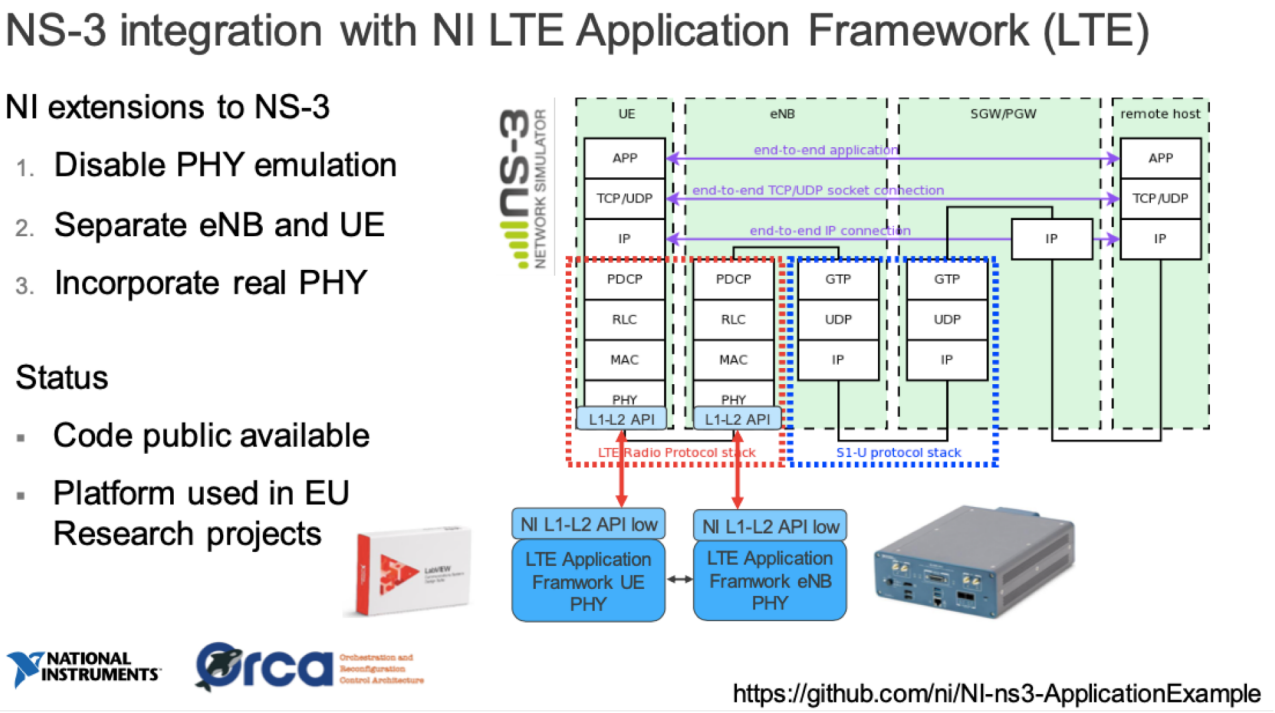
- Getting started (POWDER)
- Single node
- Two node emulation
  - fd-emu-send.cc and scripts
- srsLTE handover example
- Hybrid experiment
- Larger scripted experiment
  - NYU wireless SCE L4S Bakeoff
- POWDER data in ns-3 models

Note: we ran out of time for this example; will provide future Documentation on it

Possible hybrid approaches

Use ns-3 and PAWR testbed simultaneously to create a hybrid environment (with ns-3 running in real-time)

