Part 3: Network Simulator – 2

NS2: Contents

- NS2 – Introduction to NS2 simulator
  - Background info
  - Main concepts, basics of Tcl and Otcl
  - NS2 simulation building blocks
- Some NS2 examples
- NS2 project work instructions

References

Material based on following sources:

1. Haobo Yu, Nader Salehi, “NS2 tutorial”, IEC'2000 ns workshop, San Diego, USA, June 2000.

2. John Heideman, ”IPAM tutorial: Network modeling and traffic analysis with ns-2”, presentation at the UCLA/Institute for Pure and Applied Mathematics, Los Angeles, USA, March 2002.

Both available from

- http://www.isi.edu/nsnam/ns/ns-tutorial/index.html

What is NS2?

- Short characterization
  - discrete event network simulator
  - packet-level
  - link layer and up
  - wired and wireless
- A collaborative simulation platform
  - freely distributed, open source
  - developed by researchers in universities and research institutes
  - provide common reference ⇒ promote sharing
  - test suites ⇒ increase confidence in results
- Intended users
  - researchers
  - developers
  - educators

History and status

- Brief history
  - REAL simulator by UCB (1989)
  - ns1 (Floyd and McCanne, then at LBL)
  - ns2
    - VINT project (Virtual InterNet Testbed)
    - LBL, PARC, UCB, USC/ISI
  - currently maintained at USC/ISI, with input from K. Fall, S. Floyd et al.
- Status
  - size: > 200k loc (lines of code) of C++ and Tcl, 350 page manual
  - user base: >1k institutions, >10k users
  - platforms: (almost) all Unix and Windows
    - Windows needs some manual work, Unix (Linux) is the preferred platform
  - releases about every 6 months, plus daily snapshots of the CVS archive
    - current version ns-2.30, released Sept '06

NS components

- ns, the simulator itself
- nam, the Network AniMator
  - for visualizing ns output
  - GUI for simple ns scenarios
- Pre-processing
  - traffic and topology generators
- Post-processing
  - simple trace analysis
  - using Awk, Perl, or Tcl

NS models

- Traffic models and applications
  - web, FTP, telnet, constant bit rate, on-off
- Transport protocols
  - unicast: TCP (Tahoe, Reno, Vegas, …), UDP
  - multicast: SRM
- Routing and queuing
  - wired routing (unicast, multicast), ad hoc routing, Mobile IP
  - queuing models: drop tail, RED, fair queuing
- Physical media
  - wired (point-to-point, LANs), wireless (multiple propagation models), satellite

Installation

- http://www.isi.edu/nsnam/ns/
  - for easy installation, download ns-allinone
  - includes Tcl, Otcl, TclCL, ns, nam, etc.
  - to optimize size, it is possible to compile from pieces (see URL for details)
- Mailing list: ns-users@isi.edu
  - “subscribe ns-users” in body
  - for archive of mails see URL
- Documentation (on web at URL above)
  - Marc Greis tutorial
  - ns manual

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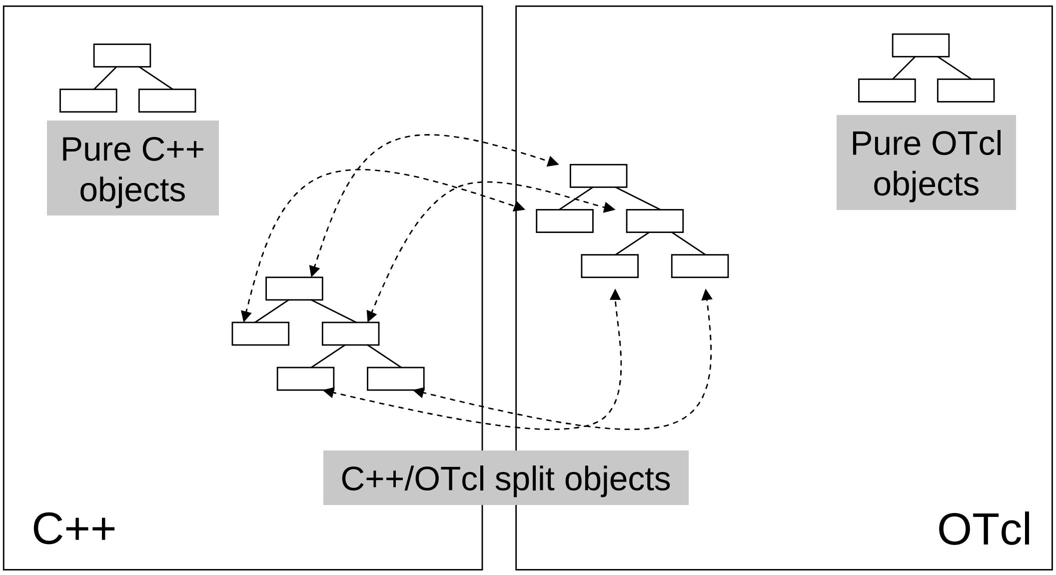
NS architecture (1)

