Networks Simulation

Corso di Tecnologie di Infrastrutture di Reti

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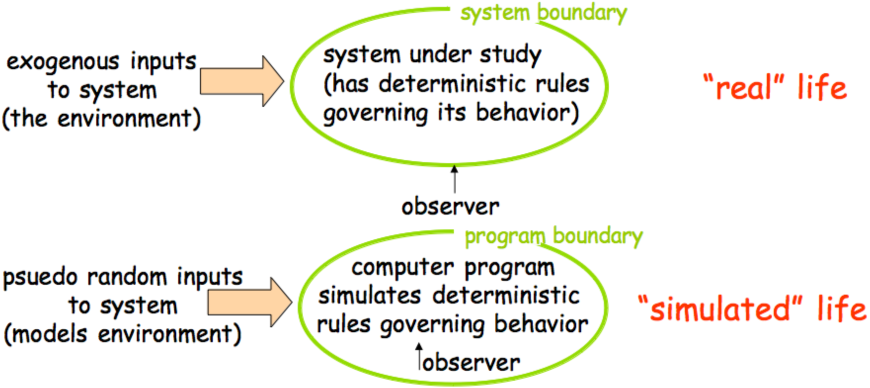
UNIVERSITÀ DEGLI STUDI
DI MODENA E REGGIO EMILIA

Modena, 16th March 2016

Overview

- Motivations
  - What is Simulation
  - Why is it important?
  - What is Emulation
- Different Simulators
  - Why ns-3 is better?
- Inside ns-3
- Demo/Tutorial

Simulation in a nutshell



Why simulation

- Real-system not *available*:
  - complexity (e.g. huge networks);
  - cost (e.g. space communications, satellite);
  - dangerous (e.g. PPDR systems, emergency networks).
- Quick *alternatives* evaluation:
  - star/mesh topology;
  - TCP or UDP for an App;
  - WiMAX or LTE connection;
  - ...
- Evaluate *complex* analytical models (optimal formula unavailable):
  - different QoS solutions;
  - optimizations routing problem for WSN;
  - channel access techniques for challenging environment;
  - ...

Simulation: Pros and Cons

- Pros
  - cheaper: quite always;
  - find bugs in advance;
  - generality: over numerical techniques, over topology, . . .;
  - detail: tuning the granularity system detail.
- Cons
  - accuracy: does the system reflects reality?;
  - large scale system: lot of resources to simulation;
  - may be slow: (computationally expensive, 1 min real time could be hours of simulated time).

Inside Simulation

What's in a simulation program?

- ***simulated time:*** internal variable that keeps track of simulated time (could be faster or slower than real time);
- ***system "state":*** variables maintained by simulation program define system "stat" (e.g. track number of packets in queues, current value of TX timer, ...);
- ***events:*** points in the time when system changes state:
  - each event has associate *event time* (e.g. enqueue/dequeue event, state changes, ...);
  - model for time between events (probabilistic) caused by external environment.

Inside Simulation

Simulation structure:

- simulation program maintains and updates list of future events: the *event list*;
- well defined set of events;
- for each event there is a simulated system action, un update of the event list.

Inside Simulation: A formal view

$$simulation : (\mathcal{S}, \mathcal{E}^n) \xrightarrow{f} (\mathcal{S}, \mathcal{E}^m)$$

where:
$\mathcal{S}$ is the *state* space;
$\mathcal{E}$ is the *event* space;
$\mathcal{E}^n = \{ \, (e_1, e_2, \ldots, e_n) \mid e_i \in \mathcal{E}, \ \forall i \in [1, n] \, \}$.

$$simulation_{step} : (s, (e_1, \ldots, e_n)) \longmapsto (s', (e_2, \ldots, e_n) \cup (e'_1, \ldots, e'_m))$$

where:
$(e_1, \ldots, e_n) \in \mathcal{E}^n$ in the current list of event of the system;
$s \in \mathcal{S}$ is the current system state;
$(e_2, \ldots, e_n) \cup (e'_1, \ldots, e'_m) \in \mathcal{E}^{n+m-1}$ is the new event list of the system;
$s' \in \mathcal{S}$ is the new system state.

Emulation

Emulator is an hw/sw that duplicates the functions of one computer system, so that the emulated behaviour closely resembles the behaviour of the real system.

- Common in gaming (Nintendo game over PC ...);
- A simulation 2.0;
- Real packets over simulated network;
- Simulated packets over real network.

Models of a Simulator

A list of common models "modelled" by a network simulator ...

... **what is a network!?**

Models of a Simulator

A list of common models "modelled" by a network simulator ...

... **what is a network!?**

- **Nodes**
- **Links**

Models of a Simulator

A list of common models "modelled" by a network simulator ...

... **what is a network!?**

- **Nodes**
  - End-system (host)
  - Router
  - Hub . . .
- **Links**
  - Ethernet
  - Point-to-Point
  - Wireless . . .

Models of a Simulator

- **Applications**
  - Bulk TCP transfer (very common)
  - TCP/UDP "on-off" application
  - Web Browsing
  - P2P file transfer
  - Video streaming
  - VoIP
  - Chat ...
- **Protocols**
  - TCP vs UDP
  - IPv4 vs IPv6
  - Routing Protocol (BGP, OSPF, ...)

