CS551
NS Tutorial

Slides Developed by:

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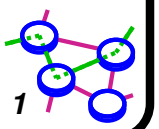
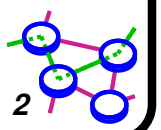
USC/ISI



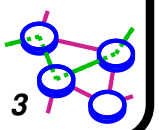
ns-2, the network simulator

- a discrete event simulator
  - simple model
- focused on modeling network protocols
  - wired, wireless, satellite
  - TCP, UDP, multicast, unicast
  - web, telnet, ftp
  - ad hoc routing, sensor networks
  - infrastructure: stats, tracing, error models, etc.



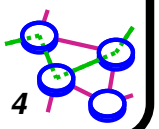
ns goals

- support networking research and education
  - protocol design, traffic studies, etc.
  - protocol comparison
- provide a collaborative environment
  - freely distributed, open source
- share code, protocols, models, etc.
  - allow easy comparision of similar protocols
  - increase confidence in results
- more people look at models in more situations
- experts develop models
- multiple levels of detail in one simulator



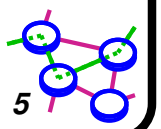
ns history

- Began as REAL in 1989
- ns by Floyd and McCanne at LBL
- ns-2 by McCanne and the VINT project (LBL, PARC, UCB, USC/ISI)
- currently maintained at USC/ISI, with input from Floyd et al.



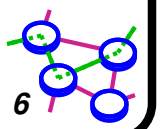
"ns" components

- ns, the simulator itself
- nam, the Network AniMator
  - visualize ns (or other) output
  - GUI input simple ns scenarios
- pre-processing:
  - traffic and topology generators
- post-processing:
  - simple trace analysis, often in Awk, Perl, or Tcl



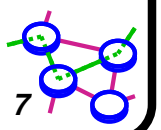
ns models

- Traffic models and applications:
  - web, FTP, telnet, constant-bit rate, Real Audio
- Transport protocols:
  - unicast: TCP (Reno, Vegas, etc.), UDP
  - multicast: SRM
- Routing and queueing:
  - wired routing, ad hoc rtg and directed diffusion
  - queueing protocols: RED, drop-tail, etc.
- Physical media:
  - wired (point-to-point, LANs), wireless (multiple propagation models), satellite



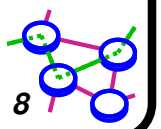
ns status

- platforms: basically all Unix and Windows
- size: about 200k loc each C++ and Tcl, 350 page manual
- user-base: >1k institutions, >10k users
- releases about every 6 months, plus daily snapshots



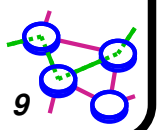
Outlines

- ***Concepts***
- **Essentials**
- **Getting Started**
- **Fundamental tcl, otcl and ns**



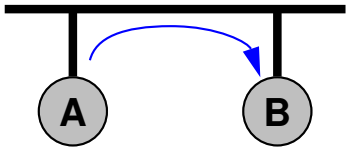
Discrete Event Simulation

- model world as events
  - simulator has list of events
  - process: take next one, run it, until done
  - each event happens in an instant of virtual (simulated) time, but takes an arbitrary amount of real time
- ns uses simple model: single thread of control => no locking or race conditions to worry about (very easy)



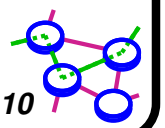
Discrete Event Examples

Consider two nodes on an Ethernet:

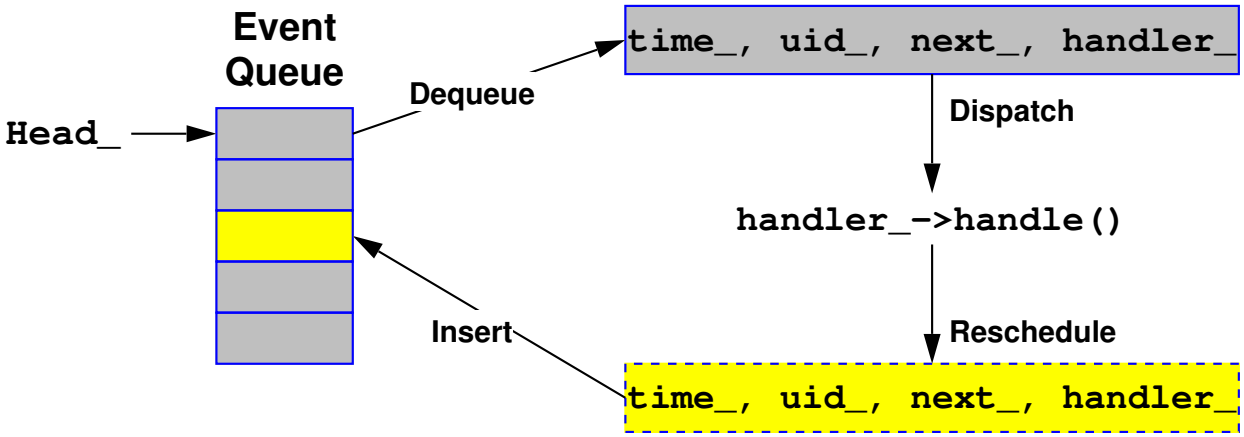


simple queuing model:	t=1:	A enqueues pkt on LAN
	t=1.01:	LAN dequeues pkt and triggers B

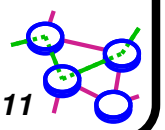
detailed CSMA/CD model:	t=1.0:	A sends pkt to NIC A's NIC starts carrier sense
	t=1.005:	A's NIC concludes cs, starts tx
	t=1.006:	B's NIC begins reciving pkt
	t=1.01:	B's NIC concludes pkt B's NIC passes pkt to app



Discrete Event Scheduler

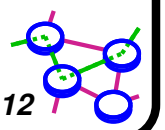


- Four types of scheduler:
  - List: simple linked list, order-preserving, O(N)
  - Heap: O(logN)
  - Calendar: hash-based, fastest, default, O(1)
  - Real-time: subclass of list, sync with real-time, O(N)



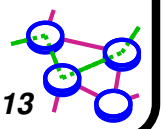
ns Software Structure: object orientation

- Object oriented:
  - lots of code reuse (ex. TCP + TCP variants)
- Some important objects:
  - NsObject: has recv() method
  - Connector: has target() and drop()
  - BiConnector: uptarget() & downtarget()