1. Example SDR integration: the NI LTE ns-3 integration



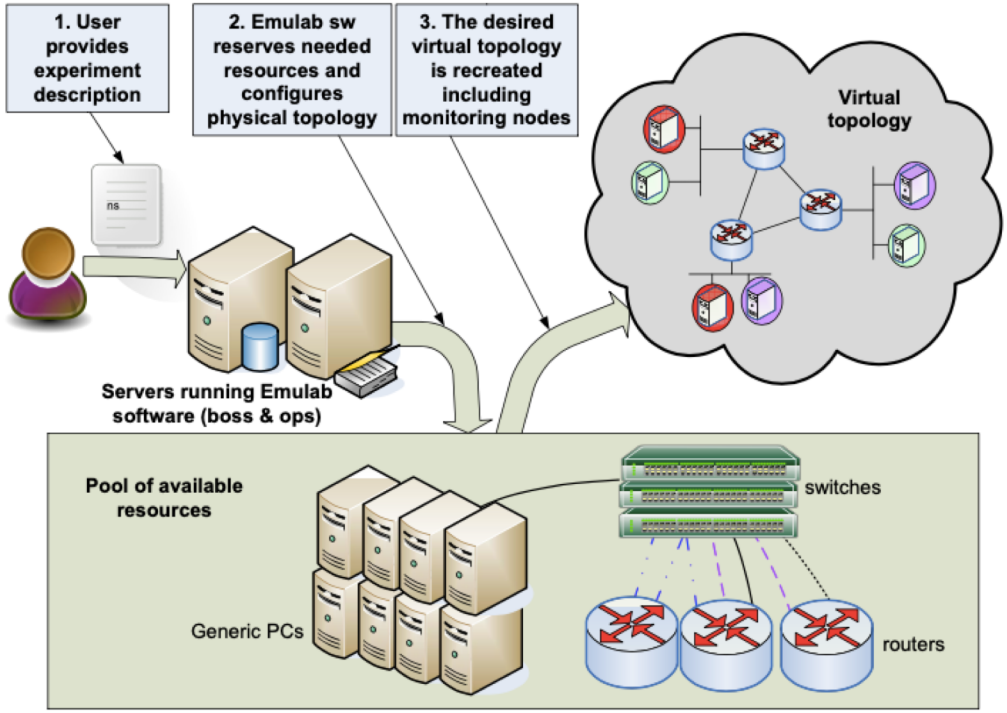
Not pictured: control-plane orchestration to coordinate SDRs and ns-3

Figure source: Clemens Felber, Prototyping wireless systems with NI SDR and open source stacks

Possible hybrid approaches (cont.)

Use ns-3 and PAWR testbed simultaneously to create a hybrid environment (with ns-3 running in real-time)

2. ns-3 could provide the virtual topology depicted in the below figure (e.g. a virtual future RF-based topology)



ns-3 implements interoperable models of TCP/IP, with standards-compliant packet formats, emulation interfaces, and a real-time simulation scheduler

Figure source: Christos Siaterlis et al., On the Use of Emulab Testbeds for Scientifically Rigorous Experiments

Discussion

ns-3/SDR integration as depicted in the first option is challenging because ns-3 is not primarily designed as a real-time emulator

- **Challenges:** Tends to work only for lower data rate use cases, or systems where low-latency coordination between MAC and PHY is not needed. Significant software development and maintenance is required, but for uncertain use cases/user demand.
- National Instruments already supports this capability (LTE only) for users who may want it
- Raytheon/BBN announced a similar capability at GNU Radio Conference in September 2020