Models of a Simulator

- **Network Interfaces**
  - Wired/Wireless
  - Layer 2 protocol (802.x family)
- **Packets**
  - Real data vs "Dummy"
- **Routers and Queueing**
  - I/O buffers
  - Route lookup delays
  - Routing table representation
  - Queueing techniques

Output of a Simulator

How to analyse the simulation results?

- **Trace file**
  - Log packet receipt/transmit
  - Log queue size, drop ...
- **Built-in statistics gathering**
  - Link utilization
  - Queue occupancy
  - Throughput
  - Loss rate
- **Custom Tracing**
  - User specifies which packets/links/nodes to trace

Simulation Tools

Who is the best?

- **ns2**
  - Original "design" by Steve McCanne
  - OTcL/C++ hybrid
  - open source
  - De-facto standard in academic research (last decade)
- **Georgia Tech Network Simulator (GTNetS)**
  - Completely C++
  - Designed for distributed simulation (scalable)
  - BGP model

Simulation Tools

- **OPNET**
  - Commercial, closed source tool
  - De-facto standard in Military (cash!)
  - Full-Featured, nice GUI
  - Fine-grained data analysis feature
- **QualNet**
  - Commercial, closed source tool
  - Competes primarily with OPNET
  - Strong in Wireless models

Simulation Tools

- **SSFNet**
  - Both Java and C++ versions
  - Designed for "parallel" simulations (multiCore, not distributed)
- **OMNet++**
  - C++ engine
  - Common in European Community
- **MiniNet**
  - Python models
  - Used by the SDN community (OpenFlow paradigm)
  - Full Emulator

Simulation Tools: NS3

Network Simulator 3

discrete-event network simulator for Internet systems

- Partially founded by US NSF grant
- Large Community (Investigators, Programmer, Staff, Volunteers)
- Modular and Scalable software
- Abstraction and Realism (Accurate!)
- Integration, between emulation
- Lot of Modules (WiFi, cellular, ...)
- Education (examples, tutorials, projects, courses)
- Maintenance (validations, documentation, distribution)

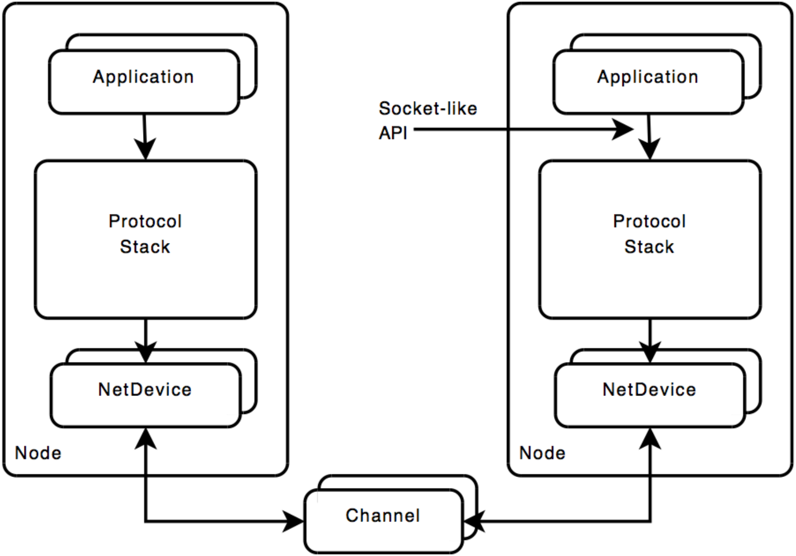
Simulation Tools: NS3 key Features

- Flexible event scheduler
- Output traces in ascii or Pcap (readable with WireShark)
- Emulation mode
  - Integration with real networks or real packets
  - Real-Time Scheduler
- Doxygen documentation
- Mercurial code repo

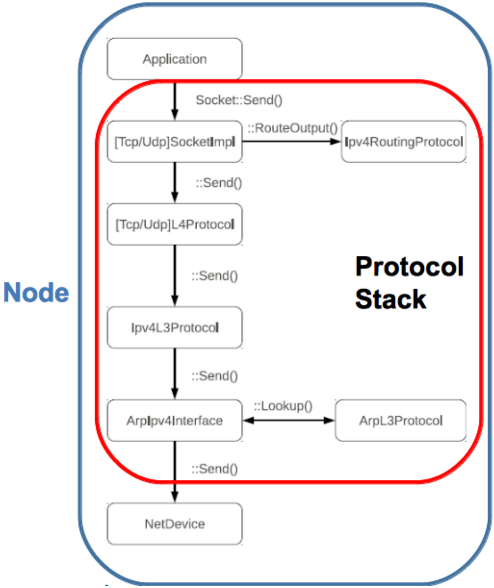
Simulation Tools: NS3 key Decisions

- Use of "smart pointers" to ease memory management
- Use of "Object Aggregation" to allow easy object extension functionality
- Simulation event scheduling on arbitrary functions with arbitrary argument lists
- Packet objects manage sequential array (easy add/remove headers or data)

ns3 basic model



ns3 protocol stack



Protocol stack encapsulates:

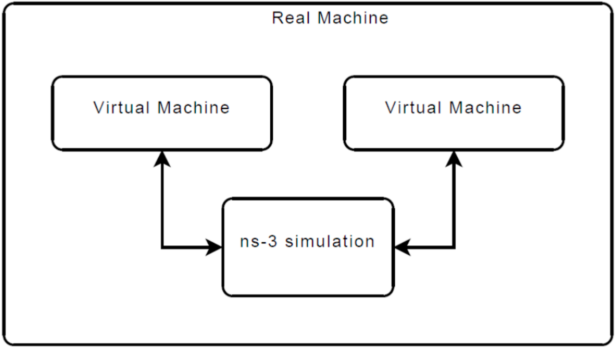
- TCP sockets
- transport protocol
- network protocol
- routing
- ...

ns3 current modules

aodv	applications	bridge
click	config-store	core
csma	dama	dsdv
emu	energy	flow-monitor
internet	lte	mesh
mobility	mpi	netanim
network	nix-vector-routing	olsr
openflow	point-to-point	point-to-point-layout
propagation	spectrum	stats
tap-bridge	test	tools
topology-read	uan	virtual-net-device
visualizer	wifi	wimax

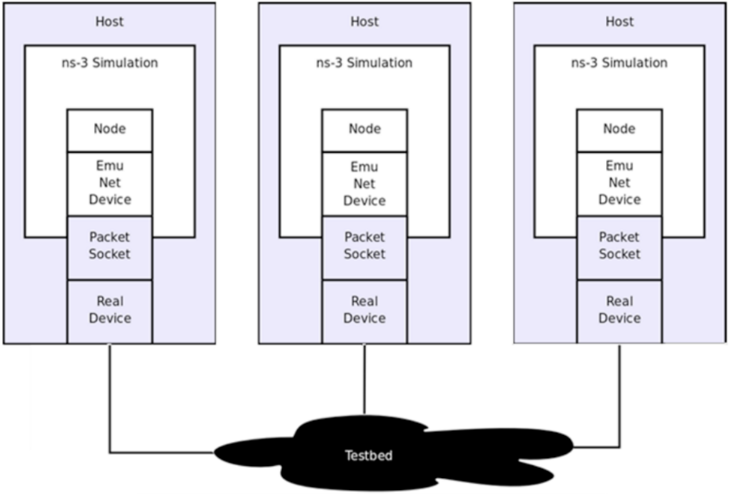
ns3 emulation 1/2

- Stack : *real*
- Network : *simulated*

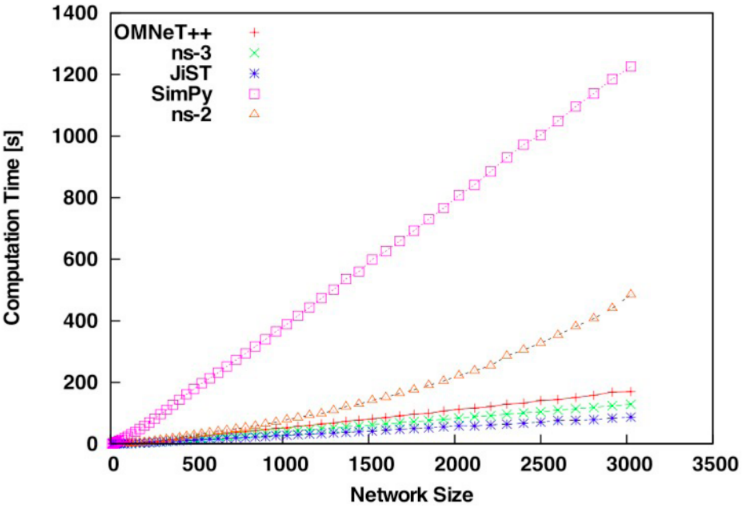


ns3 emulation 2/2

- Stack : *simulated*
- Network : *real*

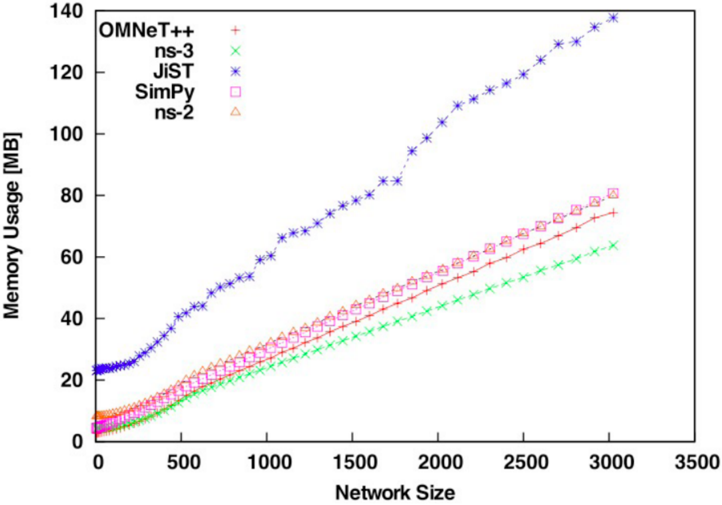


ns3 time performance



E. Weingartner, H. Lehn, and K. Wehrle, "A performance comparison of recent network simulators", *IEEE ICC*, 2009.

ns3 memory performance



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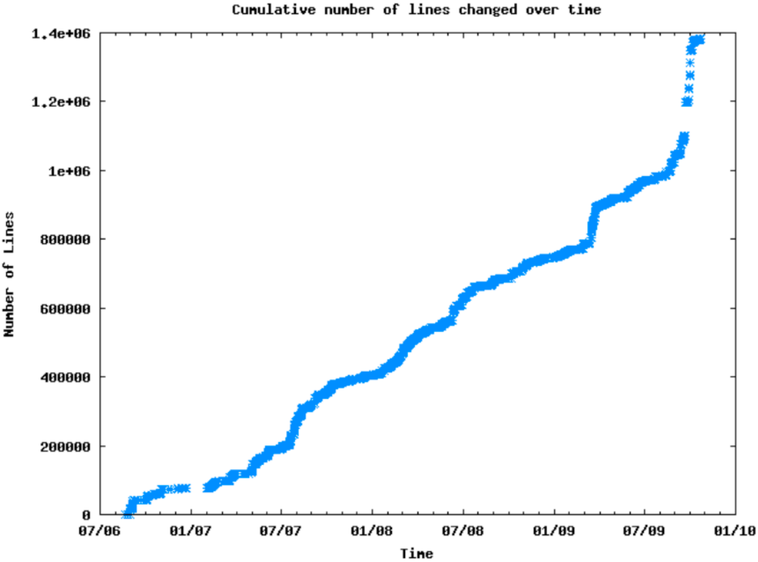
ns3 code evolution



Numbers about ns3

- Line of code: $\sim 300k$
- Downloads: $> 50k$;
- Subscribed users: $> 3.5k$;
- Developers: $> 1k$;
- Citations: $> 100k$

Citations about ns2/ns3

- ns2/ns3 became the main choice for research usage. Source: ACM Digital Library:

	ns2	**OPNET**	**QualNet**
$\geq$ **layer 4**	123 (75%)	30 (18%)	11 (7%)
$=$ **layer 3**	186 (70%)	48 (18%)	31 (12%)
$\leq$ **layer 2**	114 (43%)	96 (36%)	55 (21%)

- nowadays ns3 moves also conferences, workshops, tutorials and GSoC;
- ns3 is currently the standard *de-facto* for research purposes.

LXC

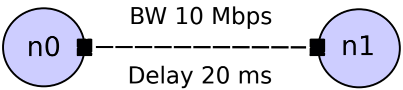
Tutorial on **NON**-Simulation

How to perform a **real** TCP connection on a Linux system

Only facing the non-flexibility of a real system we'll understand the usefulness of simulators

Real TCP Connection on a Real System

We want this:

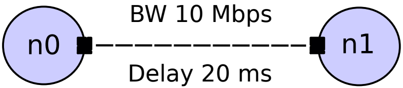


How to run it? We need:

- Two nodes
  - a TCP sender
  - a TCP receiver
- a real (configurable) **link**/connection between the nodes
- something to generate (the desired) TCP **traffic**
