ns-3 tutorial

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Acknowledgments

- Thanks to Mathieu Lacage and Craig Dowell for assembling the tutorial source code and materials
- Thanks to ns-3 development team!
- Tom Henderson is supported by NSF CNS-0551686 (University of Washington)

Goals of this tutorial

- Learn about the ns-3 project and its goals
- Understand the software architecture, conventions, and basic usage of ns-3
- Read and modify an example ns-3 script
- Learn how you might extend ns-3 to conduct your own research
- Provide feedback to the ns-3 development team

Assumptions

- Some familiarity with C++ programming language
- Some familiarity with Unix Network Programming (e.g., sockets)
- Some familiarity with discrete-event simulators

Outline

- Introduction to ns-3
- Reading ns-3 code
- Tweaking ns-3 code
- Extending ns-3 code

What is *ns (or ns-2)*?

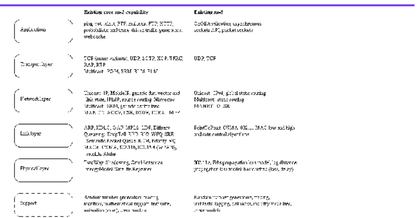
- *ns* is a discrete-event network simulator for Internet systems
  - protocol design, multiple levels of abstraction
  - written in multiple languages (C++/OTcl)
- *ns* has a companion network animator called *nam*
  - hence, has been called the *nsnam* project

ns-3 is a *research-oriented*, discrete event simulator

ns-3 features

- open source licensing (GNU GPLv2) and development model
- Python scripts or C++ programs
- alignment with real systems (sockets, device driver interfaces)
- alignment with input/output standards (pcap traces, ns-2 mobility scripts)
- testbed integration is a priority
- modular, documented core

ns-3 models



Project focus has been on the software core, to date

ns-3 people

- **NSF PIs:**
  - Tom Henderson, Sumit Roy (University of Washington), George Riley (Georgia Tech.), Sally Floyd (ICIR)
- **Associated Team:** INRIA Sophia Antipolis, Planete group
  - Walid Dabbous, Mathieu Lacage (software lead)
- **Developers:** Raj Bhattacharjea, Gustavo Carneiro, Craig Dowell, Joseph Kopena, Emmanuelle Laprise

ns-3 relationship to ns-2

ns-3 is ***not*** an extension of ns-2

- does not have an OTcl API
  - C++ wrapped by Python
- synthesis of yans, ns-2, GTNetS simulators, and new software
  - example ns-2 models so far: random variables, error models, OLSR
- guts of simulator are completely replaced
- new visualizers are in works

ns-3 status (March 2008)

ns-3 is in a pre-alpha state

- monthly development releases
- APIs being finalized
- emphasis has been on setting the architecture
- new users should expect rough edges
- many opportunities to work on the core models

ns-3 status (March 2008)

What others are already using ns-3 for:

- wifi-based simulations of OLSR and other MANET routing
- MANET routing (SMF and unicast protocols)
- OntoNet: Scalable Knowledge Based Networking" by Joe Kopena and Boon Thau Loo (UPenn)

ns-3 roadmap (2008)

near term (through June)

- finalize and release simulation core (April/May)
  - core APIs
- ns-3.1 complete release (June timeframe)
  - add Internet and Device models
  - add validation framework
  - some higher-level topology/scenario APIs

ns-3 roadmap (2008)

planned for later this year

- emulation modes
- statistics
- support for real code
- additional ns-2 porting/integration
- distributed simulation
- visualization

Resources

Web site:
    http://www.nsnam.org
Mailing list:
    http://mailman.isi.edu/mailman/listinfo/ns-developers
Tutorial:
    http://www.nsnam.org/docs/tutorial/tutorial.html
Code server:
    http://code.nsnam.org
Wiki:
    http://www.nsnam.org/wiki/index.php/Main_Page

Links to materials

- Today's code
  - http://www.nsnam.org/tutorials/simutools08/ns-3-tutorial.tar.gz
- Tutorial slides:
  - PPT: http://www.nsnam.org/tutorials/simutools08/ns-3-tutorial.ppt
  - PDF: http://www.nsnam.org/tutorials/simutools08/ns-3-tutorial.pdf

Questions so far?

