ns-3 Training

ns-3 Annual Meeting June 2018



ns-3 training goals

- Make attendees more productive with ns-3
 - -Learn about the project scope, and where to get additional help
 - Understand the architecture and design goals of the software
 - Introduce how to write new code for the simulator
 - -Learn about selected topics in more detail
 - -Answer your questions



ns-3 training wiki page

https://www.nsnam.org/wiki/AnnualTraining2018



See the flyer for more agenda information: https://www.nsnam.org/docs/consortium/training/ns-3-training-2018.pdf

Slides will be posted here once available.



Agenda and Instructors

- Monday: ns-3 overview (T. Henderson)
 - project overview
 - software overview
 - simulator introduction via sample workflows
- Tuesday AM: traffic control (M. Tahiliani)
- Tuesday AM: ns-3 advanced modes: DCE, MPI, emulation (S. Jain and T. Henderson)
- Tuesday PM: Wi-Fi (S. Deronne)
- Tuesday PM: LTE (N. Patriciello)



Project overview



ns-3 in a nutshell

- **Purpose:** Tool for network performance analysis
- Users: Researchers and academia
- Development model: Open source, community maintained





ns timeline





ns-3 discrete-event simulation basics

- Simulation time moves in discrete jumps from event to event
- C++ functions schedule events to occur at specific simulation times
- A simulation scheduler orders the event execution
- Simulation::Run() executes a single-threaded event list
- Simulation stops at specific time or when events end



Packet level simulation overview





Network performance evaluation options

 ns-3 enables researchers to more easily move between simulations, test beds, and experiments



Increasing complexity



ns-3 overview

 ns-3 is a leading 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





Software overview



Software overview

- ns-3 is written in C++, with bindings available for Python
 - simulation programs are C++ executables or Python programs
 - $-\sim$ 350,000 lines of C++ (cloc estimate)
 - almost exclusively C++98, beginning to use C++11
- ns-3 is a GNU GPLv2-licensed project
- ns-3 is mainly supported for Linux, OS X, and FreeBSD
 - Windows Visual Studio port in progress
- ns-3 is not backwards-compatible with ns-2 ns-3 Training, June 2018

The basic ns-3 architecture





Key differences from other network simulators:

- 1) Command-line, Unix orientation
 - vs. Integrated Development Environment (IDE)
- 2) Simulations and models written directly inC++ and Python
 - vs. a domain-specific simulation language



ns-3 not written in a high-level language

Submodule vectors, gate vectors and multiple connections are illustrated in the following example:

```
simple Hub
gates:
    out: outport[];
endsimple
simple Station //...
module Star
    submodules:
    hub: Hub
        gatesizes: outport[4];
        station: Station[4];
        connections:
        for i=0..3 do
            hub.outport[i] --> station[i].in;
        endfor
endmodule
```

The result of the above is depicted in Fig.4.



Example of OMNeT++ Network Description (NED) language Figure excerpted from <u>http://www.ewh.ieee.org/soc/es/Nov1999/18/ned.htm</u>



ns-3 does not have a graphical IDE



NETWORK SIMULATOR

ns-3 uses outside programs for graphics





ns-3 uses scripting for plotting





Software organization

- Two levels of ns-3 software and libraries
 - 1) Several supporting libraries, not system-installed, can be in parallel to ns-3





Modules



utilities

Module organization

- models/
- examples/
- tests/
- bindings/
- doc/
- wscript



ns-3 programs

- ns-3 programs are C++ executables that link the needed shared libraries
 - or Python programs that import the needed modules
- The ns-3 build tool, called 'waf', can be used to run programs
- waf will place headers, object files, libraries, and executables in a 'build' directory



Python bindings

 ns-3 uses a program called PyBindGen to generate Python bindings for all libraries





Python bindings status

- API scanning for Python used to use a tool called gccxml
- ns-3 has moved to the successor, CastXML
 requires a development installation of clang
- Automated testing currently only for Linux 64-bit systems
 - MacOS bindings require some manual changes



Integrating other tools and libraries



Other libraries

- more sophisticated scenarios and models typically leverage other libraries
- ns-3 main distribution uses optional libraries (libxml2, gsl, mysql) but care is taken to avoid strict build dependencies
- the 'bake' tool (described later) helps to manage library dependencies
- users are free to write their own Makefiles or wscripts to do something special





• src/core/examples/sample-rng-plot.py

```
# Demonstrate use of ns-3 as a random number generator integrated
# plotting tools; adapted from Gustavo Carneiro's ns-3 tutorial
```

```
import numpy as np
import matplotlib.pyplot as plt
import ns.core
```

```
# mu, var = 100, 225
rng = ns.core.NormalVariable(100.0, 225.0)
x = [rng.GetValue() for t in range(10000)]
```

```
# the histogram of the data
n, bins, patches = plt.hist(x, 50, normed=1, facecolor='g', alpha=0.75)
```

```
plt.title('ns-3 histogram')
plt.text(60, .025, r'$\mu=100,\ \sigma=15$')
plt.axis([40, 160, 0, 0.03])
plt.grid(True)
plt.show()
```





