Tutorial:

The *ns-2* Network Simulator

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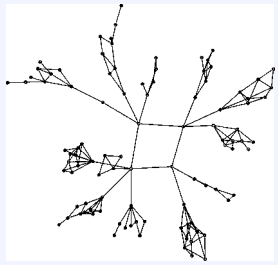
Outline

- ns-2 overview
- Writing simulation scripts
- Obtaining results
- General network simulation hints
- Teaching with ns-2
- Conclusion



simulated transit-stub network
(ns/nam dump)

ns-2 overview

Some thoughts about network simulation

- Real-world experiments sometimes impossible
- Mathematical modeling can be painful
  - Sometimes even painful and inaccurate!
- Simulation cannot totally replace real-world experiments:
  - stack processing delay, buffering, timing, ..
- and vice versa!
  - scaling, simulated vs. real time (long simulations), ..
- Simulation sometimes misses the whole picture
  - focus on specific layers, wrong assumptions, ..

ns-2 (ns version 2) overview

- discrete event simulator (but does not strictly follow DEVS formalism)
- OTcl and C++
  - OTcl scripts, C++ mechanism implementations, timing critical code
- de facto standard for Internet simulation
- open source! advantages:
  - facilitates building upon other work
  - allows others to use your work
- disadvantages:
  - huge and complicated code
  - partially missing, somewhat poor documentation

What to use it for

- Mainly research
  - Examining operational networks, e.g. with Cisco brand names: OPNET
- Focus on Internet technology
  - the tool for TCP simulations
- Not ideal for new link layer technologies etc.
  - typically neglects everything underneath layer 3
  - there are special simulators for things like ATM
- But: lots of features!
  - CSMA/CD, 802.11 now available ... if you really want it
  - Some things must be added manually ("Contributed Modules")

Some ns-2 features

- Lots of TCP (and related) implementations
- Mobility
- Satellite nodes: specify longitude, latitude, altitude
- Internet routing protocols
- Various link loss models
- Various traffic generators (e.g., web, telnet, ..)
- Network emulation capability (real traffic traverses simulated net)

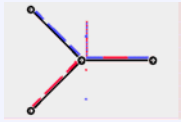
flexible, but hard to use; alternatives: NISTNet, Dummynet

Simulation process

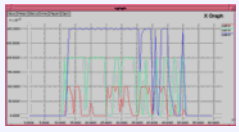
- Not interactive
- Script describes scenario, event scheduling times
- Typical last line: $ns run
- ns generates output files
- "Interactive simulation": view .nam output file with network animator nam
- .nam files can become huge!

Typical long-term simulation process

- Mechanism implementation in C++, test with simple OTcl script
- Simulation scenario development in OTcl
- Test simulation with nam

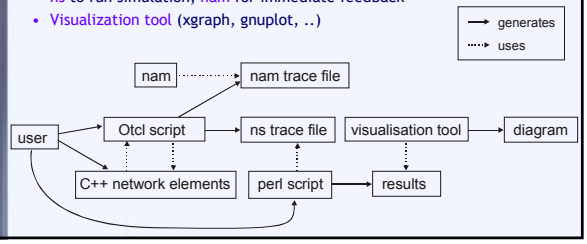


- One way to obtain a useful result:
  perl script -> simulations with varying parameter(s) -> several output files -> perl script -> result file -> xgraph (gnuplot, MS Excel, ..) -> ps file



Simulation elements

- Code: C++ network elements, OTcl simulator elements and simulation script, perl (or whatever) scripts for running simulation and interpreting results
- ns to run simulation, nam for immediate feedback
- Visualization tool (xgraph, gnuplot, ..)