Outline

- Introduction to ns-3
- Reading ns-3 code
- Tweaking ns-3 code
- Extending ns-3 code

Reading ns-3 code

- Browsing the source code
- Conceptual overview
- Script walkthrough

Basics

- ns-3 is written in C++
- Bindings in Python
- ns-3 uses the waf build system
- i.e., instead of `./configure;make`, type `./waf`
- simulation programs are C++ executables (python scripts)

Browse the source

```
tomh@A3803721 ~/home/ns-3-dev
$ ls
AUTHORS  README         VERSION  examples  samples  tutorial  waf      wscript
LICENSE  RELEASE_NOTES  doc      ns3       src      utils     waf.bat
```

Pause presentation to browse source code

http://www.nsnam.org/tutorials/simutools08/ns-3-tutorial.tar.gz

Doxygen documentation

- Most of the ns-3 API is documented with Doxygen
  - http://www.stack.nl/~dimitri/doxygen/

Pause presentation to browse Doxygen

http://www.nsnam.org/doxygen/index.html

the waf build system

- Waf is a Python-based framework for configuring, compiling and installing applications.
  - It is a replacement for other tools such as Autotools, Scons, CMake or Ant
  - http://code.google.com/p/waf/

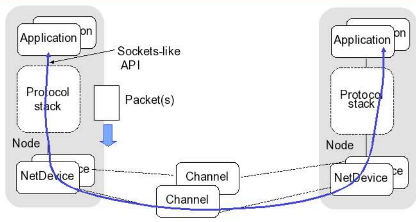
Pause presentation to build with waf

waf key concepts

- For those familiar with autotools:
- configure -> ./waf -d [optimized|debug] configure
- make -> ./waf
- make test -> ./waf check (run unit tests)

- Can run programs through a special waf shell; e.g.
  - `./waf --run simple-point-to-point`
  - (this gets the library paths right for you)

The basic model



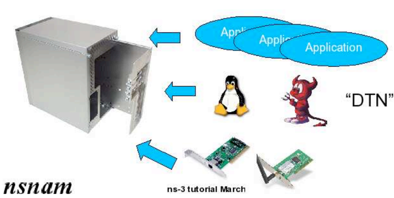
Fundamentals

Key objects in the simulator are Nodes, Packets, and Channels

Nodes contain Applications, “stacks”, and NetDevices

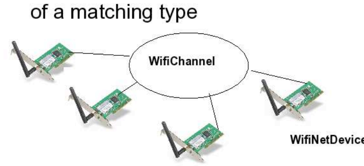
Node basics

A Node is a husk of a computer to which applications, stacks, and NICs are added



NetDevices and Channels

NetDevices are strongly bound to Channels of a matching type



Nodes are architected for multiple interfaces

Node basics

Two key abstractions are maintained:

1) applications use an (asynchronous, for now) sockets API

2) the boundary between IP and layer 2 mimics the boundary at the device-independent sublayer in Linux

i.e., Linux Packet Sockets

ns-3 Packets

- each network packet contains a byte buffer, a list of tags, and metadata
  - **buffer:** bit-by-bit (serialized) representation of headers and trailers
  - **tags:** set of arbitrary, user-provided data structures (e.g., per-packet cross-layer messages, or flow identifiers)
  - **metadata:** describes types of headers and and trailers that have been serialized
    - optional-- disabled by default

ns-3 Packets

- to add a new header, subclass from Header, and write your Serialize() and Deserialize() methods
  - how bits get written to/from the Buffer
- Similar for Packet Tags
- Packet Buffer implements a (transparent) copy-on-write implementation

example: UDP header

```
class UdpHeader : public Header
{
public:
  void SetDestination (uint16_t port);
  ...
  void Serialize (Buffer::Iterator start) const;
  uint32_t Deserialize (Buffer::Iterator start);
private:
  uint16_t m_sourcePort;
  uint16_t m_destinationPort;
  uint16_t m_payloadSize;
  uint16_t m_initialChecksum;
}
```