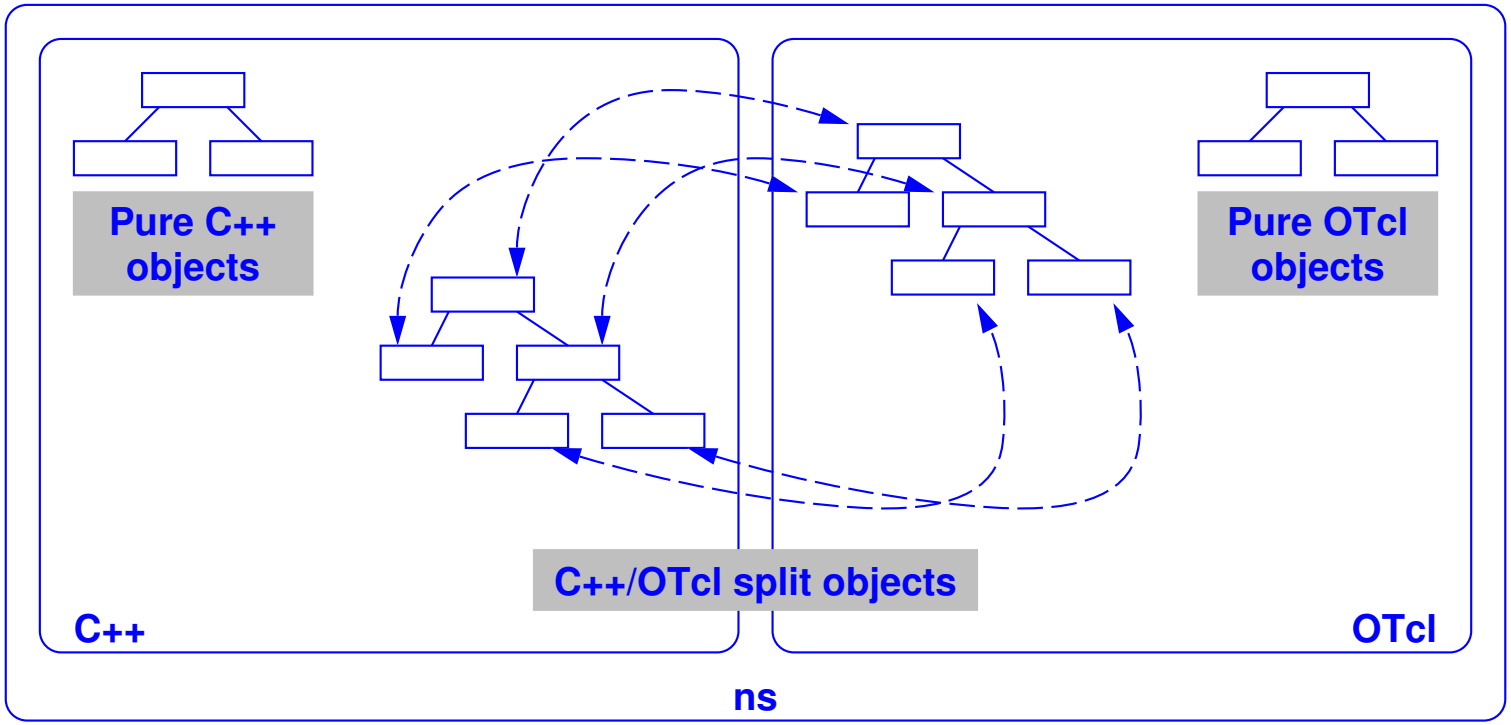


ns Software Structure: C++ and Otcl

- Uses two languages
- C++ for packet-processing
  - fast to run, detailed, complete control
- OTcl for control
  - simulation setup, configuration, occasional actions
  - fast to write and change
- pros: trade-off running vs. writing speed, powerful/documented config language
- cons: two languages to learn and debug in



OTcl and C++: The Duality



- OTcl (object variant of Tcl) and C++ share class hierarchy
- TclCL is glue library that makes it easy to share functions, variables, etc.

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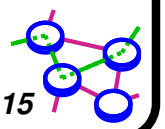
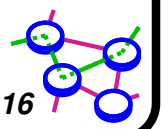
- *Getting Started*
- Fundamental tcl, otcl and ns



Installation and Documentation

- *http://www.isi.edu/nsnam/ns/*
  - download ns-allinone (if you have your own machine, do *not* build this on USC servers)
  - includes Tcl, OTcl, TclCL, ns, nam, etc.
  - run ns and nam on ISD machines:
    - ~csci551/ns
    - ~csci551/nam
- mailing list: *ns-users@isi.edu*
- documentation (see url above)
  - Marc Gries tutorial
  - ns manual



Hello World

simple.tcl:

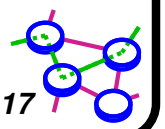
```
set ns [new Simulator]
$ns at 1 "puts \"Hello World!\""
$ns at 1.5 "exit"
$ns run
```

```
nunki 74% ~csci551/ns simple.tcl
Hello World!
nunki 75%
```

Think C++:

```
Simulator *ns=new Simulator;

ns->at(1,   "puts \"Hello World!\"");
ns->at(1.5, "exit");
ns->run();
```