Writing simulation scripts

Writing simulation scripts

- OTcl - what you require is some Tcl knowledge
  - not complicated, but troublesome:
    e.g., line breaks can lead to syntax errors
- Some peculiarities
  - variables not declared, generic type: set a 3 instead of a=3
  - expressions must be explicit: set a [expr 3+4]
    set a 3+4 stores string "3+4" in a
  - use "$" to read from a variable: set a $b instead of set a b
    set a b stores string "b" in a
- Write output: puts "hello world"
- OTcl objects: basically used like variables
  - method calls: $myobject method param1 param2

not (param1, param2) !

Code template *(Marc Greis tutorial)*

```
#Create a simulator object
set ns [new Simulator]

#Open the nam trace file
set nf [open out.nam w]
$ns namtrace-all $nf

#Define a 'finish' procedure
proc finish {} {
    global ns nf
    $ns flush-trace
    #Close the trace file
    close $nf
    #Execute nam on the trace file
    exec nam out.nam &
    exit 0
}
```

set variable value
[new Simulator] generates a new Simulator object

open "out.nam" for writing, associate with nf

$ns ns-command parameters
log everything as nam output in nf

Run nam with parameter out.nam as background process (unix)

More about Tcl & OTcl:
http://www.isi.edu/nsnam/ns/tutorial/index.html
("finding documentation")

Code template /2

```
# Insert your own code for topology creation
# and agent definitions, etc. here

#Create two nodes
set n0 [$ns node]
set n1 [$ns node]

#Create a duplex link between the nodes
$ns duplex-link $n0 $n1 1Mb 10ms DropTail

#Create a CBR agent and attach it to node n0
set cbr0 [new Agent/CBR]
$ns attach-agent $n0 $cbr0
$cbr0 set packetSize_ 500
$cbr0 set interval_ 0.005

#Create a Null agent (a traffic sink) and attach it to node n1
set sink0 [new Agent/Null]
$ns attach-agent $n1 $null0

#Connect the traffic source with the traffic sink
$ns connect $cbr0 $sink0

#Schedule events for the CBR agent
$ns at 0.5 "$cbr0 start"
$ns at 4.5 "$cbr0 stop"

#Call the finish procedure after 5 seconds simulation
$ns at 5.0 "finish"

#Run the simulation
$ns run
```

Other agents: TCP, UDP, ..

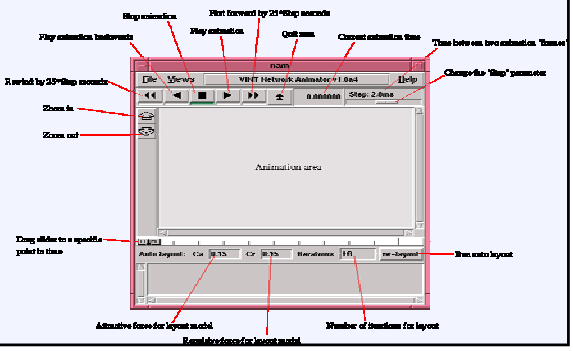
Agent parameters

CBR <-> Null, TCP <-> TCPSink!

"$cbr0 start" contains no destination address

$ns at time "command"
schedule command

nam



Applications

- Apps: layered on top of agents
- CBR the "clean" way:

```
set udp [new Agent/UDP]
$ns attach-agent $myNode $udp

set cbr [new Application/Traffic/CBR]
$cbr set packetSize_ 500
$cbr set interval_ 0.005
$cbr attach-agent $udp

$ns connect $udp $myNullAgent

$ns at 0.5 $cbr start
$ns at 4.5 $cbr stop
```

Other applications:
`ftp` *(greedy tcp source)*
`telnet`
`Traffic/Exponential`
`Traffic/Pareto`

or LossMonitor

always connect agents, sometimes also apps!

start / stop the app, not the agent!

More agents

- CBR <-> Null, CBR <-> LossMonitor
  - note: CBR agent deprecated!
- TCP <-> TCPSink
  - one-way Tahoe implementation
  - other flavours: TCP/Reno, TCP/NewReno, TCP/Sack1, TCP/Vegas
  - two-way: use FullTCP at both sides
- TCP-friendly connectionless protocols:
  - RAP <-> RAP
    Rate Adaptation Protocol (rate-based AIMD + Slow Start)
  - TFRC <-> TFRCSink
  - TCP Friendly Rate Control protocol (based on TCP throughput-equation)

requires TCPSink/Sack1!