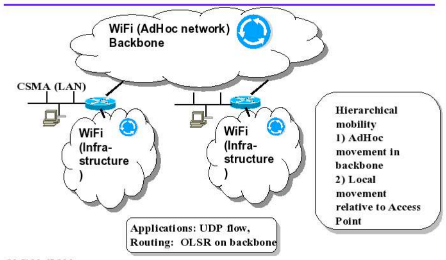

example: UDP header

```
void
UdpHeader::Serialize (Buffer::Iterator start) const
{
  Buffer::Iterator i = start;
  i.WriteHtonU16 (m_sourcePort);
  i.WriteHtonU16 (m_destinationPort);
  i.WriteHtonU16 (m_payloadSize + GetSerializedSize ());
  i.WriteU16 (0);
  if (m_calcChecksum)
    {
      uint16_t checksum = Ipv4ChecksumCalculate (...);
      i.WriteU16 (checksum);
    }
}
```


Simulation basics

- Simulation time moves discretely from event to event
- C++ functions schedule events to occur at specific simulation times
- A simulation scheduler orders the event execution
- Simulation::Run() gets it all started
- Simulation stops at specific time or when events end

Sample script walkthrough



Sample script walkthrough

Walk through mixed-wireless.cc

(aside) similar looking code in Python

```
import sys
import ns3 as ns


def main():
## Set up some default values for the simulation.  Use the Bind()
## technique to tell the system what subclass of Queue to use,
## and what the queue limit is
## The below Bind command tells the queue factory which class to
## instantiate, when the queue factory is invoked in the topology code

ns.DefaultValue.Bind("Queue", "DropTailQueue")
ns.DefaultValue.Bind("OnOffApplicationPacketSize", "210")
ns.DefaultValue.Bind("OnOffApplicationDataRate", "448kb/s")

ns.CommandLine.Parse(sys.argv)

## Here, we will explicitly create four nodes.  In more sophisticated
## topologies, we could configure a node factory.

n0 = ns.InternetNode()
n1 = ns.InternetNode()
n2 = ns.InternetNode()
n3 = ns.InternetNode()
...
```


examples/ directory

- examples/ contains other scripts with similar themes

```
$ ls
csma-broadcast.cc              simple-point-to-point.cc
csma-multicast.cc              tcp-large-transfer-errors.cc
csma-one-subnet.cc             tcp-large-transfer.cc
csma-packet-socket.cc          tcp-nonlistening-server.cc
mixed-global-routing.cc        tcp-small-transfer-oneloss.cc
simple-alternate-routing.cc    tcp-small-transfer.cc
simple-error-model.cc          udp-echo.cc
simple-global-routing.cc       waf
simple-point-to-point-olsr.cc  wscript
```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ns-3 logging

- ns-3 has a built-in logging facility to stderr
- Features:
  - can be driven from shell environment variables
  - Multiple log levels like syslog
  - Function and call argument tracing
- Intended for debugging, but can be abused to provide tracing
  - we do not guarantee that format is unchanging

ns-3 logging example

- NS_LOG_UNCOND();
- NS_LOG environment variable
- per-source-file logging
- log levels
- example scripts

attributes and tracing

- Next, we would like to talk about attributes (default values, settable and gettable values) and tracing
- To understand this, we'll introduce the ns-3 Object system

Object metadata system

- ns-3 is, at heart, a C++ object system
- ns-3 objects that inherit from base class ns3::Object get several additional features
  - dynamic run-time object aggregation
  - an attribute system
  - smart-pointer memory management

Disclaimer: This is not all main-line ns-3 code-- parts are in a proposal in the mathieu/ns-3-param repository

Object aggregation use case

- You can aggregate objects to one another at run-time
  - Avoids the need to modify a base class to provide pointers to all possible connected objects
- Object aggregation is planned to be the main way to create new Node types (rather than subclassing Node)

Object aggregation example

```
void
WifiChannel::Send (Ptr<WifiPhy> sender, Ptr<const
  Packet> packet, ...)
{
  Ptr<MobilityModel> senderMobility = 0;
  Ptr<MobilityModel> receiverMobility = 0;
  ...
  senderMobility = sender->GetNode ()->
    GetObject<MobilityModel> ();
}
```

class Node does not need to know about MobilityModel

Use cases for attributes

- An Attribute represents a value in our system
- An Attribute can be connected to an underlying variable or function
  - e.g. TcpSocket::m_cwnd;
  - or a trace source

Use cases for attributes (cont.)