Hello World, Deconstructed

```
set ns [new Simulator]
```

create a simulator, put in var ns

```
$ns at 1 "puts \"Hello World!\""
```

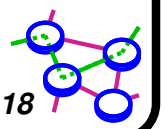
schedule an event at time t=1 to print HW

```
$ns at 1.5 "exit"
```

and exit at a later time

```
$ns run
```

run time simulator



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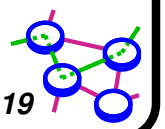


Basic Tcl

variables:

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

functions and expressions:

```
set y [pow x 2]
set y [expr x*x]
```

control flow:

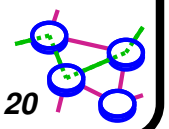
```
if {$x > 0} { return $x }
else { return [expr -$x] }
while { $x > 0 } {
    puts $x
    incr x -1
}
```

procedures:

```
proc pow {x n} {
    if {$n == 1} { return $x }
    set part [pow x [expr $n-1]]
    return [expr $x*$part]
}
```

Also lists, associative arrays, etc.

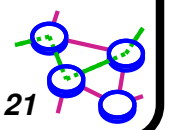
⇒ **can use a real programming language to build network topologies, traffic models, etc.**



Basic otcl

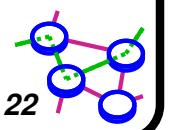
```
Class Person
# constructor:
Person instproc init {age} {
    $self instvar age_
    set age_ $age
}
# method:
Person instproc greet {} {
    $self instvar age_
    puts "$age_ years old: How are you doing?"
}
# subclass:
Class Kid -superclass Person
Kid instproc greet {} {
    $self instvar age_
    puts "$age_ years old kid: What's up, dude?"
}

set a [new Person 45]
set b [new Kid 15]
$a greet
$b greet
```

⇒ **can easily make variations of existing things (TCP, TCP/Reno)**



Basic ns-2

- Creating the event scheduler
- [Turn on tracing]
- Creating network
- Setting up routes
- Inserting errors
- Creating transport connection
- Create traffic



Creating Event Scheduler

Create scheduler

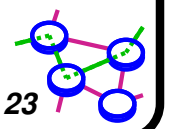
- `set ns [new Simulator]`

Schedule event

- `$ns at <time> <event>`
- `<event>`: **any legitimate ns/tcl commands**

Start scheduler

- `$ns run`



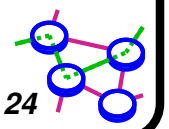
Creating Network

Nodes

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

Links & Queuing

- `$ns duplex-link $n0 $n1 <bandwidth> <delay> <queue_type>`
- `<queue_type>`: **DropTail, RED, CBQ, FQ, SFQ, DRR**



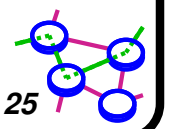
Computing routes

Unicast

- `$ns rtproto <type>`
- `<type>`: **Static, Session, DV, cost, multi-path**

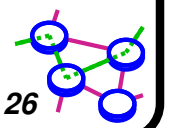
Multicast

- `$ns multicast`
  - **right after** `[new Simulator]`
- `$ns mrtproto <type>`
- `<type>`: **CtrMcast, DM, ST, BST**



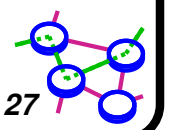
Traffic

- simple two layers: transport and app
- transports:
  - TCP, UDP, etc.
- applications: (agents)
  - ftp, telnet, etc.