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NEWS (Septen	ber 24, 2011): Click 2.0.1 released!			
SyClick: Sympo available.	sium on Click Modular Router [#] was November 23-24, 2009, Ghent, Belgium! An ex	excellent	time was had. V	Video of the presentations is now
This is the Dok Meraki⁴.	aWiki* for the Click modular router. Click was originally developed at MIT^* with subsequences of the second	uent de	velopment at Ma	azu Networks*, ICIR*, UCLA*, and



OpenFlow Switch





CORE emulator





mininet emulator

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Co-simulation frameworks have emerged

• PNNL's FNCS framework integrates ns-3 with transmission and distribution simulators



Image source: PNNLgov YouTube video: Introducing FNCS: Framework for Network Co-Simulation



FAQs

- Does ns-3 have a Windows version?
 - A new Windows Visual Studio release is underway
 - Windows 10 'Linux subsystem' also worksDoes ns-3 support Eclipse or other IDEs?
 - Instructions have been contributed by users
 - <u>http://www.nsnam.org/wiki/HOWTO_configure_Eclipse_with_ns-3</u>
- Is ns-3 provided in Linux or OS X package systems (e.g. Debian packages)?

- Not officially, but some package maintainers exist



Summarizing

- ns-3 models are written in C++ and compiled into libraries
 - -Python bindings are optionally created
- ns-3 programs are C++ executables or Python programs that call the ns-3 public API and can call other libraries
- ns-3 is oriented towards the command-line
- ns-3 uses no domain specific language
- ns-3 is not compatible with ns-2



Project overview



ns-3 main website

Project home: <u>https://www.nsnam.org</u>



ns-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use. ns-3 is free software, licensed under the <u>GNU GPLv2 license</u>, and is publicly available for research, development, and use.

NS-3.

Consortium:



Get ns-3:

Most recent stable release:

Download ns-3.28 code

View documentation

Other releases and docs:

- All releases
- All documentation

Get involved:

Current activities:

ns-3.29 release

- Workshop on ns-3
- Meeting flyer
- Mailing lists:

Building a great network simulator for research and education requires

- For users
- For developers



October 2017 ns-3.27 released : ns-3.27 was released on 12 October 2017 and features th...

2018 editi

Recent Posts:

July 2017 ns-3 in ESA Summer of Code in Space (SOCIS) program : The ns-3 project has been selected to participate in th...

November 2017 WNS3 2018 : The Workshop

on ns-3 (WNS3) is a one and one-half day w ...

March 2018 ns-3.28 released : ns-3.28 was released on 22 March 2018 and features the

February 2018 Google Summer of Code 2018 : ns-3 is excited to have been selected to the

May 2017 ns-3 participating in SOCIS 2017 : ns-3 has been invited to participate in the 2017 editio...





How the project operates

- Project provides three annual software releases
- Users interact on mailing lists and using Bugzilla bug tracker
- Code may be proposed for merge
 - Code reviews occur on a Google site
- Maintainers (one for each module) fix or delegate bugs, participate in reviews
- Project has been conducting annual workshop and developer meeting around SIMUTools through 2013

- Some additional meetings on ad hoc basis

• Summer projects (Google Summer of Code, ESA Summer of Code in Space, others...)



Maintainers, Authors, Users

- ~10-15 maintainers at any given time
- 228 authors credited in AUTHORS file
- Over 8000 subscribers to ns-3-users Google Groups forum
- Over 1500 subscribers to ns-developers mailing list
- Various project forks exist (on Github and elsewhere)