SDR-based emulation is not a focus of our effort

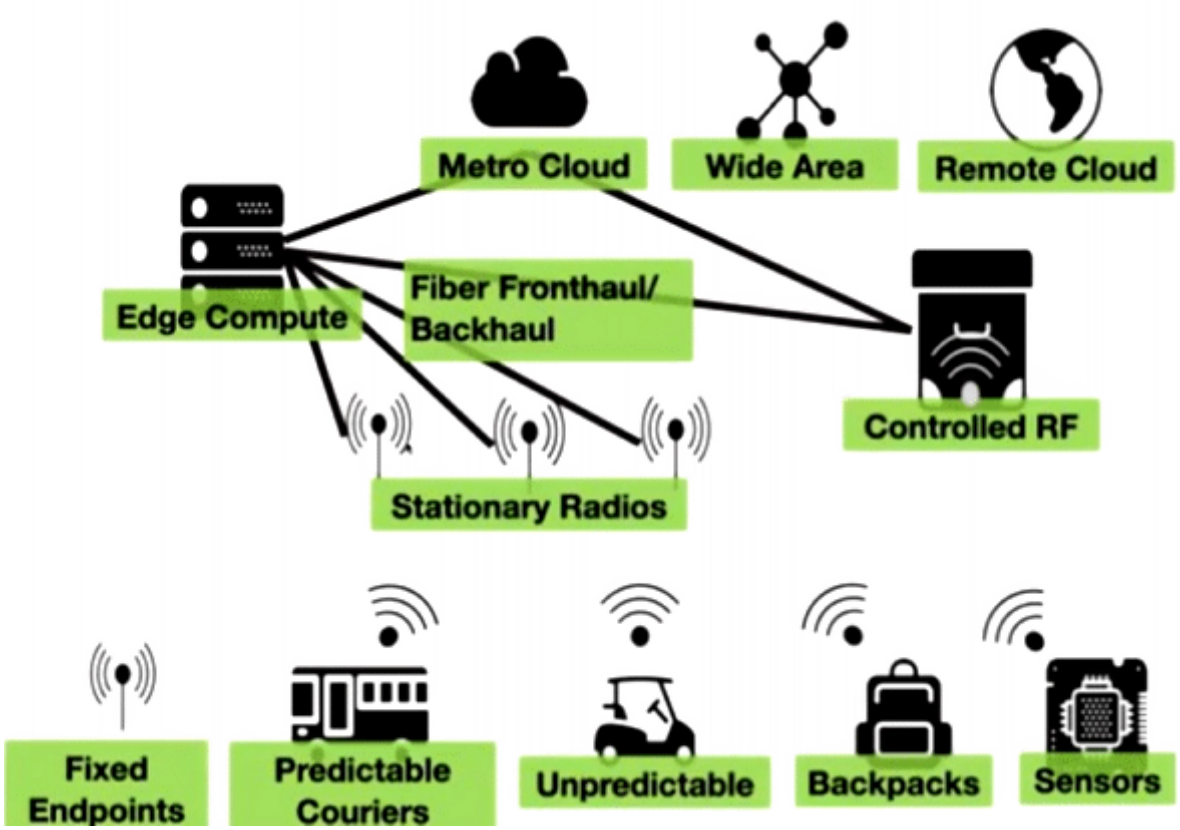
Univ. of Missouri Powder REU experiment

Experiencing integration of ns-3 and Powder

Core

Edge

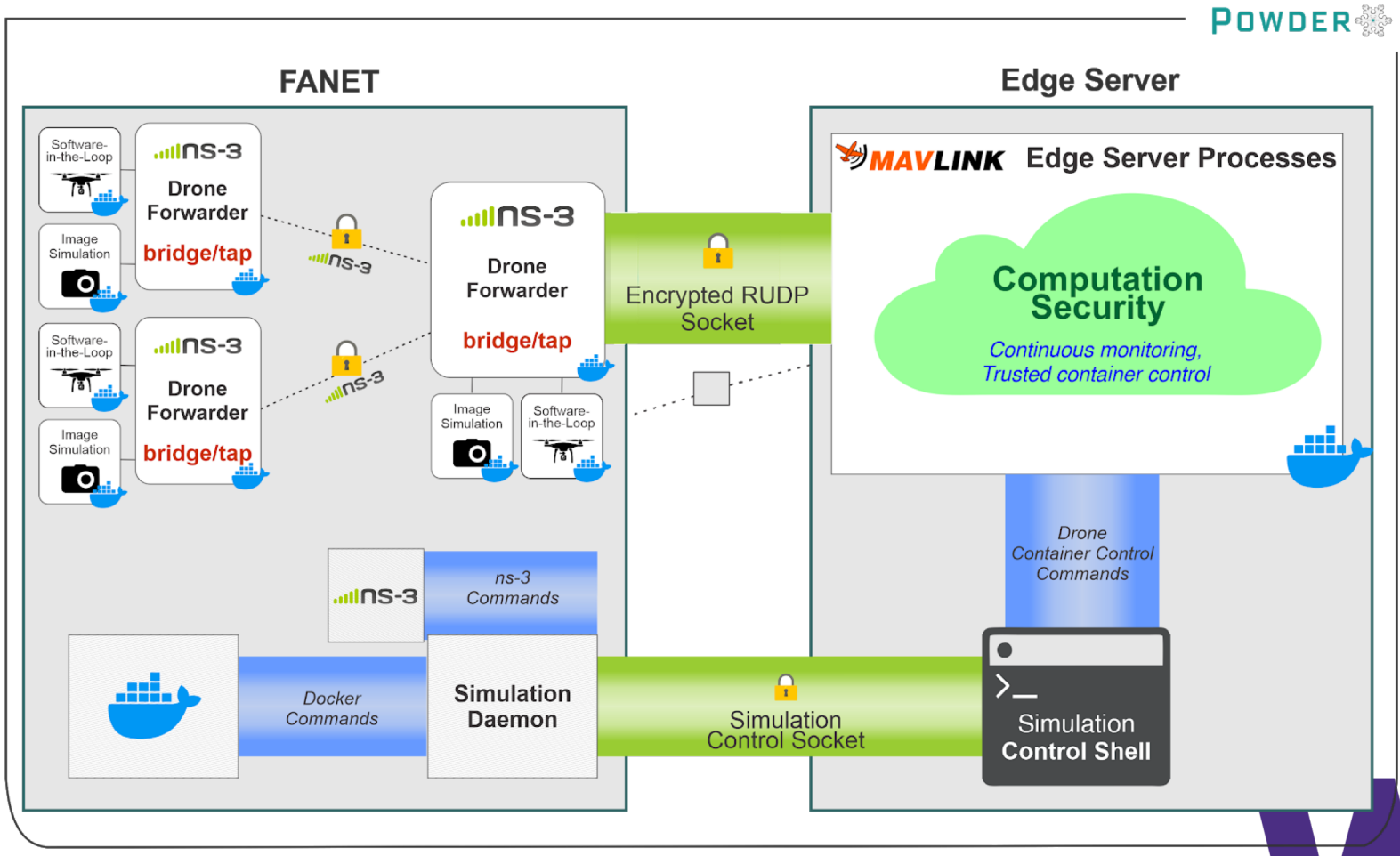
Radio Access



Slide adapted from paper https://www.flux.utah.edu/paper/breen-wintech20 and video presentations https://powderwireless.net/videos

Univ. of Missouri Powder REU experiment (Cont.)