Creating Connection: UDP

- **source and sink**
  - `set usrc [new Agent/UDP]`
  - `set udst [new Agent/NULL]`
- **connect them to nodes, then each other**
  - `$ns attach-agent $n0 $usrc`
  - `$ns attach-agent $n1 $udst`
  - `$ns connect $usrc $udst`



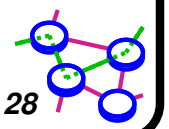
Creating Connection: TCP

source and sink

- `set tsrc [new Agent/TCP]`
- `set tdst [new Agent/TCPSink]`

connect to nodes and each other

- `$ns attach-agent $n0 $tsrc`
- `$ns attach-agent $n1 $tdst`
- `$ns connect $tsrc $tdst`



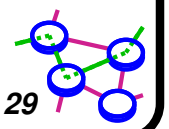
Creating Traffic: On Top of TCP

FTP

- `set ftp [new Application/FTP]`
- `$ftp attach-agent $tsrc`
- `$ns at <time> "$ftp start"`

Telnet

- `set telnet [new Application/Telnet]`
- `$telnet attach-agent $tsrc`



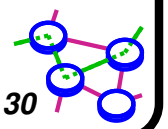
Creating Traffic: On Top of UDP

CBR

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

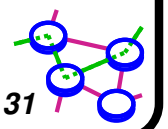
Exponential or Pareto on-off

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



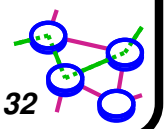
Creating Traffic: Trace Driven

- **Trace driven**
  - `set tfile [new Tracefile]`
  - `$tfile filename <file>`
  - `set src [new Application/Traffic/Trace]`
  - `$src attach-tracefile $tfile`
- `<file>:`
  - **Binary format**
  - **inter-packet time (msec) and packet size (byte)**



Compare to Real World

- more abstract (much simpler):
  - no addresses, just global variables
  - connect them rather than name lookup/bind/listen/accept
- easy to change implementation
  - `set tsrc2 [new Agent/TCP/Newreno]`
  - `set tsrc3 [new Agent/TCP/Vegas]`



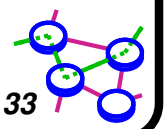
Inserting Errors

Creating Error Module

- `set loss_module [new ErrorModel]`
- `$loss_module set rate_ 0.01`
- `$loss_module unit pkt`
- `$loss_module ranvar [new RandomVariable/Uniform]`
- `$loss_module drop-target [new Agent/Null]`

Inserting Error Module

- `$ns lossmodel $loss_module $n0 $n1`



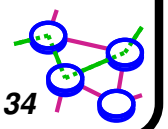
Tracing

- **Trace packets on all links into `test.out`**
  - `$ns trace-all [open test.out w]`