- a smart way to **monitor** what's happening on our system

Real TCP Connection on a Real System

We want this:



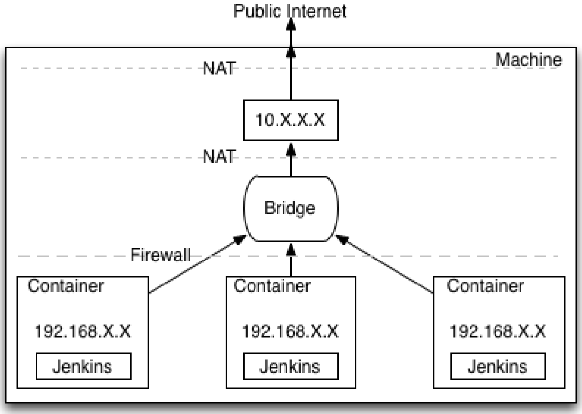
Dummy solution:

- Buy two laptops
- Buy a 10mbit/s Ethernet long enough to have 20ms of propagation delay (unreal)
- Configure the two laptops in order to communicate through the cable
- Start a specific TCP connection, generate some traffic and analyse it

First *better* solution:

LXC is a very flexible and easy-yo-configure *virtual machine* well integrated with the main Linux system

First *better* solution:



We can easily create nodes and let them communicate

First *better* solution:

Install LXC and execute the ex. test: Step-by-step guide

Install LXC and create two containers: on Ubuntu

Legend: **ms** = main system, **ca** = container a and **cb** = container b.

Open a terminal Terminal:

```
ms$ sudo apt-get install lxc
ms$ sudo lxc-create -t ubuntu -n my-container-a
ms$ sudo lxc-create -t ubuntu -n my-container-b
```

both *my-container-a* and *my-container-b* have the default config with user/pass equal to ubuntu/ubuntu.

See the containers status with:

```
ms$ sudo lxc-ls
```

Move **into** a container (*ca*: container a)

On the main system:

```
ms$ sudo lxc-start -n my-container-a
ms$ sudo lxc-attach -n my-container-a
```

this command switch environment and we move into a *ca* shell

See the connections of *ca* with:

```
ca$ ifconfig
```

we focus on **eth0**, we refer to the ip address of *ca* as $eth0_a$

Move **into** a container (*cb*: container b)

On the main system:

```
ms$ sudo lxc-start -n my-container-b
ms$ sudo lxc-attach -n my-container-b
```

this command switch environment and we move into a *cb* shell

See the connections of *cb* with:

```
cb$ ifconfig
```

we focus on **eth0**, we refer to the ip address of *cb* as $\mathrm{eth0}_b$

Create the TCP connection *ca* -> *cb*

On *cb*, our server:

```
cb$ sudo apt-get install iperf
cb$ sudo iperf -s
```

On *ca*, our client:

```
ca$ sudo apt-get install iperf
ca$ sudo iperf -c eth0_b -t 5
```

Good news: *ca* -> *cb* works!