> What we have done:



Univ. of Missouri Powder REU experiment (Cont.)

> Hybrid Testbed for Network-edge Connectivity Security

- End-to-end secure **hybrid testbed**, along with **FANET network simulation on ns-3** side together with **emulation of edge resources on allocated real nodes on POWDER.**
- Flexible setup that can use virtually any number of drones
- Drone forwarders from Software in the Loop (SITL) simulators
- Standalone image/camera simulator
- Encrypted RUDP socket using ChaCha20 cipher suite

Univ. of Missouri Powder REU experiment (Cont.)

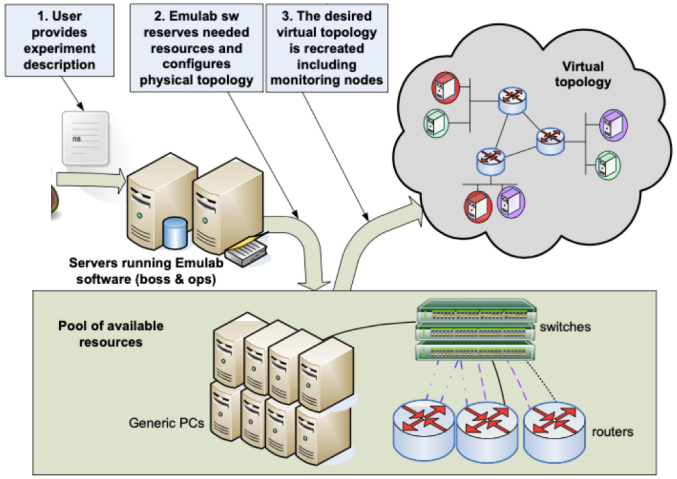
- Future research opportunities
  - Further **development of the hybrid implementation**, different use cases and integration with other drone simulators.
  - **Security aspects in end-to-end mobile network**, other attack vectors, security in wireless environments, intrusion detection systems, etc.

- Help us answer questions such as:
  - How wireless edge resources can be used in drone-to-ground computation offloading decisions considering dynamic QoS conditions?
  - How wireless channel conditions in air-to-air as well as air-to-ground links can impact transport protocol performance and video quality?

General goals

> Align ns-3 models and workflows with PAWR equivalents, to allow users to migrate more easily between two environments

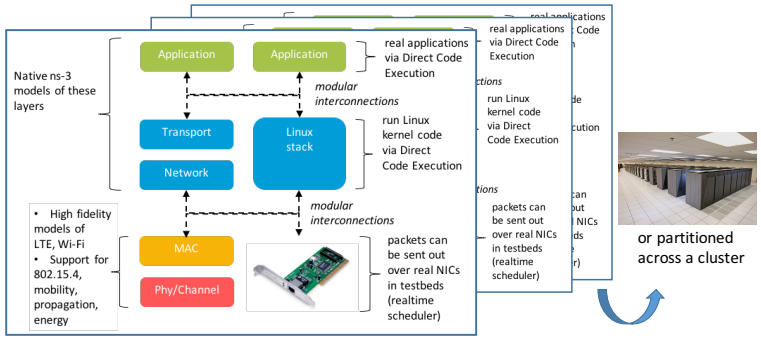
user may conduct some testbed expts.



Testbed

provide similar software/documentation support to allow user to more easily instantiate ns-3-based experiments related to PAWR