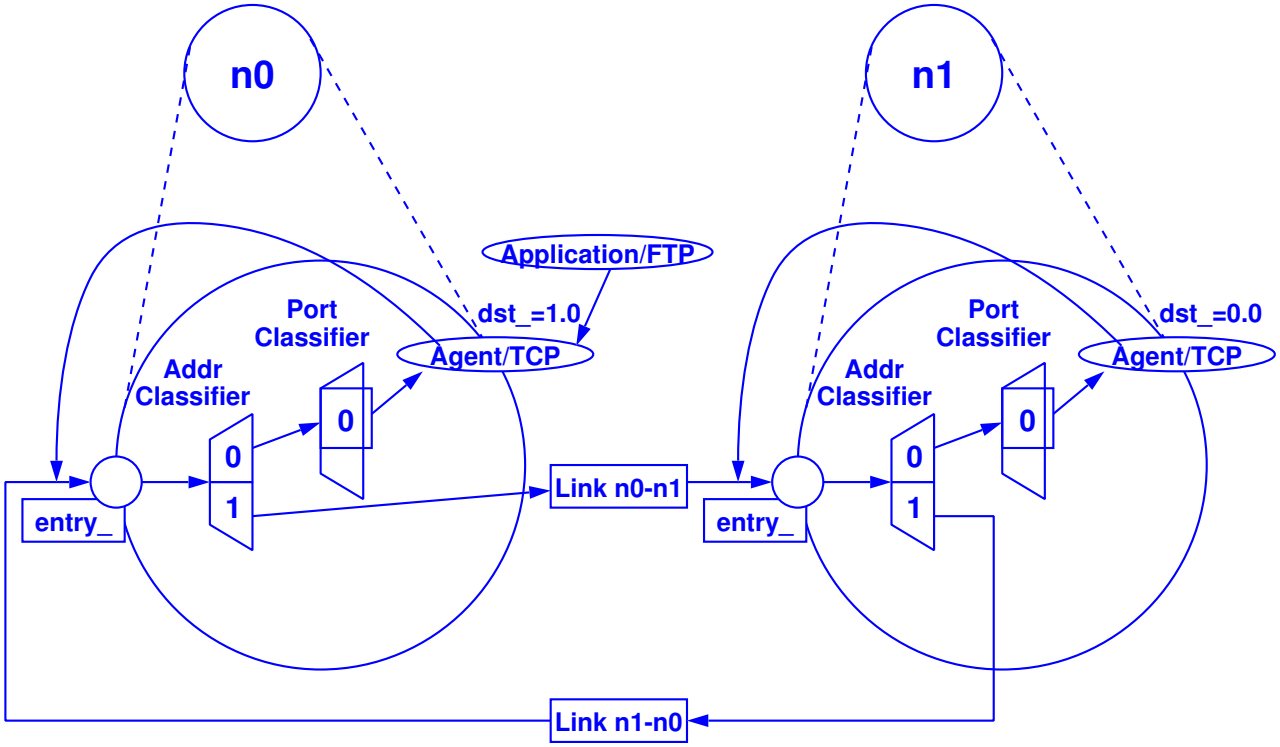
```
<event> <time> <from> <to> <pkt> <size>--<flowid> <src> <dst>
<seqno> <aseqno>

   + 1 0 2 cbr 210 ------- 0 0.0 3.1 0 0
   - 1 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>` can