Monitor the TCP connection *ca* -> *cb*

On the main system:

```
ms$ wireshark
```

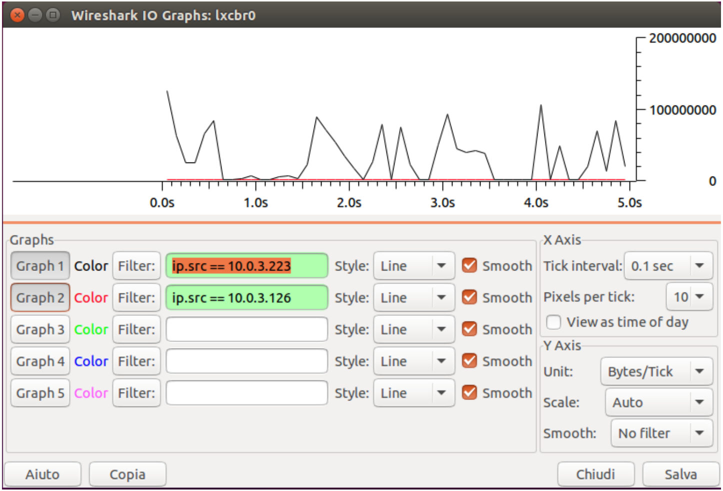
or simply open the program “graphically” by click on it

Start to monitor the interface *lxcbr0*, create by the main system immediately after the creation of the first lxc. Start again the client *ca*, what you will see is this:

(continue)

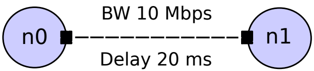
Monitor the TCP connection *ca* -> *cb*

On WireShark: Statistics -> IO Graph -> done!

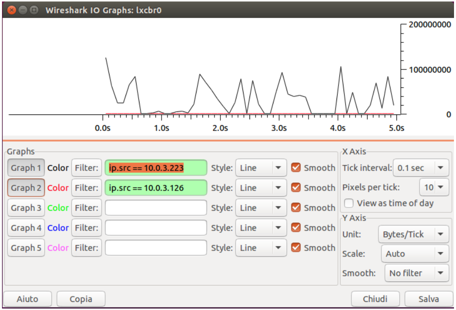


But remember

We want this:



But we have this:



Set bandwidth and delay on both *ca* and *cb*

On container a:

```
ca$ sudo tc qdisc add dev eth0 handle 1: root htb default 11
ca$ sudo tc class add dev eth0 parent 1: classid 1:1 htb rate 1.2mbps
ca$ sudo tc class add dev eth0 parent 1:1 classid 1:11 htb rate 1.2mbps
ca$ sudo tc qdisc add dev eth0 parent 1:11 handle 10:1 netem delay 20ms
```

do the same on *cb*

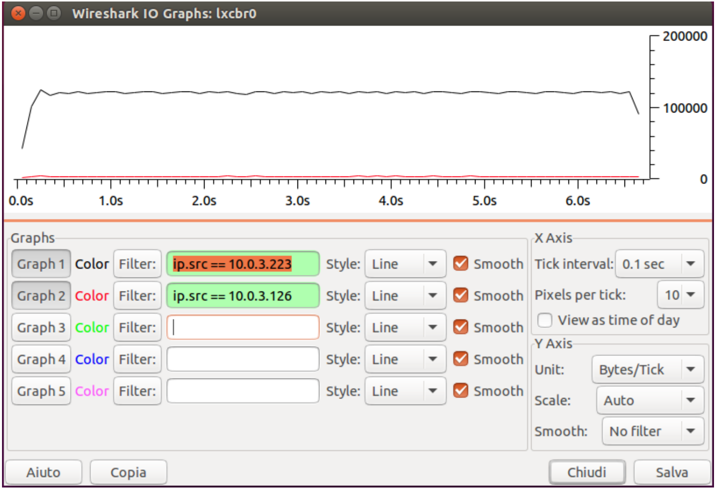
NOTE

mbps fot *tc* tool is MBps actually

painful? not as a **real** system...but if we want more...this is not enough

Monitor the TCP connection *ca -> cb*

Start again WireShark monitoring *lxcbr0*, start the client *ca* and:



NETWORK SIMULATOR

Tutorial on ns3
Install and Execute

Install ns3: Using git as source code manager

On Ubuntu:

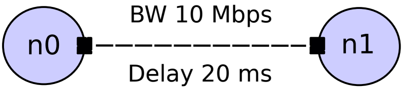
```
$ git clone https://github.com/nsnam/ns-3-dev-git.git
$ cd ns-3-dev-git
$ ./waf configure –enable-examples
$ ./waf –run first
```

On Mac OSx

```
$ git clone https://github.com/nsnam/ns-3-dev-git.git
$ cd ns-3-dev-git
$ ./waf configure –enable-examples
$ ./waf –run first
```

Run first example: TCP Bulk

Draft of the example:

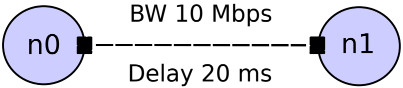


How to run it?

```
$ ./waf –run "tcp-bulk-send –tracing"
$
$ cat tcp-bulk-send.tr
$ tcpdump -tt -r tcp-bulk-send-0-0.pcap
$ wireshark tcp-bulk-send-0-0.pcap
```