Use app on top
`$app start`
`$app stop`

`$agent start`
`$agent stop`

More about links

- Link creation:
  - `$ns_ duplex-link node1 node2 bw delay qtype args`
  - qtypes: DropTail, FQ, SFQ, DRR, CBQ, RED, RED/RIO, ...
- Link commands:
  - `set mylink [$ns link $node1 $node2]`
  - `$mylink command`
- Queue parameters:
  - `set myqueue [$mylink queue]`
  - `$myqueue set parameter_ value` or `$myqueue command`
- Note: for all default parameters, see:
  `ns/tcl/lib/ns-default.tcl`

`down, up` *... control link status*
`cost` *value ... sets cost* (influences routing!)

or directly:
set myqueue [[$ns link $node1 $node2] queue]

Transmitting user data

- TcpApp application - use on top of Agent/TCP/SimpleTCP

```
set tcp1 [new Agent/TCP/SimpleTCP]
set tcp2 [new Agent/TCP/SimpleTCP]
$ns attach-agent $node1 $tcp1
$ns attach-agent $node2 $tcp2
$ns connect $tcp1 $tcp2
$tcp2 listen
( $tcp1 listen )

set app1 [new Application/TcpApp $tcp1]
set app2 [new Application/TcpApp $tcp2]
$app1 connect $app2
( $app2 connect $app1 )

$ns at 1.0 "$app1 send 100 \"$app2 app-recv 123\""

Application/TcpApp instproc app-recv { number }  { ... }
```

if you want to receive ...

to send back

size

content

Writing your own protocol

- simple (for teaching): use TcpApp
  - inefficient, not very flexible
- more useful (for researchers): change ns code
- two basic approaches
  1. truly understand architecture
     (class hierarchy, including "shadow objects" in OTcl etc.)
  2. "hack" code
     - change existing code to suit your needs
     - generally use C++ (and not OTcl) if possible

works surprisingly well; I recommend this.

How to "hack" ns code

- "ping" example in the Marc Greis tutorial (easy - try it!)
  - simple end-to-end protocol
- how to integrate your code in ns:
  - write your code: e.g., *ping.h* and *ping.cc*
  - if it's an agent...
    - "command" method = method call from OTcl
    - recv method = called when a packet arrives
  - if it's a new packet type: change *packet.h* and *tcl/lib/ns-packet.tcl*
  - change *tcl/lib/ns-default.tcl*
    - define and initialize attributes that are visible from OTcl
  - do a *"make depend"*, then *"make"*
- Note: ns manual mixes "how to use it" with "what happens inside"
  - this is where you look for details

Obtaining results

Obtaining results

Use LossMonitor instead of Null agent

```
proc record {} {
        global sink0 ns
        #Set the time after which the procedure should be called again
        set time 0.5
        #How many bytes have been received by the traffic sinks?
        set bw0 [$sink0 set bytes_]
        #Get the current time
        set now [$ns now]
        #Calculate the bandwidth (in MBit/s) and write it to the files
        puts $f0 "$now [expr $bw0/$time*8/1000000]"
        #Reset the bytes_ values on the traffic sinks
        $sink0 set bytes_ 0
        #Re-schedule the procedure
        $ns at [expr $now+$time] "record"
}
```

read byte counter

puts [$filehandle] "text"
write text

Note:
puts "[expr 1+1]" -> 2
puts "1+1" -> 1+1

Important:
$ns at 0.0 "record"

Obtaining results /2

- LossMonitor: simple solution for CBR, but TCP <-> TCPSink !
- Very common solution: generate tracefile

```
set f [open out.tr w]
$ns trace-all $f
```