- What would users like to do?
  - Know what are all the attributes that affect the simulation at run time
  - Set a default initial value for a variable
  - Set or get the current value of a variable
  - Initialize the value of a variable when a constructor is called
- The attribute system is a unified way of handling these functions

How to handle attributes

- The traditional C++ way:
  - export attributes as part of a class's public API
  - walk pointer chains (and iterators, when needed) to find what you need
  - use static variables for defaults
- The attribute system provides a more convenient API to the user to do these things

The traditional C++ way

```
class Foo
{
public:
  void SetVar1 (uint32_t value);
  uint32_t GetVar1 (void);
  static void SetInitialVar1(uint32_t value);
  void SetVar2 (uint32_t value);
  uint32_t GetVar2 (void);
  static void SetInitialVar2(uint32_t value);
  ...
private:
  uint32_t m_var1;  // document var1
  uint32_t m_var2;  // document var2
  static uint32_t m_initial_var1;
  static uint32_t m_initial_var2;
}

Foo::Foo() : m_var1(Foo::m_initial_var1), m_var2(Foo::m_initial_var2)
{
}
```

to modify an instance of Foo, get the pointer somehow, and use the public accessor functions
to modify the default values, modify the statics
Default values may be available in a separate framework (e.g. ns-2 Bind())

Navigating the attributes

- Attributes are exported into a string-based namespace, with filesystem-like paths
  - namespace supports regular expressions
- Attributes also can be used without the paths
  - e.g. `"WifiPhy::TxGain"`
- A Config class allows users to manipulate the attributes

Navigating the attributes using paths

- Examples:
  - Nodes with NodeIds 1, 3, 4, 5, 8, 9, 10, 11:
    - "/NodeList/[3-5]|[8-11]|1"
  - UdpL4Protocol object instance aggregated to matching nodes:
    - "/$UdpL4Protocol"
  - EndPoints which match the SrcPort=1025 specification:
    - "/EndPoints/*:SrcPort=1025"

What users will do

- e.g.: Set a default initial value for a variable
- (Note: this replaces DefaultValue::Bind())

```
Config::Set ("WifiPhy::TxGain", Double (1.0));
```

- Syntax also supports string values:

```
Config::Set ("WifiPhy::TxGain", "1.0");
```

Attribute Value

What users will see

- Set or get the current value of a variable
  - Here, one needs the path in the namespace to the right instance of the object

```
Config::SetAttribute("/NodeList/5/DeviceList/3/Phy
  /TxGain", Double(1.0));
Double d =
  Config::GetAttribute("/NodeList/5/NetDevice/3/Phy
  /TxGain");
```

- Users can get Ptrs to instances also, and Ptrs to trace sources, in the same way

CreateObject<> ();

- CreateObject<> is a wrapper for operator new.
- ns3::Object objects must be created on the heap using CreateObject<> (), which returns a smart pointer; e.g.

```
Ptr<Node> rxNode = CreateObject<Node> ();
```

Create<> ();

- What is Create<> ()?
- Create<> provides some smart pointer help for objects that use ns3::Ptr<> but that do not inherit from Object.
- Principally, class ns3::Packet

```
Ptr<Packet> p = Create<Packet> (data,size);
```


Non-default constructors

- The attribute system allows you to also pass them through the CreateObject<> constructor.
- This provides a *generic* non-default constructor for users (any combination of parameters), e.g.:

```
Ptr<WifiPhy> phy = CreateObject<WifiPhy> (
   "TxGain", Double (1.0));
```


How is all this implemented (overview)

```
class Foo P public Object
{
public:
  static TypeId GetTypeId (void);
private:
  uint32_t m_var1;  // document var1
  uint32_t m_var2;  // document var2
}

Foo::Foo() {
}

TypeId Foo::GetTypeId (void)
{
  static TypeId tid = TypeId("Foo");
  .SetParent (<ooParent>
  .SetGroupName ("FooDefaults")
  .AddConstructor<Foo> ();
  .AddAttribute ("m_var1", "document var1",
    UInteger(3),
    MakeUIntegerAccessor (&Foo::m_var1),
    MakeUIntegerChecker<uint32_t> ())
  .AddAttribute ("m_var2", "", ...)
  return tid;
}
```