Learn from first example: TCP Bulk

The goal is:



Learn from first example: TCP Bulk

Step 0 header and main:

```
#include <string>
#include <fstream>
#include "ns3/core-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/internet-module.h"
#include "ns3/applications-module.h"
#include "ns3/network-module.h"
#include "ns3/packet-sink.h"

using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("TcpBulkSendExample");

int
main (int argc, char *argv[])
{

  bool tracing = false;
  uint32_t maxBytes = 0;
```

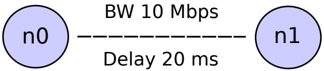
Learn from first example: TCP Bulk

Step 1 create the nodes:


```
//
// Explicitly create the nodes required by the topology (shown
    above).
//
  NS_LOG_INFO ("Create nodes.");
  NodeContainer nodes;
  nodes.Create (2);
```

Learn from first example: TCP Bulk

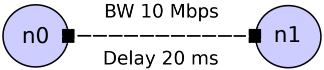
Step 2 create the link:




```
  NS_LOG_INFO ("Create channels.");
//
// Explicitly create the point-to-point link required by the
    topology (shown above).
//
  PointToPointHelper pointToPoint;
  pointToPoint.SetDeviceAttribute ("DataRate", StringValue
      ("10Mbps"));
  pointToPoint.SetChannelAttribute ("Delay", StringValue ("20ms"));
```

Learn from first example: TCP Bulk

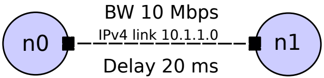
Step 3 connect nodes and link:




```
  NetDeviceContainer devices;
  devices = pointToPoint.Install (nodes);
//
// Install the internet stack on the nodes
//
  InternetStackHelper internet;
  internet.Install (nodes);
```

Learn from first example: TCP Bulk

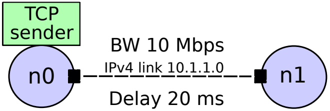
Step 4 configure the network:




```
//
// We've got the "hardware" in place.  Now we need to add IP
    addresses.
//
  NS_LOG_INFO ("Assign IP Addresses.");
  Ipv4AddressHelper ipv4;
  ipv4.SetBase ("10.1.1.0", "255.255.255.0");
  Ipv4InterfaceContainer i = ipv4.Assign (devices);
```

Learn from first example: TCP Bulk

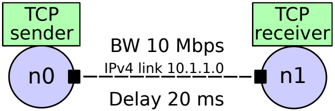
Step 5 create the application:




```
  NS_LOG_INFO ("Create Applications.");
//
// Create a BulkSendApplication and install it on node 0
//
  uint16_t port = 9;  // well-known echo port number
  BulkSendHelper source ("ns3::TcpSocketFactory",
                         InetSocketAddress (i.GetAddress (1),
                                port));
  // Set the amount of data to send in bytes.  Zero is unlimited.
  source.SetAttribute ("MaxBytes", UintegerValue (maxBytes));
  ApplicationContainer sourceApps = source.Install (nodes.Get (0));
  sourceApps.Start (Seconds (0.0));
  sourceApps.Stop (Seconds (5.0));
```

Learn from first example: TCP Bulk

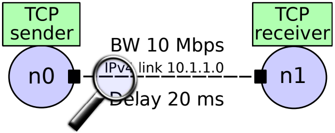
Step 6 create the receiver socket:




```
//
// Create a PacketSinkApplication and install it on node 1
//
  PacketSinkHelper sink ("ns3::TcpSocketFactory",
                         InetSocketAddress (Ipv4Address::GetAny
                             (), port));
  ApplicationContainer sinkApps = sink.Install (nodes.Get (1));
  sinkApps.Start (Seconds (0.0));
  sinkApps.Stop (Seconds (5.0));
```

Learn from first example: TCP Bulk

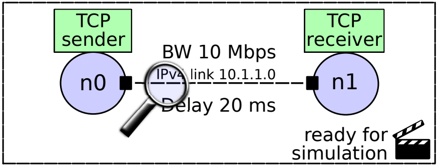
Step 7 set up tracing:




```
//
// Set up tracing if enabled
//
  if (tracing)
    {
      AsciiTraceHelper ascii;
      pointToPoint.EnableAsciiAll (ascii.CreateFileStream
          ("tcp-bulk-send.tr"));
      pointToPoint.EnablePcapAll ("tcp-bulk-send", false);
    }
```

Learn from first example: TCP Bulk

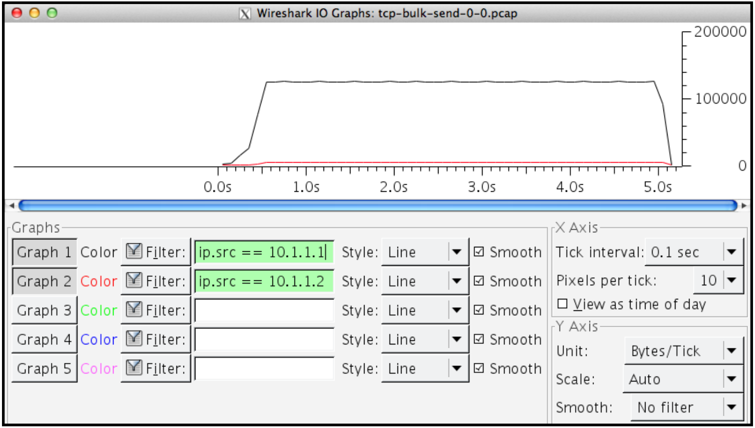
Step 8 actual simulation:




```
//
// Now, do the actual simulation.
//
  NS_LOG_INFO ("Run Simulation.");
  Simulator::Stop (Seconds (10.0));
  Simulator::Run ();
  Simulator::Destroy ();
  NS_LOG_INFO ("Done.");
```