- Object-oriented & modular
  - pros: code reuse (e.g., TCP variants), maintenance
  - cons: performance (speed and memory), careful planning of modularity
- Software structure
  - uses two languages: C++ and OTcl (Object TCL)
    - to achieve separation of control- and packet level
  - C++ for packet processing
    - fast execution, detailed, full control over execution
    - to make simulator scalable, packet processing must be done at C++ level
  - OTcl for control
    - simulation setup, configuration, occasional actions (e.g., creating new TCP flows)
  - compromise between speed and abstraction level(s) offered to the user
  - draw back: need to learn two languages and debug in two “worlds”

NS architecture (2)

- Architecture aims at scalability and easy extensibility
- Scalability
  - per packet actions need to be implemented such that execution is quick
  - achieved by separating control and packet handling
- Extensibility
  - must be “easy” for users to add own objects and functionality
  - fine-grained object composition:
    - basically, easy to understand role of each object and to identify which object(s) to modify
  - split C++/OTcl objects:
    - do not have to change anything at C++ level if new functionality only needed at OTcl level

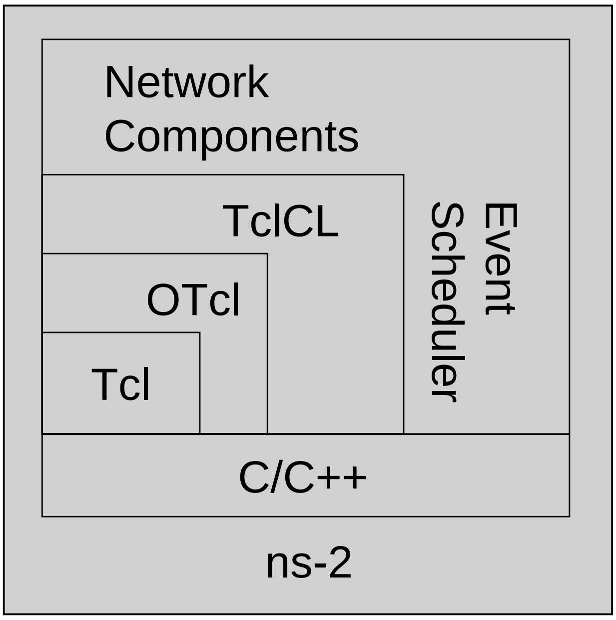
OTcl and C++: the duality



- OTcl and C++ share class hierarchy
- TclCL-library implements mechanisms that make sharing of functions, variables, etc., possible between C++ code and OTcl

Software architecture

- OTcl: object-oriented Tcl
- TclCL: C++ and OTcl linkage
- Discrete event scheduler
- Data network components
  - link layer and up
  - emulation support



Hello World!

```
simple.tcl
   # Create the simulator object and assign it name “ns”
   set ns [new Simulator]

   # Schedule event at time 1 to print Hello World!
   $ns at 1 “puts \“Hello World!\””

   # ... and exit at time 1.5
   $ns at 1.5 “exit”

   # Run the simulation
   $ns run

swallow 74% ns simple.tcl
Hello World!
swallow 75%
```

Basic tcl

Variables:
```
set x 10
puts "x is $x"
```

Functions and expressions:
```
Set y [pow $x 2]
Set y [expr $x*$x]
```

Control flow:
```
if {$x > 0} {return $x} else
   {return [expr -$x]}

while {$x > 0} {
  puts $x
  incr x –1
}

for {set i 0} {$i < 10} {incr i}
   {puts $i}
```

Procedures:
```
proc fact {n} {
  if {$n == 1} {
    return 1
  } else {
      expr $n*[fact [incr n –1]]
  }
}

proc sum {} {
  global a b
  expr $a+$b
}
```

Tcl benefits:
- Tcl also contains lists, arrays, etc.
- Can use a real programming language to construct topologies, traffic sources, applications, etc.