Contributed code and associated projects

®® _® 77∕	NS-3 based Named Data Networking (NDN) simulator ndnSIM: NDN, CCN, CON, content: centric networks	Overall ndnSIM documentat	ion
ndnSIM ndnSIM API			nex
Next topic	Welcome to ndnSIM NS-3 based NDN simulator		
Introduction	We invite you to join our mailing list to see and participate in discussions about ndnSIM implementation and simulations in c	general (mailing list archives).	
Show Source	Contents:		
Quick search	Introduction Nore documentation Support		•
Go	A very short guide to the code Cogging	a mptcp-n	s3
Enter search terms or a module, class or function name.	Getting Started o Portability o Requirements	implement multipath TC	2 on ns-3
	Downloading ndnSIM source Compiling and running ndnSIM	Project Home Downloads	Wiki Issues Source
	IndiStM holpers o Stat-CiteJeper s.touta touta touta could routes colobal routing controller		
		Summary Opdates People	
	Default routes Content Store Pending Interest Table	Project Information	Project description
	 Forwarding strategy AppHelper 	🟠 Starred by 4 users	The mptcp-ns3 project focuses on developing implementation of Multipath TCP on ns-3 for research purposes. The project implement the entire
	Content Store Simple content stores Least Recently Liced (LRII) (default)	Activity III Medium Project feeds	transport layer in ns-3.
	First-In-First-Out (FIFO) Random	Code license	Multipath TCP is an extension to TCP which aims to use multiple paths to handle a communication between two endpoints. MPTCP is the IETF
	Content stores with entry lifetime tracking Least Recently Used (LRU) Signature Signature (USEO)	GNU Lesser GPL	working group to standardize Multipath TCP.
	Random Content stores respecting freshness field of ContentObjects	Labels	Please check the following URL for more information about multipath TCP. http://datatracker.ietf.org/wg/mptcp/charter/
	Least Recently Used (LRU) First-In-First-Out (FIFO) Bander	Academic, ns-3, MPTCP, TCP, CPlusPlus, Study,	Current Status
		MultipathTCP, multipath, Simulator	The surrant implementation is raply close to the MDTCD encoderation:
			MDTCD settings: MDC (Multimeth Carable), ADD and DEMOVE address. (ON) ata
	A MARKEN AND A MARKEN A	chihan@gmail.com	WE FOR Options, MEO (Wolkipath Capable), ADD and REMOVE address, 30%, etc.
Karlsruhe Institute of Technolog	Decentralized Systems and Network Services Research Group - TM & SCC	Links	Congestion Control: Pully Coupled, Uncoupled TCPS, Linked Increases, RTT Compensator.
Home	PhySimWiFi for NS-3	Etitiks External links	Packet Reordering: None, Eifel, USACK and F-RTU algorithms
> News	Contact: Jens Mittag, Stylianos Papanastasiou (CSS) Project DSN, Chalmers University of Technology - Signals and Systems (CSS)	MPTCP IETF's Working Group	Getting Started
> Staff	Group:	Multipath TCP in INL	Follow the instructions in the wilkingge http://code.google.com/n/metch.ge3/wiki/Makelt to successfully run simulations
→ Research	Overview		Tollow the instructions in the writipage interforcede google.company.cpms.crwitiwakeit to successibility full simulations.
Publications	PhySim-WiFi for NS-3 is a detailed and accurate implementation of the OFDM-based IEEE 802.11 standard within the po	pular	
 Traffic Telematics Jun Research Group 	or an average signal strength per paket und the length of the packet, the PhySim-WiFi implementation simulates the unde processing stens of a transcription down to the signal level, and introduces an increases source for the device what	rlying signal	
Miscellaneous / Softw Averages Applet	are could be received correctly or not. At the same time, the new implementation allows to incoorporate more sophisticated models. For instance, due to the modeling of packets on a signal level, channel models can emulate multi-name hefferts received correctly or not.	d channel much more	
JKad JaaS Dispatcher	accurately and are able to reflect Doppler effects and their impact on the physical layer signal processing algorithm. The DhySim Wife implementation is a drop-in replacement of the default YansWifePhy model thus it can be used with a	inly minor	
PhySimWiFi for NS-3 > BitMON	modifications in the existing simulation code and the existing scenario setups.		
JAAS Dispatcher EMDV Visualizer	rur auunuunan muurmauon and a changelog, piease take a look at the PhySimWifi Manual 1.1		
Ovivis IEEE 802.11 Buofix in	Full package download		
ns-2.28 Overhaul of IEEE 802	NS-3.9-PhySimWiFi v1.0 (based on NS-3.9 and PhySim-WiFi) - August 17, col1 NS-3.9-PhySimWiFi v1.0 (based on NS-3.9 and PhySim-WiFi) - September 12, 2010		
> How to contact us!	Patches for NS-3 PhySimWiFi v1.1 for NS-3.9 - August 19, 2011		
	 PhySimWiFi v1.1 for NS-3.9-PhySimWiFi v1.0 August 19, 2011 PhySimWiFi v1.0 for NS-3.9 September 12, 2010 		



Migrating to an ns-3 app store

- **Developed by:** Abhijith Anilkumar, National Institute of Technology Karnataka, India.
- Goal: Support modularization of ns-3 codebase.
- Beta site: https://apps.nsnam.org





Sustainment

- The NS-3 Consortium is a collection of organizations cooperating to support and develop the ns-3 software.
- It operates in support of the open source project
 - by providing a point of contact between industrial members and ns-3 developers,
 - by sponsoring events in support of ns-3 such as users' days and workshops,
 - by guaranteeing maintenance support for ns-3's core, and
 - by supporting administrative activities necessary to conduct a large open source project.



ns-3 Consortium governance





Acknowledgment of support