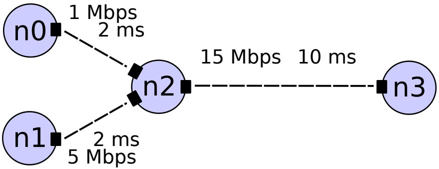
Demo on TCP Bulk

Pcap analysis of TCP Bulk example with WireShark:



Run second example: Global Routing

Draft of the example:

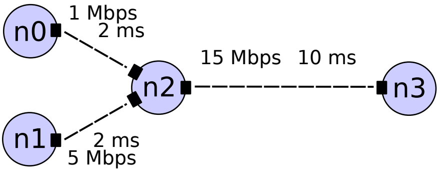


How to run it?

```
$ ./waf –run simple-global-routing
$
$ cat simple-global-routing.tr
$ tcpdump -tt -r simple-global-routing-2-3.pcap
$ wireshark simple-global-routing-2-3.pcap
```

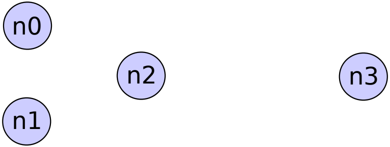
Learn from second example: Global Routing

The goal is:



Learn from second example: Global Routing

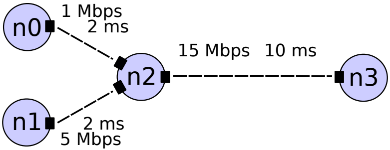
Step 1 create the nodes:




```
// Here, we will explicitly create four nodes.  In more
    sophisticated
// topologies, we could configure a node factory.
NS_LOG_INFO ("Create nodes.");
NodeContainer c;
c.Create (4);
NodeContainer n0n2 = NodeContainer (c.Get (0), c.Get (2));
NodeContainer n1n2 = NodeContainer (c.Get (1), c.Get (2));
NodeContainer n3n2 = NodeContainer (c.Get (3), c.Get (2));

InternetStackHelper internet;
internet.Install (c);
```

Learn from second example: Global Routing

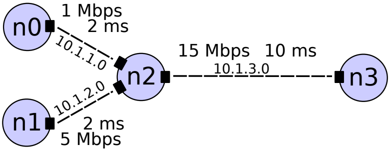
Step 2 create the link:




```
// We create the channels first without any IP addressing
    information
  NS_LOG_INFO ("Create channels.");
  PointToPointHelper p2p;
  p2p.SetDeviceAttribute ("DataRate", StringValue ("1Mbps"));
  p2p.SetChannelAttribute ("Delay", StringValue ("2ms"));
  NetDeviceContainer d0d2 = p2p.Install (n0n2);

  p2p.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
  NetDeviceContainer d1d2 = p2p.Install (n1n2);

  p2p.SetDeviceAttribute ("DataRate", StringValue ("15Mbps"));
  p2p.SetChannelAttribute ("Delay", StringValue ("10ms"));
  NetDeviceContainer d3d2 = p2p.Install (n3n2);
```

Learn from second example: Global Routing

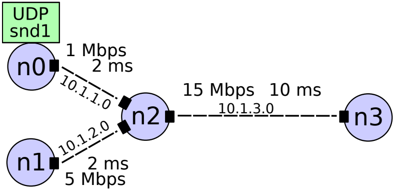
Step 3 configure the network:




```
// Later, we add IP addresses.
NS_LOG_INFO ("Assign IP Addresses.");
Ipv4AddressHelper ipv4;
ipv4.SetBase ("10.1.1.0", "255.255.255.0");
Ipv4InterfaceContainer i0i2 = ipv4.Assign (d0d2);

ipv4.SetBase ("10.1.2.0", "255.255.255.0");
Ipv4InterfaceContainer i1i2 = ipv4.Assign (d1d2);

ipv4.SetBase ("10.1.3.0", "255.255.255.0");
Ipv4InterfaceContainer i3i2 = ipv4.Assign (d3d2);

// Create router nodes, initialize routing database and set up
    the routing
// tables in the nodes.
Ipv4GlobalRoutingHelper::PopulateRoutingTables ();
```

Learn from second example: Global Routing

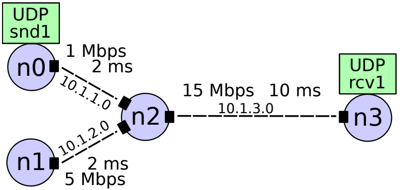
Step 4 create first app sender:




```
// Create the OnOff application to send UDP datagrams of size
// 210 bytes at a rate of 1 Mb/s
NS_LOG_INFO ("Create Applications.");
uint16_t port = 9;   // Discard port (RFC 863)
OnOffHelper onoff ("ns3::UdpSocketFactory",
                   Address (InetSocketAddress (i3i2.GetAddress
                        (0), port)));
onoff.SetConstantRate (DataRate ("1Mb/s"));
ApplicationContainer apps = onoff.Install (c.Get (0));
apps.Start (Seconds (1.0));
apps.Stop (Seconds (10.0));
```