Basic OTcl

```
Class Person
# constructor
Person instproc init {age} {
  $self instvar age_
  set age_ $age
}

# method greet
Person instproc greet {} {
  $self instvar age_
  puts "$age_ years old: How
   are you doing?"
}
```

```
Class Kid -superclass Person
# new greet-method
Kid instproc greet {} {
  $self instvar age_
  puts "$age_ years old kid:
    What's up, dude?"
}

set person [new Person 45]
set kid [new Kid 15]

$person greet
$kid greet
```

⇒ Can easily make variations of existing objects (e.g., TCP variants)

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Elements of ns2

- Assumption:
  - we only consider wired simulations (without routing)
- Important elements:
  - Create the event scheduler and random number generator
  - Create network
    - nodes and links
  - Create transport connection
    - TCP, UDP
  - Create applications
    - CBR, FTP
  - Setup tracing
    - trace queues and flows

Creating the event scheduler

- Create event scheduler
  ```
  set ns [new Simulator]
  ```
- Schedule events
  ```
  $ns at <time> <event>
  ```
  - <event>: any legitimate ns/tcl commands
- Start scheduler
  ```
  $ns run
  ```


Creating random number generators (1)

- Random number generator based on MRG32k3a generator (L'Ecuyer, 1999)
- Creating a pseudo random number generator with seed
  ```
  set rng [new RNG]
  $rng seed 12345
  ```
  - Note: seed 0 uses a heuristic seeding method (non-deterministic seed)
- Choosing the next independent random number stream
  ```
  $rng next-substream
  ```
  - This is good for controlling independent replications
  - Altogether $2.3*10^{15}$ independent streams, each with $7.6*10^{22}$ different numbers

Creating random number generators (2)

- Generating rv’s from other distributions can be done in two ways
- Using the class RNG
  - uniform rv’s: `$rng uniform a b`, `$rng integer k`
  - exponential (with average 1): `$rng exponential`
- Using the class RandomVariable
  - available distributions: uniform, exponential, hyper-exponential, Pareto
  - example: hyper-exponential

```
# Create and configure generator
set hypexp [new RandomVariable/HyperExponential]
$hypexp set avg_ 10
$hypexp set cov_ 2
# Draw values
$hypexp value
```


Creating the network

- Nodes

```
set n0 [$ns node]
set n1 [$ns node]
```

- Links and queuing

```
$ns duplex-link $n0 $n1 <bandwidth> <delay> <queue_type>
```

  - <queue_type>: DropTail, RED, CBQ, FQ, SFQ, DRR
  - example: link with 10 Mbps, 10 ms delay, buffer size 100, RED buffer control

```
$ns duplex-link $n0 $n1 10Mbps 10ms RED
# Set queue size
$ns queue-limit $n0 $n1 100
# Set RED parameters
set redq [[$ns link $n0 $n1] queue]
$redq set thresh_ 0
$redq set maxthresh_ 100
$redq set linterm_ 20
$redq set mean_pktsize_ 500
$redq set q_weight_ 0.001
```

Creating connections: UDP

- UDP

```
set udp [new Agent/UDP]
set null [new Agent/Null]
$ns attach-agent $n0 $udp
$ns attach-agent $n1 $null
$ns connect $udp $null
```

- All above combined into one command:
  - Format:

```
$ns create-connection <src_type> <src_node> <dst_type> <dst_node>
   <packet_class>
```

  - Example:

```
$ns create-connection UDP $n0 Null $n1 1
```


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Creating traffic: on top of UDP

- CBR (Constant Bit Rate)

```
set src [new Application/Traffic/CBR]
```

- Exponential or Pareto on-off
  - on/off times exponentially/Pareto distributed

```
set src [new Application/Traffic/Exponential]
set src [new Application/Traffic/Pareto]
```

- Connecting application to transport

```
$src attach-agent $udp
```

  - “$udp” defined earlier

- Above are only traffic sources for a single user
  - ns2 does not provide much support for generating background (aggregate) traffic
  - for example, generating pure GI/GI/1 – type traffic needs to be done “manually” (either at C++ or OTcl level)

Creating Connection: TCP

- TCP
```
set tcp [new Agent/TCP]
set tcpsink [new Agent/TCPSink]
$ns attach-agent $n0 $tcp
$ns attach-agent $n1 $tcpsink
$ns connect $tcp $tcpsink
```
- … or above in one command:
```
$ns create-connection TCP $n0 TCPSink $n1 1
```
- Different TCP variants:
  - TCP = Tahoe TCP (slow start, AIMD)
  - TCP/Reno = Reno TCP (above + fast retransmit/fast recovery)
  - TCP/NewReno = modified Reno TCP with improved fast retransmit
  - TCP/Sack1 = SACK TCP (selective ACK)
  - other sources: TCP for asymmetric links (wireless), RTP source, RTCP source
  - different sinks: for each TCP type, LossMonitor (sink with packet loss monitoring)