A real TypeId example

```
TypeId
RandomWalk2dMobilityModel::GetTypeId (void)
{
  static TypeId tid = TypeId ("RandomWalkMobilityModel")
    .SetParent<MobilityModel> ()
    .SetGroupName ("Mobility")
    .AddConstructor<RandomWalk2dMobilityModel> ()
    .AddAttribute ("bounds",
                   "Bounds of the area to cruise.",
                   Rectangle (0.0, 0.0, 100.0, 100.0),
                   MakeRectangleAccessor (&RandomWalk2dMobilityModel::m_bounds),
                   MakeRectangleChecker ())
    .AddAttribute ("time",
                   "Change current direction and speed after moving for this delay.",
                   Seconds (1.0),
                   MakeTimeAccessor (&RandomWalk2dMobilityModel::m_modeTime),
                   MakeTimeChecker ())
    .AddAttribute ("distance",
                   "Change current direction and speed after moving for this distance.",
                   Seconds (1.0),
                   MakeTimeAccessor (&RandomWalk2dMobilityModel::m_modeTime),
                   MakeTimeChecker ())
```


Also part of Object: smart pointers

- ns-3 uses reference-counting smart pointers at its APIs to limit memory leaks
  - Or "pass by value" or "pass by reference to const" where appropriate
- A "smart pointer" behaves like a normal pointer (syntax) but does not lose memory when reference count goes to zero
- Use them like built-in pointers:

```
Ptr<MyClass> p = CreateObject<MyClass> ();
p->method ();
```


Statements you should understand now

```
Ptr<Ipv4AddressAllocator> ipAddrs = CreateObject<Ipv4AddressAllocator> ();
```

C++ Smart Pointer

ns3::Object

```
Config::SetDefault ("OnOffApplication::DataRate", String("448kb/s"));
Config::SetDefault ("/NodeList/*/DeviceList/*/Phy/TxGain", Double(10.0));
```

Attribute namespace

Tracing model

- Tracing is a structured form of simulation output
  - tracing format should be relatively static across simulator releases
- Example (from ns-2):

```
+ 1.84375 0 2 cbr 210 ------- 0 0.0 3.1 225 610
- 1.84375 0 2 cbr 210 ------- 0 0.0 3.1 225 610
r 1.84471 2 1 cbr 210 ------- 1 3.0 1.0 195 600
r 1.84566 2 0 ack 40 ------- 2 3.2 0.1 82 602
+ 1.84566 0 2 tcp 1000 ------- 2 0.1 3.2 102 611
```

- Needs vary widely

Crude tracing

```
#include <iostream>
...
int main ()
{
  ...
  std::cout << "The value of x is " << x <<
  std::endl;
  ...
}
```


slightly less crude

```
#include <iostream>
...
int main ()
{
  ...
  NS_LOG_UNCOND ("The value of x is " << x);
  ...
}
```


Simple ns-3 tracing

- these are wrapper functions/classes
- see examples/mixed-wireless.cc

```
#include "ns3/ascii-trace.h"


 AsciiTrace asciitrace ("mixed-wireless.tr");
 asciitrace.TraceAllQueues ();
 asciitrace.TraceAllNetDeviceRx ();
```


Simple ns-3 tracing (pcap version)

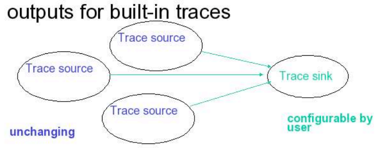
- these are wrapper functions/classes
- see examples/mixed-wireless.cc

```
#include "ns3/pcap-trace.h"


 PcapTrace pcaptrace ("mixed-wireless.pcap");
 pcaptrace.TraceAllIp ();
```


ns-3 tracing model (revisit)

- Fundamental #1: decouple trace sources from trace sinks
- Fundamental #2: prefer standard trace outputs for built-in traces



Tracing overview

- Simulator provides a set of pre-configured trace sources
  - Users may edit the core to add their own
- Users provide trace sinks and attach to the trace source
  - Simulator core provides a few examples for common cases
- Multiple trace sources can connect to a trace sink