Runs on a single machine

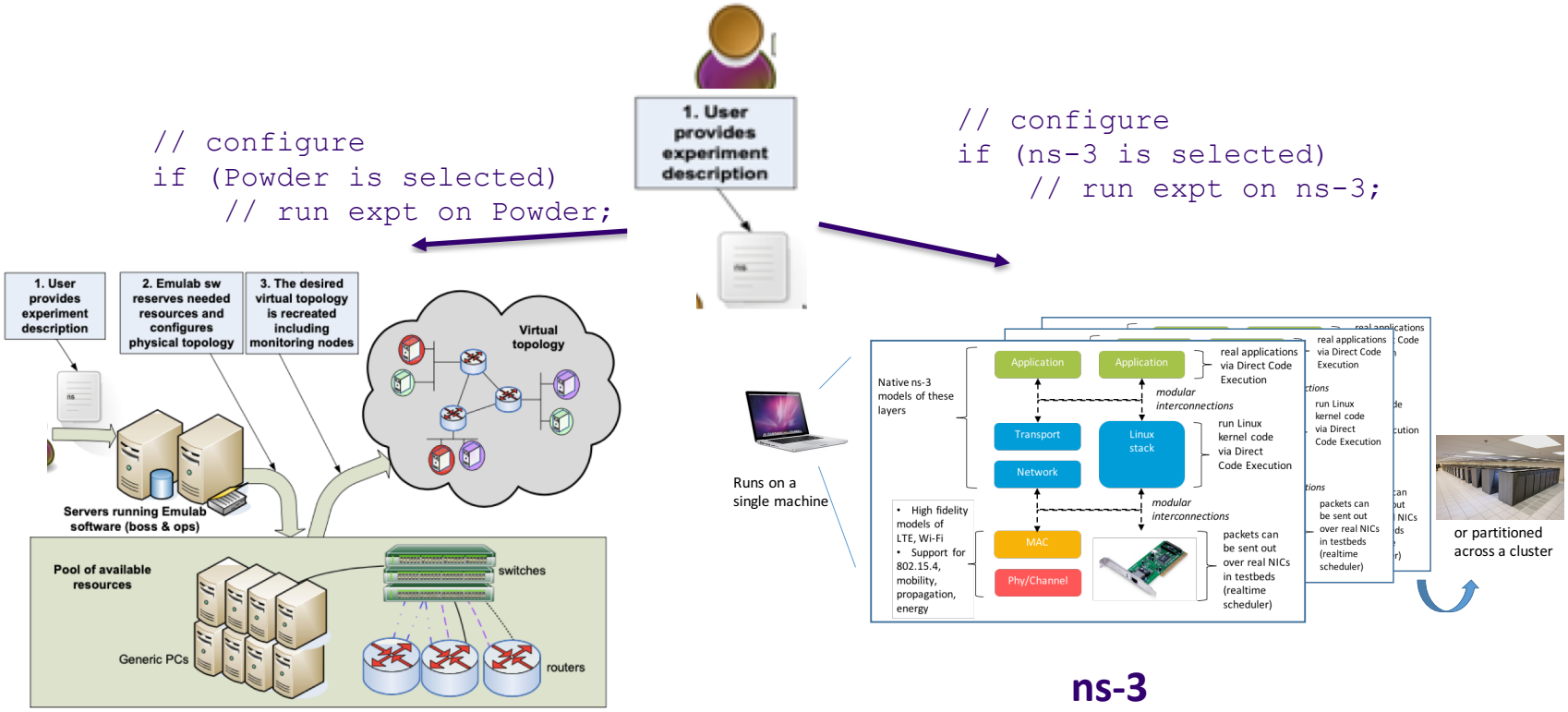


ns-3

Distill experimental traces into ns-3 trace-based models

Related work

> What about developing an abstraction so that a common experimental definition could drive both environments?



Discussion

- Common configuration driving both testbeds and ns-3 was attempted in the Inria NEPI project
  - ns-3 and PlanetLab/OneLab unification (Alina Quereilhac et al., NEPI: An integration framework for Network Experimentation , In Proceedings of the 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), 2011)
  - **Challenges:** Hard to develop and maintain; the API differences and simulation model vs. device capabilities are hard to overcome, leading to very constrained applicability

RF measurements deriving path loss exponent

- Prof. Neal Patwari has supervised a summer REU project aimed at empirically measuring the RF path loss exponent in the CBRS band (3.6 GHz) using 8 rooftop nodes
  - Could be used as the basis to explore diurnal or seasonal environment changes
- Experiment not automated but a GitHub repository contains utility scripts and methodology description
- The derived path loss exponent could then be used in an ns-3 program (LogDistancePathLossModel) if desired

This is a simple example of how POWDER data could be reused in ns-3 models

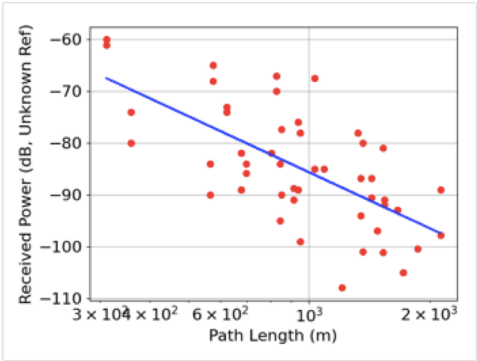
Overview

> Description and link to repository available at: https://powderwireless.net/use

RF monitoring//Radio Channel Measurement and Modeling

Powder is capable of being used in large-scale repeatable channel measurement studies. In addition to being frequency-agile, the Powder platform has a large number of endpoints, both at rooftop height and at endpoint height. These can be reserved for use in a large channel measurement study, and can be repeatedly used to measure the same exact network in different weather / seasons, interference, and time-of-day conditions.