Learn from second example: Global Routing

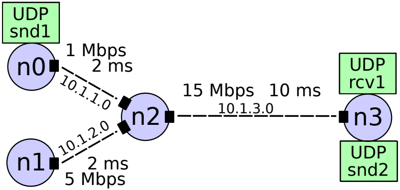
Step 5 create first app receiver:




```
// Create a packet sink to receive these packets
PacketSinkHelper sink ("ns3::UdpSocketFactory",
                       Address (InetSocketAddress
                           (Ipv4Address::GetAny (), port)));
apps = sink.Install (c.Get (3));
apps.Start (Seconds (1.0));
apps.Stop (Seconds (10.0));
```

Learn from second example: Global Routing

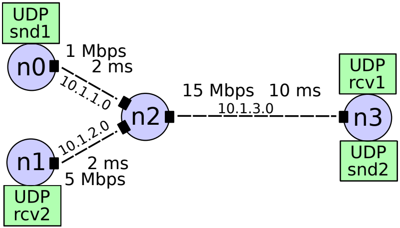
Step 6 create second app sender:




```
// Create a similar flow from n3 to n1, starting at time 1.1
    seconds
onoff.SetAttribute ("Remote",
                    AddressValue (InetSocketAddress
                        (i1i2.GetAddress (0), port)));
onoff.SetConstantRate (DataRate ("5Mb/s"));
apps = onoff.Install (c.Get (3));
apps.Start (Seconds (1.1));
apps.Stop (Seconds (10.0));
```

Learn from second example: Global Routing

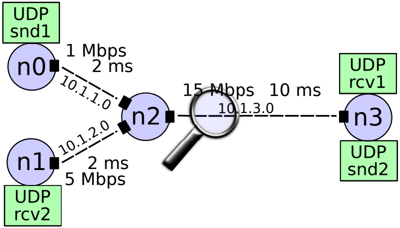
Step 7 create second app receiver:




```
// Create a packet sink to receive these packets
apps = sink.Install (c.Get (1));
apps.Start (Seconds (1.1));
apps.Stop (Seconds (10.0));
```

Learn from second example: Global Routing

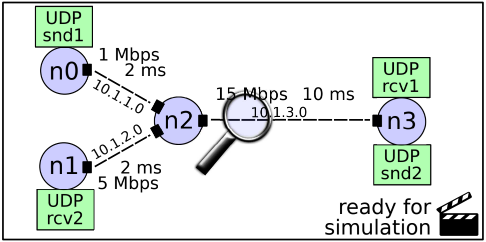
Step 8 set up tracing:




```
AsciiTraceHelper ascii;
p2p.EnableAsciiAll (ascii.CreateFileStream
    ("simple-global-routing.tr"));
p2p.EnablePcapAll ("simple-global-routing");
```

Learn from second example: Global Routing

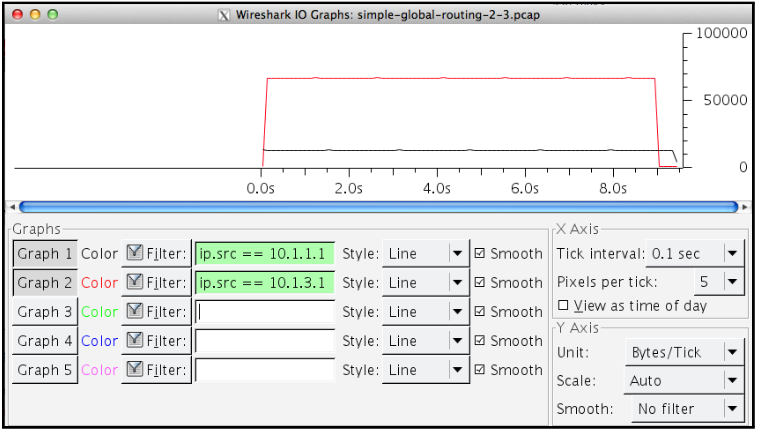
Step 9 actual simulation:




```
NS_LOG_INFO ("Run Simulation.");
 Simulator::Stop (Seconds (12));
 Simulator::Run ();
 NS_LOG_INFO ("Done.");
 Simulator::Destroy ();
 return 0;
```

Demo on Global Routing

Pcap analysis of Global Routing example with WireShark:



Next steps with ns3

- Download it (see slide 46 of this presentation for details)
- Try it (look at the examples of this presentation)
- Play it (tune your own code)
- Do not forget to use WireShark

Next *practical* lesson: end of the course

- Bring your own laptop (with ns-3 on)
  - you can't? form a group
    - you can't? follow at least. Don't worry
- Follow the lesson actively
- Try to solve some exercises (together)

Exam Proposals about ns3

- MultiPath-TCP
- TCP variants (like Cubic, default linux TCP)
- Performance measurements
- Narrow time measurement
- Cross-layer message passing
- User mobility study
- AQM algorithms (queueing discipline)
- Bash scripting with LXC

Resources

- ns3 web site: `http://www.nsnam.org`
- Developer mailing list: `http://mailman.isi.edu/mailman/listinfo/ns-developers`
- User mailing list: `http://groups.google.com/group/ns-3-users`
- 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`

Contacts

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