Multiple levels of tracing

- Highest-level: Use built-in trace sources and sinks and hook a trace file to them
- Mid-level: Customize trace source/sink behavior using the tracing namespace
- Low-level: Add trace sources to the tracing namespace
  - Or expose trace source explicitly

Highest-level of tracing

- Highest-level: Use built-in trace sources and sinks and hook a trace file to them

```
// Also configure some tcpdump traces; each interface will be traced
// The output files will be named
// simple-point-to-point.pcap-<nodeId>-<interfaceId>
// and can be read by the "tcpdump -r" command (use "-tt" option to
// display timestamps correctly)
PcapTrace pcaptrace ("simple-point-to-point.pcap");
pcaptrace.TraceAllIp ();
```


Mid-level of tracing

- Mid-level: Customize trace source/sink behavior using the tracing namespace

Regular expression editing

```
void
PcapTrace::TraceAllIp (void)
{
  NodeList::Connect ("/nodes/*/ipv4/(tx|rx)",
                     MakeCallback (&PcapTrace::LogIp, this));
}
```

Hook in a different trace sink

Asciitrace: under the hood

```
void
AsciiTrace::TraceAllQueues (void)
{
  Packet::EnableMetadata ();
  NodeList::Connect ("/nodes/*/devices/*/queue/enqueue",
                     MakeCallback (&AsciiTrace::LogDevQueueEnqueue, this));
  NodeList::Connect ("/nodes/*/devices/*/queue/dequeue",
                     MakeCallback (&AsciiTrace::LogDevQueueDequeue, this));
  NodeList::Connect ("/nodes/*/devices/*/queue/drop",
                     MakeCallback (&AsciiTrace::LogDevQueueDrop, this));
}
```


Lowest-level of tracing

- Low-level: Add trace sources to the tracing namespace

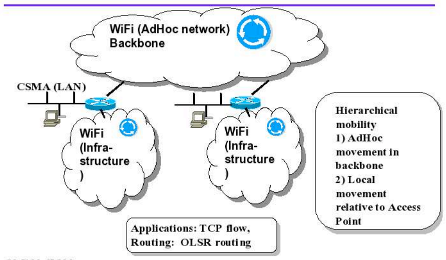
```
Config::Connect ("/NodeList/.../Source",
                 MakeCallback (&ConfigTest::ChangeNotification, this));
```

Statistics

Disclaimer: not yet part of ns-3

- Avoid large trace files
- Full statistics support planned for later in 2008
- Reuse tracing framework
- One similar approach: ns-2-measure project
  - http://info.iet.unipi.it/~cng/ns2measure/
  - Static “Stat” object that collects samples of variables based on explicit function calls inserted into the code
  - Graphical front end, and framework for replicating simulation runs

Revisit our script



Design patterns for topology scripts

Design approaches

- Use simple helper functions with attributes
- Use reusable “frameworks”

Note: This area of our API is under discussion; feedback wanted

The Helper approach

- Is not generic
- Does not try to allow code reuse
- Provides simple 'syntactical sugar' to make simulation scripts look nicer and easier to read for network researchers
- Each function applies a single operation on a "set of same objects”

Helper Objects

- NodeContainer: vector of Ptr<Node>
- NetDeviceContainer: vector of Ptr<NetDevice>
- InternetStackHelper
- WifiHelper
- MobilityHelper
- OlsrHelper
- ... Each model provides a helper class

setup backbone

```
NodeContainer backbone;
backbone.Create (20);
MobilityHelper mobility;
mobility.SetPositionAllocator (“GridPositionAllocator”, “MinX”,
   Double (-100), ...);
mobility.SetMobilityModel (“RandomDirectionMobilityModel”)
mobility.Layout (backbone
WifiHelper wifi;
wifi.SetMac (“AdhocWifiMac”);
wifi.SetPhy (“WifiPhy”, “TxGain”, Double (10));
wifi.SetRemoteStationManager (“ConstantRateWifiManager”, “DataMode”,
   String (“wifia-54mb”))
Ptr<WifiChannel> channel = ...;
NetDeviceContainer backboneDev = wifi.Build (backbone, channel);
```