- Trace file format:

event | time | from | to | type | size | flags | flow ID | src addr | dst addr | seqno | uid

event: "r" receive, "+" enqueue, "-" dequeue, "d" drop
type: "cbr", "tcp", "ack", ...
flags: ECN, priority, ...
flow id: similar to IPv6
uid: unique packet identifier

$agent set class_ num
(e.g. $udp set class_ 1)

Color your flow in nam:
$ns color num color
(e.g. $ns color 1 blue)

Monitoring queues in nam:
$ns duplex-link-op $node1 $node2 queuePos 0.5

Obtaining results /3

- Problem: trace files can be very large
- Solution 1: use pipe

```
set f [open | perl filter.pl parameters w]
$ns trace-all $f
```

perl script to filter irrelevant information (could be any script file)

- Other solutions:
  - Use specific trace or monitor - more efficient!
  - direct output in C++ code - even more efficient, but less flexible!
- Note: TCP throughput != TCP "goodput"
  - Goodput: bandwidth seen by the receiving application
  - should not include retransmits!
  - requires modification of TCP C++ code

Dynamic vs. long-term behavior

- Typically two types of simulation results:
  - dynamic behavior
  - long-term behavior: 1 result per simulation (behavior as function of parameter)
- Dynamic behavior: parse trace file (e.g. with "throughput.pl")
  - *roughly:*

```
oldtime = trace_time;
while (read != eof)
      if (trace_time - oldtime < 1)
            sum_bytes += trace_bytes;
      else {
            print "result: sum_byte /
                              (trace_time - oldtime);
            oldtime = trace_time; }
```

  - actually slightly more difficult - e.g., "empty" intervals should be included
- long-term behavior
  - script calls simulations with varying parameter
  - each simulation trace file parsed (simply summarize data or calculate statistics)

Long-term behavior

- Simulation script:

```
– (..)
  set parameter [lindex $argv 0]
  (..)
  set f [open "| perl stats.pl tcp w]
  $ns trace-all $f
  (..)
  ($parameter used in simulation!)
```

external parameter

write 1 result line (+ line break) to stdout

- loop:

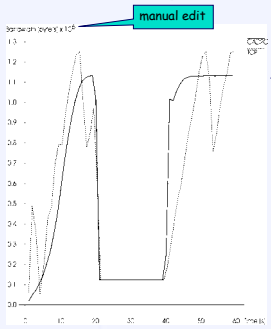
```
– for {set i 1} {$i <= 10} {set i [expr $i+1]} {
        exec echo $i >> results.dat
        exec ns sim.tcl $i >> results.dat
  }
```

append result line

- Plot final file with additional tool (e.g. gnuplot)

Visualizing dynamic behavior: CADPC Routing robustness

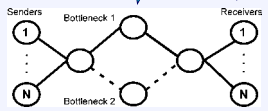
manual edit



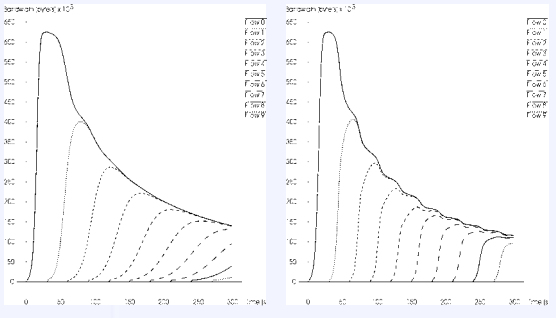
xgraph plot of throughput.pl result

nam output ("print" + postscript driver)

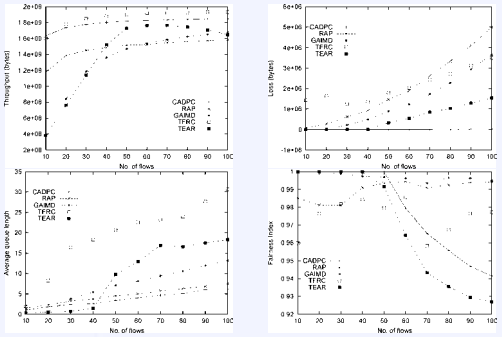
manual edit



Example 2: CADPC startup (xgraph)