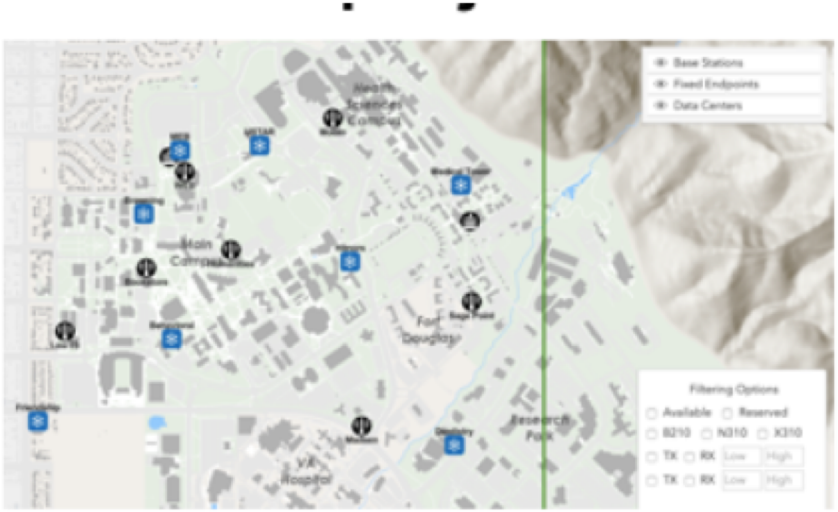
As an example, we use eight rooftop CBRS nodes, that is, the NI X310 on each rooftop node. We run an experiment as described at PathLossMeasurement.md. We use one rooftop node at a time as a transmitter, and measured received power within the other seven; then repeat with the next node as transmitter, and repeat until all 7*8 links are measured. We determine from that the measurements fit the path loss exponent model with an exponent of 3.6, that is, that the power decays proportionally to $d^{-3.6}$, where d is the path length. Such path loss models are useful for cellular deployment planning. Improvements in path loss models can aid in automated development of better deployment plans, which then ensure sufficient SINR across a cellular network.



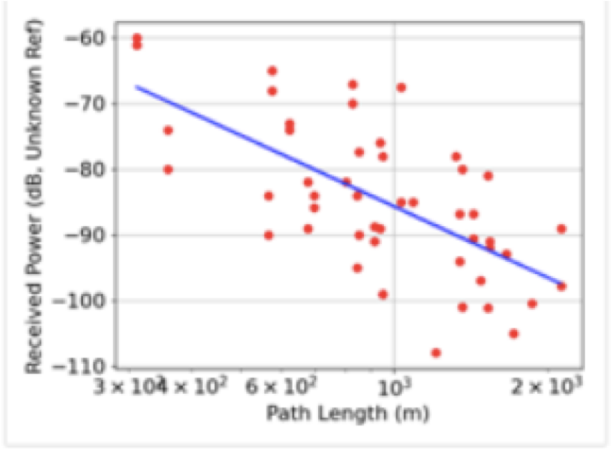
The figure shows the received power (red dots) vs. path length for 56 links between pairs of CBRS rooftop nodes. The dB received power is not calibrated, so is listed as referred to an unknown reference. The path loss exponent model for the measurements (blue line) has a path loss exponent of 3.6 and standard deviation of 8.5 dB.

We can also conduct wideband channel impulse response (CIR) measurements, and use them to develop multipath models which then impact wireless system design. For example, we use a pseudo-noise (PN) signal transmitter and a correlation receiver to measure the CIR between two base stations in the figure below. As expected, we see multipath powers with exponentially decreasing magnitude as a function of excess time delay. We

Overview (cont.)