Creating traffic: on top of TCP

- FTP
```
set ftp [new Application/FTP]
$ftp attach-agent $tcp
```
- Telnet
```
set telnet [new Application/Telnet]
$telnet attach-agent $tcp
```

Starting/stopping traffic agents

- Starting and stopping times scheduled as events to the scheduler
```
$ns at <time> <event>
```
- Starting
```
$ns at 1.0 “$ftp start”
```
  - greedy source (sends infinitely long)
  - similarly for CBR, telnet and on/off sources
- Stopping
```
$ns at 5.0 “$ftp stop”
```
  - similarly for CBR, telnet and on/off sources
- Sending for example 1000 packets (only for FTP!)
```
$ns at 7.0 “$ftp produce 1000”
```


Creating Traffic: Trace Driven

- Trace driven
```
set tfile [new Tracefile]
$tfile filename <file>
set src [new Application/Traffic/Trace]
$src attach-tracefile $tfile
```
- <file>:
  - each record consists of two 32 bit fields
  - inter-packet time (msec) and packet size (byte)

Tracing

- Trace packets on all links of the network

```
$ns trace-all [open test.out w]
```

- Turn on tracing on specific links

```
$ns trace-queue $n0 $n1
```

- Tace format:

```
+ 0.89456 0 2 cbr 210 ------- 0 0.0 3.1 0 0
- 0.89456 0 2 cbr 210 ------- 0 0.0 3.1 0 0
r 1.00234 0 2 cbr 210 ------- 0 0.0 3.1 0 0
```

  - event type: (enque = +, deque = -, receive = r, drop = d)
  - event time
  - node ids of traced link (2 fields)
  - name of packet ("source's name")
  - packet size
  - flags (not used here)
  - flow identifier
  - source/destination addresses (2 fields)
  - sequence number
  - unique packet identifier (all packets created in the simulation have a unique id)

Monitoring

- Sometimes tracing produces "too much" data
  - e.g., just want to know number of arrivals or dropped packets on a link or per flow
- Queue monitors
  - E.g. you only want to monitor the queue length on the link between n0 and n1
  - Prepare the queue for monitoring

```
set interval 0.01
set qm [$ns monitor-queue $n0 $n1 stdout $interval]
```

  - To read the counters maintained by queue monitor object one needs a procedure to read the counters and to separately schedule the procedure!!!
- Flow monitors
  - enable flow monitoring

```
set fmon [$ns makeflowmon Fid]
$ns attach-fmon [$ns link $n0 $n1] $fmon
```

  - count arrivals and drops for flow with id xx

```
set fclassifier [$fmon classifier]
set flow1 [$fclassifier lookup auto 0 0 xx]
set parr [$flow1 set parrivals_]
set pdrops [$flow1 set pdrops_]
```

Summary: generic script structure

```
set ns [new Simulator]
# [Turn on tracing]
# Create topology
# Setup packet loss, link dynamics
# Create routing agents
# Create:
#   - multicast groups
#   - protocol agents
#   - application and/or setup traffic sources
# Post-processing procs
# Start simulation
```


Where to look for information?

- NS2 manual
  - http://www.isi.edu/nsnam/ns/ns-documentation.html
  - big document, can download into own directory to make accessing faster
- Daily snapshot of the class hierarchy
  - http://www-sop.inria.fr/planete/software/ns-doc/ns-current/
  - good source of information, can see the whole class hierarchy with one “snap shot”

If you need to view the C++/OTcl code…

- Viewing code is one way to find out how things work
  - manuals often don't explain everything
  - want to see, e.g., what variables are visible in OTcl from C++
- All paths given here are relative to your ns2 top directory
  - here we assume it is ns-allinone-2.1b9a
- C++ code:
  - /ns-allinone-2.1b9a/ns-2.1b9a/
- OTcl
  - /ns-allinone-2.1b9a/ns-2.1b9a/tcl/lib
    - ns-default.tcl (contains all default values of ns2-objects)
    - also OTcl definitions of many other basic objects used during simulations
  - /ns-allinone-2.1b9a/ns-2.1b9a/tcl
    - most specialized objects under sub-directories

Other functionality, but not covered here…

- In ns2
  - link level errors (error modules for generating random packet corruptions)
  - LAN simulations (including WLAN/IEEE 802.11)
  - routing
  - multicast
  - Mobile IP
  - DiffServ
- Visualization tools
  - mobility patterns
    - cbrgen.tcl for creating connections (CBR/TCP)
    - setdest-program for generating node movement patterns (RWP mobility model)
  - nam-1 (Network AniMator Version 1)
    - packet-level animation
    - well supported by ns
  - xgraph
    - conversion from ns trace to xgraph format