setup wifi subnets

```
for (uint32_t I = 0; I < 20; i++)
    NodeContainer subnet;
    subnet.Create (29);
    subnets.push_back (subnet);
    mobility.PushReferenceModel (backbone.Get (i));
    mobility.SetMobilityModel (...)
    mobility.SetPositionAllocator (...);
    mobility.Layout (subnet);
    subnet.Add (backbone.Get (i));
    Ptr<WifiChannel> subnetChannel = ...;
    NetDeviceContainer subnetDev =
      wifi.Build (subnet, subnetChannel);
    subnetDevs.push_back (subnetDev);
```


setup ip over backbone and subnets

```
IpNetworkAddressAllocator network;
network.SetMask ("192.168.0..0", "255.255.0.0");
InternetStackHelper ip;
ip.SetAddressAllocator (network.GetNext ());
ip.Setup (backboneDev);
for (uint32_t I = 0; I < 20; i++)
    NetDeviceContainer subnetDev = subnetDevs[i];
    ip.SetAddressAllocator (network.GetNext ());
    ip.Setup (subnetDev);
```


setup olsr on backbone

```
OlsrHelper olsr;
olsr.Enable (backbone);
```


setup traffic sinks everywhere

```
TrafficSinkHelper sink;
// listen on port 1026 for protocol udp
sink.EnableUdp (1026);
sink.Setup (NodeList::Begin (), NodeList::End ());
```


setup trace sources

```
OnOffApplicationHelper source;
source.SetUdpDestination ("168.192.4.10", 1026);
NodeContainer one = subnets[2].Get ();
source.Setup (one);
```


Frameworks

- Observation: Many of the operations executed by the helper class are repetitively executed, in slightly different ways

```
// Create Nodes
// Add NetDevice and Channel
// Add Protocol Stack
// Add Applications
// Add Mobility
```

Frameworks

- Idea: Can we write the same flow of operations once, but delegate them to a Manager?
- The Manager implements the functions
- The functions are virtual
- Users wishing to specialize them can override them as needed

Frameworks

- This design pattern is called Inversion Of Control
- This provides more reusable scenario/topology scripts than ones based on the Helper classes

walk through mixed-wireless-topology.cc and src/topology/

Outline

- Introduction to ns-3
- Reading ns-3 code
- Tweaking ns-3 code
- Extending ns-3 code

How do simulator objects fit together?

- ns-3 objects are C++ objects
  - can be subclassed
- ns-3 Objects support aggregation

ns-3 models are composed of hooking C++ classes together in the traditional way, and also with object aggregation

Aside: C++ templates

- templates allow a programmer to write one version of code that is applicable over multiple types
- templates are *declared*, *defined* and *used*
- Declaration:
  - `template <typename T> T Add (T first, T second);`
  - `T Add (T first, T second);`
- might eventually become
  - `int Add (int first, int second);`

Aside: C++ templates

- Definition:

```
template <typename T>
 T Add (T first, T second)
 {
   return first + second;
 }
```

- Usage:

```
int x, y, z;
z = Add<int> (x, y);
```

Classes may also be templatized

- Declaration:

```
template <typename T>
class MyStack
{
  void Push (T data);
  T Pop (void);
};
```

- Definition:

```
template <typename T> void MyStack<T>::Push (T data)
{ ... }
```

- Usage:

```
MyStack<int> stack;
stack.Push (x);
y = stack.Pop ();
```


Scheduler and callbacks

- Let's look at samples/main-simulator.cc
- Schedules a single event, then exits

```
int main (int argc, char *argv[])
{
  MyModel model;

  Simulator::Schedule (Seconds (10.0), &random_function, &model);

  Simulator::Run ();

  Simulator::Destroy ();
}
```


ns-3 callbacks

- Class template Callback<> implements the functor design pattern
- Callbacks are like function pointers, but more type-safe

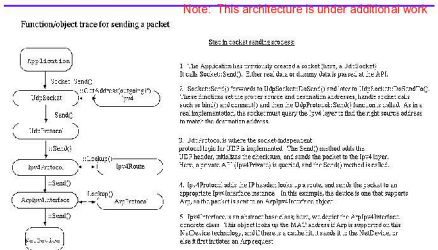
```
static double CbOne (double a, double b) {}
            ^          ^           ^
            |       ---|     ------|
            |          |        |
Callback<double, double, double> one;
```