https://powderwireless.net/map

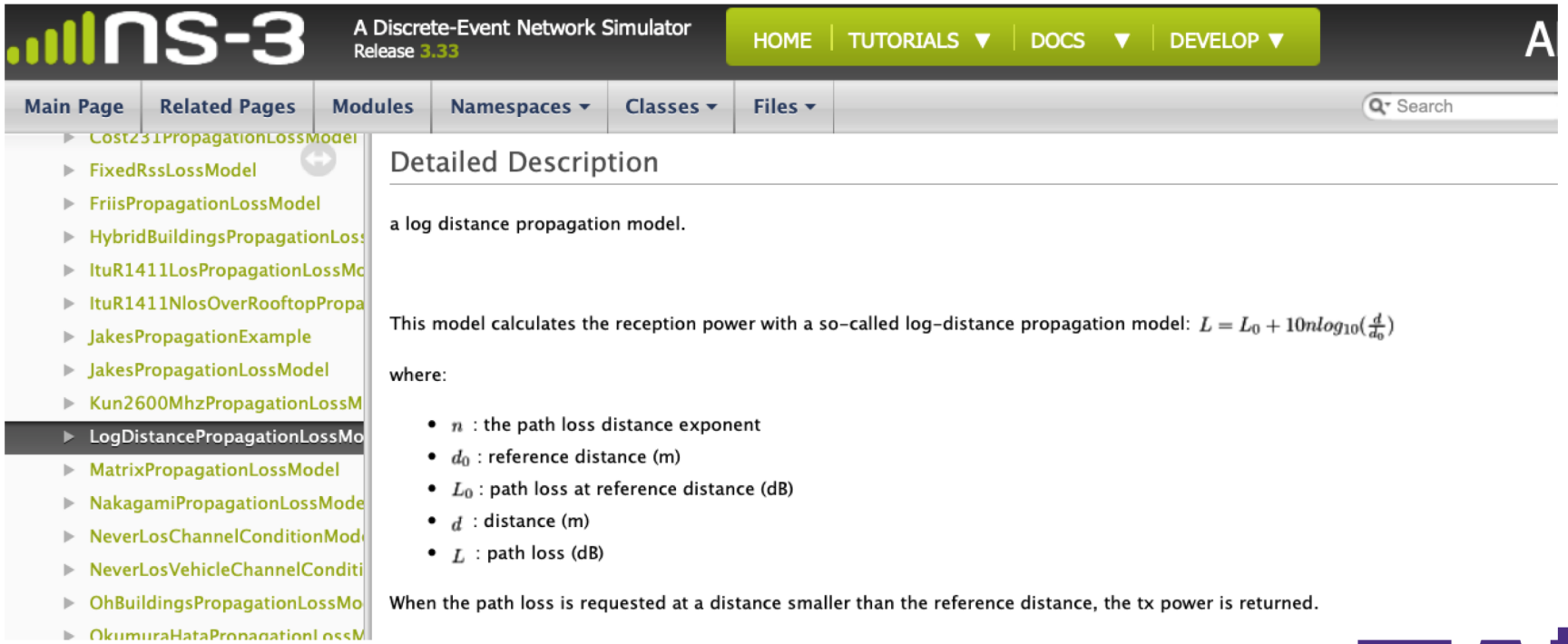


https://powderwireless.net/use

> Sample data and plotting scripts are available to organize the measurement data, generate plot, and calculate the empirical path loss exponent (3.6 in this case)

ns-3 LogDistancePropagationLossModel

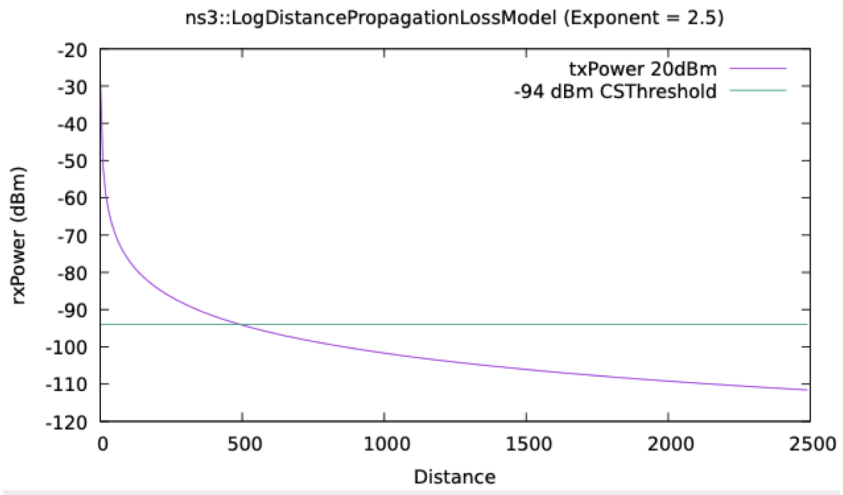
- ns-3 has a LogDistancePropagationLossModel (src/propagation/model/propagation-loss-models.cc) that has a path loss exponent value, defaulting to '3'