be + for enqueue, – for dequeue, `r` for receive, `d` for drop, and `e` for error

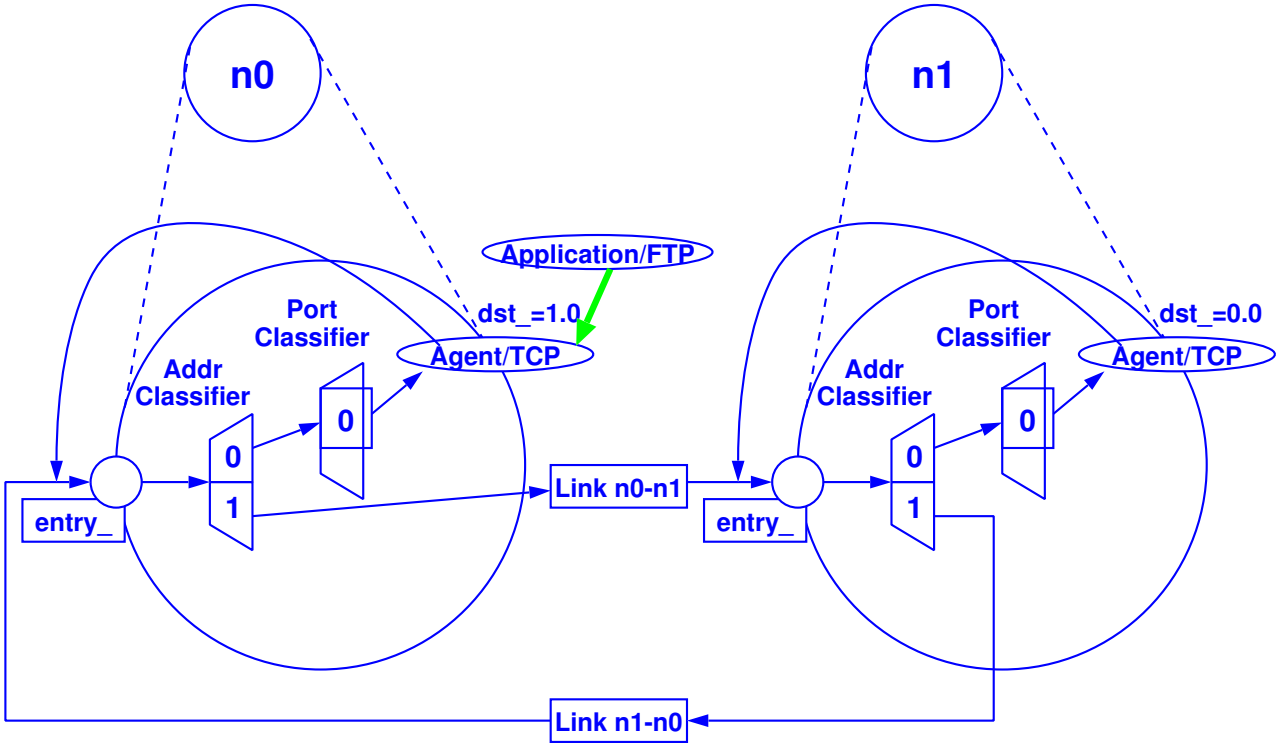
- **Trace packets on all links in nam-1 format**
  - `$ns namtrace-all [open test.nam w]`



