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:


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/](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
- TcICL-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 {
    expr $x[expr {[incr n -1]}]
}
while {$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

- Creating a pseudo random number generator (with heuristic seed)
  - set rng [new RNG]
  - $rng seed 0

- Generating rv’s from other distributions
  - 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

```bash
$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:
  - $ns create-connection <src_type> <src_node> <dst_type> <dst_node> <packet_class>
  - $ns create-connection UDP $n0 Null $n1 1
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**
  - "$udp" defined earlier
  - $src attach-agent $udp

- 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**
  - `$ns at 7.0 "$ftp produce 1000"`
  - works only for FTP
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`
- Trace 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: (enqueue = +, dequeue = −, 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
  - ⇒ monitors

- Queue monitors
  - set qmon [$ns monitor-queue $n0 $n1]
  - to read number of packet arrivals and drops
    - set parr [$qmon set parrivals_]
    - set drops [$qmon set pdrops_]

- Flow monitors
  - enable flow monitoring
    - set fmon [$ns makeflowmon Fid]
    - $ns attach-fmon [$ns link $n0 $n1] $fmon
  - count arrivals and drops for flow with id xx
    - set flow1 [$fmon classifier]
    - set flow1 [$fclassifier lookup auto 0 0 xx]
    - set parr [$flow1 set parrivals_]
    - set pdrops [$flow1 set pdrops_]

Summary: generic script structure

```bash
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
```

9.10.2006 29

S-38.3148 Simulation of data networks / ns2
Where to look for information?

- NS2 manual
  - [http://www.isi.edu/nsnam/ns/ns-documentation.html](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
  - 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
  – LAN simulations (including wireless)
  – 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