- Bind a function with a matching signature to a callback

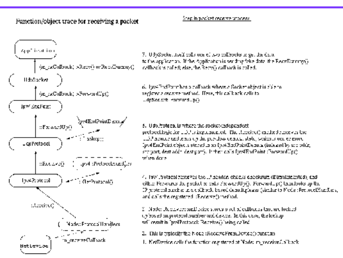
```
one = MakeCallback (&CbOne);
double returnOne = one (10.0, 20.0);
```


Path of a packet (send)

Note: This architecture is under additional work



Path of a packet (receive)



current ns-3 routing model

classes Ipv4RoutingProtocol, Ipv4Route

- Each routing protocol maintains its own RIB --> no common FIB
- Routing protocols are registered with
  `AddRoutingProtocol (Ptr<> protocol, int16_t priority)`
- Routes are looked up by querying each protocol for a route
  - `Ipv4L3Protocol::Lookup()`

Writing new ns-3 models

1) Define your requirements
   - reusability
   - dependencies
   - functionality
2) API review
   - Provide sample header file for API review
   - gather feedback from the ns-developers list

Writing new ns-3 models

3) Create a non-functional skeleton
   - review coding style
   - decide which compilation unit it resides in
   - add to waf
   - build with body ifdeffed out
   - copyright and headers
   - initial doxygen

Writing new ns-3 models

4) Build a skeleton
   - header include guards
   - namespace ns3
   - constructor, empty function prototypes
   - key variables
   - Object/TypeId code
   - write small test program
   - start a unit test

Writing new ns-3 models

5) Build core functions and unit tests
   - use of logging, and asserts
6) Plumb into other modules, if needed
7) Post for review on developers list
8) Resolve comments and merge

Porting from ns-2

- Objects can be ported from ns-2 (or other simulators)
- Make sure licensing is compatible
- Example:
  - ns-2: queue/errmodel.{cc,h}
  - ns-3: src/common/error-model.{cc,h}

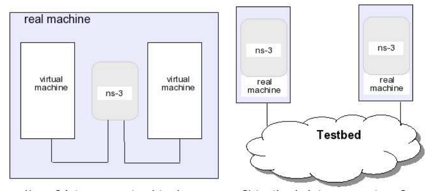
Validation

- Can you trust ns-3 simulations?
  - Can you trust *any* simulation?
  - Onus is on the researcher to verify results
- ns-3 strategies:
  - Open source benefits
  - Validation of models on testbeds
  - Reuse of code
  - Unit tests
  - Event driven validation tests

Walk through examples (time permitting)

- Beyond simple simulation scenarios
- Add a new type of MAC+PHY:
- subclass a NetDevice and a Channel
- Add new types of transport layers:
- subclass Node and Socket
- subclass Ipv4 class to implement per-node Ipv4 forwarding table and Ipv4
- interface configuration
- for example, the Linux TCP stack could be easily integrated into a new type of node, LinuxNode with a LinuxTcpSocket
- Add a new type of traffic generation and analysis:
- subclass Application
- use Socket API

ns-3 goals for emulation



1) ns-3 interconnects virtual machines

2) testbeds interconnect ns-3 stacks

Summary

- ns-3 is an emerging simulator to replace ns-2
- Consider ns-3 if you are interested in:
  - Open source and collaboration
  - More faithful representations of real computers and the Internet
  - Integration with testbeds
  - A powerful low-level API
  - Python scripting
- ns-3 needs you!

Proposed Google Summer of Code projects

- Performance Evaluation and Optimization
- Linux Kernel Network Stack Integration
- Parallel Simulations
- GUI Development
- Real World Code Integration

Resources

Web site:
http://www.nsnam.org

Mailing list:
http://mailman.isi.edu/mailman/listinfo/ns-developers

Tutorial:
http://www.nsnam.org/docs/tutorial/tutorial.html

Code server:
http://code.nsnam.org

Wiki:
http://www.nsnam.org/wiki/index.php/Main_Page