Long-term CADPC results (gnuplot)



Concluding remarks

General simulation recommendations

- Select parameters carefully
  - consider RTT: what is realistic? what is a reasonable simulation duration?
  - ideally, duration should depend on statistics
    - e.g., until variance < threshold
    - not supported by ns
    - thus, just simulate long (realistic duration for, e.g., ftp download)
- Frequently ignored (but important) parameters:
  - TCP maximum send window size (should not limit TCP behavior)
  - TCP "flavor" (should be a state-of-the-art variant like SACK)
  - buffer length (should be bandwidth*delay)
  - Active Queue Management parameters (RED = hard to tune!)

General simulation recommendations /2

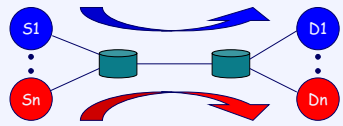
- Start simple, then gradually approach reality
  - 1 source, 1 destination
  - multiple homogeneous flows across single bottleneck
  - multiple homogeneous flows with heterogeneous RTTs
  - multiple heterogeneous flows with homogeneous and heterogeneous RTTs
  - impact of routing changes, various types of traffic sources (web, "greedy", ..)
- eventually implement and test in controlled environment
- ...and then perhaps even test in real life :)

Abstraction level	No. users	RTTs	No. resources	Traffic model	Method
1	1	equal	1	fluid	maths
2	2	equal	1	fluid	vector diagrams
3	n	equal	1	fluid	maths
4	2	heterogeneous	1	fluid	CAVT
5	n	heterogeneous	1	discrete	"normal" simulation
6	n	heterogeneous	m	discrete	"normal" simulation
7	n	heterogeneous	m	discrete	real life experiments

Common topologies

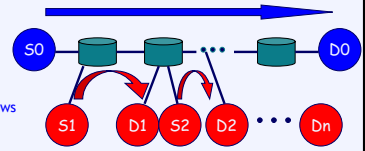
- Dumbbell:

  evaluate basic end2end behaviour, TCP-friendliness, ..
  - often: n vs. m flows



- Parking Lot:

  evaluate behaviour with different RTT's, fairness, ..
  - often: S0/D0 - n flows, all other S/D pairs - m flows



Recommended papers (simulation *method*)

- Krzysztof Pawlikowski, Hae-Duck Jeong, and Jong-Suk Ruth Lee, "On Credibility of Simulation Studies of Telecommunication Networks", IEEE Communications Magazine, January 2002, pp. 132-139.
- Mark Allman, Aaron Falk, "On the Effective Evaluation of TCP", ACM Computer Communication Review, 29(5), October 1999. http://www.icir.org/mallman/papers/tcp-evaluation.pdf
- Sally Floyd and Vern Paxson, "Difficulties in Simulating the Internet", IEEE/ACM Transactions on Networking, Vol.9, No.4, pp. 392-403.
- Sally Floyd and Eddie Kohler, "Internet Research Needs Better Models", ACM Hotnets-I, October 2002.
- and this website: http://www.icir.org/models/bettermodels.html

Key links

- Official website: http://www.isi.edu/nsnam/ns
  - docs: "ns manual", "Marc Greis' tutorial", "ns by example"
    - note: HTML version of "ns manual" not always up-to-date
  - large number of "Contributed Modules"
- Personal ns website: http://www.welzl.at/tools/ns
  - "throughput" and "stats" scripts
  - working versions of ns and nam Windows binaries
  - German ns documentation (student work)
  - these slides
- LLoyd Wood's site: http://www.ee.surrey.ac.uk/Personal/L.Wood/ns/
  - additional links

Good luck!