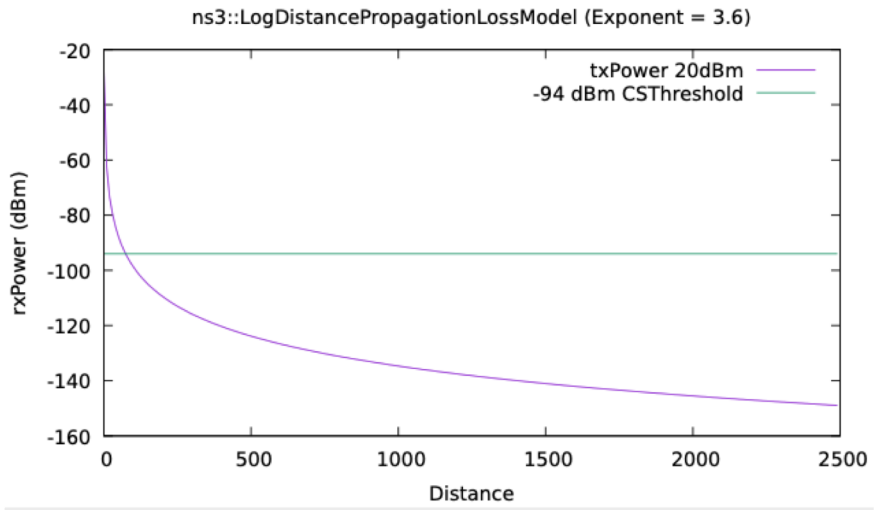


Example use in ns-3 program

> src/propagation/examples/main-propagation-loss.cc

```
235   {
236     Ptr<LogDistancePropagationLossModel> log = CreateObject<LogDistancePropagationLossModel> ();
237     log->SetAttribute ("Exponent", DoubleValue (2.5));
238
239     Gnuplot plot = TestDeterministic (log);
240     plot.SetTitle ("ns3::LogDistancePropagationLossModel (Exponent = 2.5)");
241     gnuplots.AddPlot (plot);
242   }
```





Current directions

- Provide POWDER-support ”App” in the ns-3 App Store
  - Documentation and example/utility scripts
  - For relevant pre-configured Powder experiment profiles, provide comparable ns-3 scripts and documentation
  - Reuse POWDER experimental data as appropriate (e.g. trace-based models)
- Provide ns-3 pre-built images and profiles in the POWDER datastore
- Support efforts (by other research groups) to use emulation for hybrid POWDER/ns-3 experiments

References

- PAWR: https://advancedwireless.org/
- POWDER: https://www.powderwireless.net
- Recent papers on ns-3 emulation
  - Pasquale Imputato, Stefano Avallone. Enhancing the fidelity of network emulation through direct access to device buffers, Journal of Network and Computer Applications, Volume 130, 2019, pages 63-75
  - Harsh Patel, Hrishikesh Hiraskar, and Mohit P. Tahiliani. 2019. Extending Network Emulation Support in ns-3 using DPDK. In Proceedings of the 2019 Workshop on ns-3 (WNS3 2019). Association for Computing Machinery, New York, NY, USA, 17–24.
- Hybrid ns-3/POWDER paper
  - A. E. Morel *et al*., "Enhancing Network-edge Connectivity and Computation Security in Drone Video Analytics," *2020 IEEE Applied Imagery Pattern Recognition Workshop (AIPR)*, 2020, pp. 1-12, doi: 10.1109/AIPR50011.2020.9425341.

References (cont.)

- Dustin Maas's srsLTE Handover profile
  - https://gitlab.flux.utah.edu/dmaas/srsran-handover
  - https://www.powderwireless.net/show-profile.php?uuid=d7d95166-c42a-11eb-b1eb-e4434b2381fc
- Fraida Fund and Ashutosh Srivastava's SCE/L4S profile
  - This is another example of a git-backed repository profile showing how to automate the execution of a larger experiment on CloudLab/POWDER
  - https://github.com/ffund/sce-l4s-bakeoff
- Neil Patwari's scripts for path loss measurements
  - https://gitlab.flux.utah.edu/powderrenewpublic/mww2019/
  - https://gitlab.flux.utah.edu/powderrenewpublic/mww2019/blob/master/Path%20Loss%20Measurement.md

Next steps

If you are interested in using ns-3 with POWDER:

- Create your own account and select the ‘ns-3-users’ project
- Contact Tom Henderson (tomh@tomh.org) if you need further assistance with account creation or using this project
- Subscribe to the powder-users Google Group (link found on the main POWDER web page)
- Check for updates of the *powder-support* app in the ns-3 app store