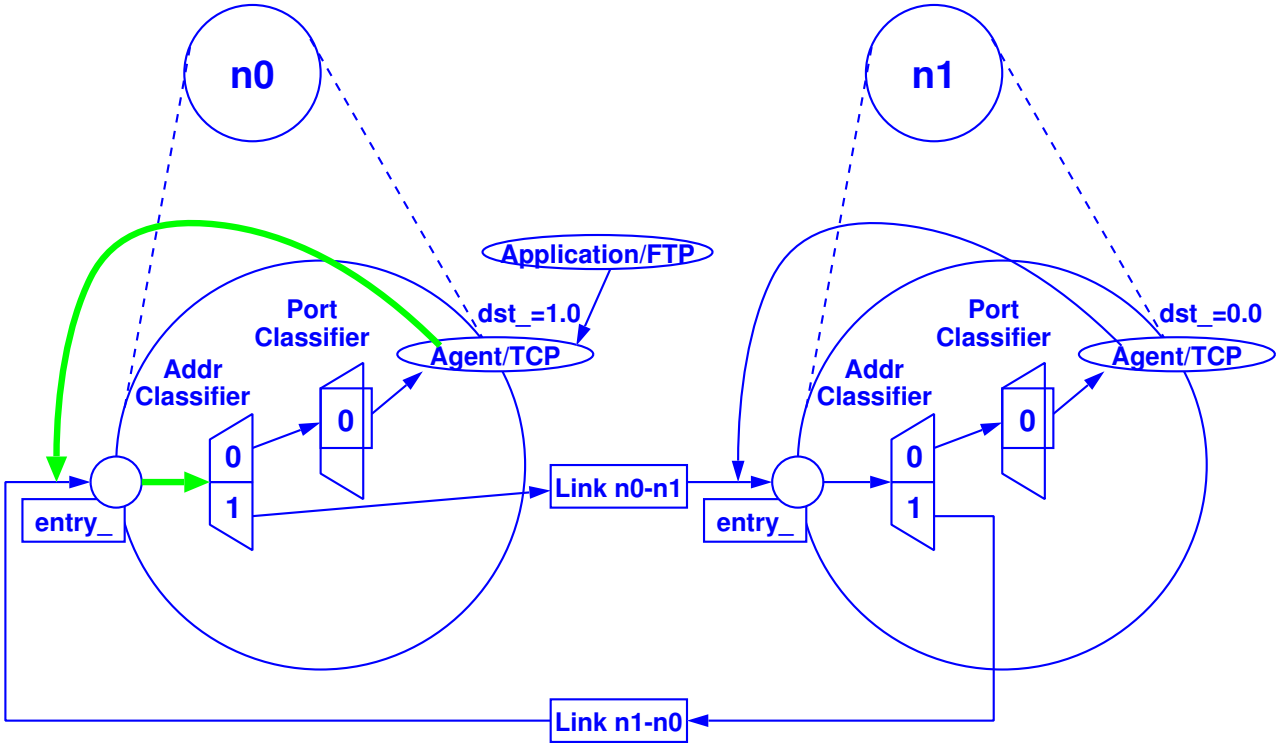
Plumbing: Packet Flow



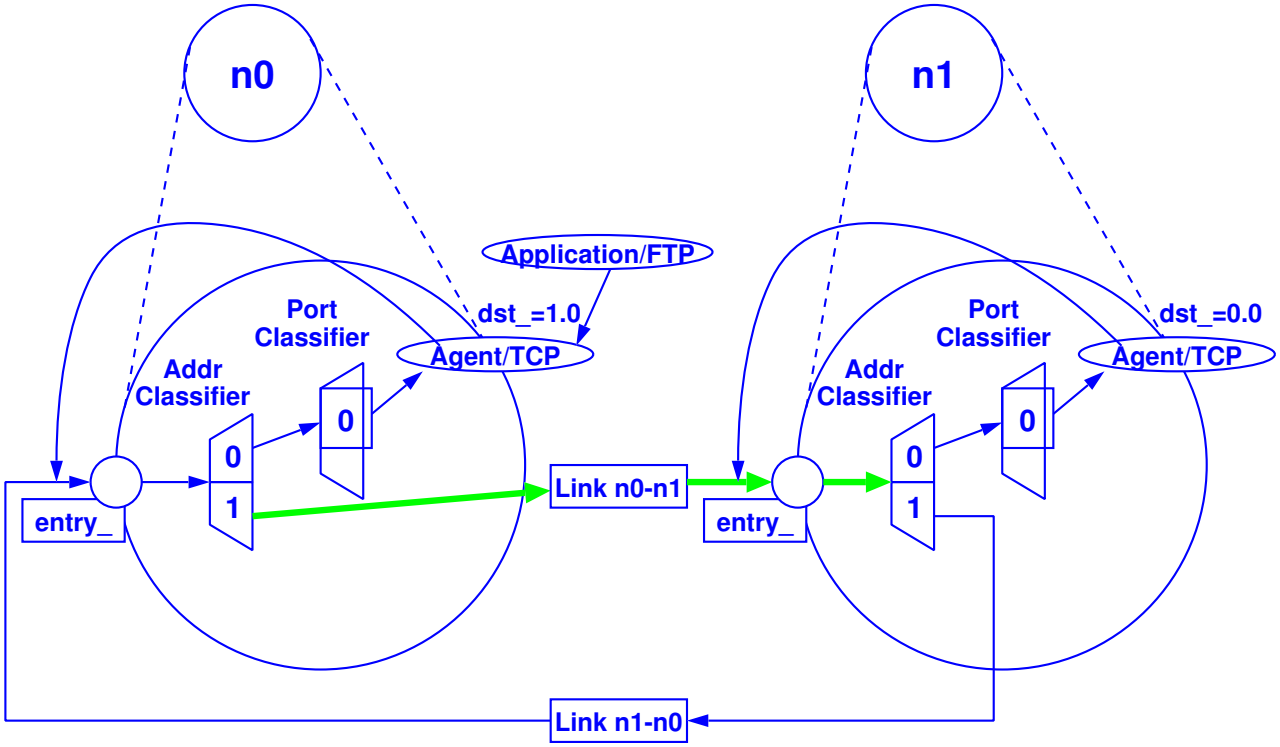
Plumbing: Packet Flow

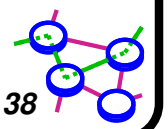


Plumbing: Packet Flow

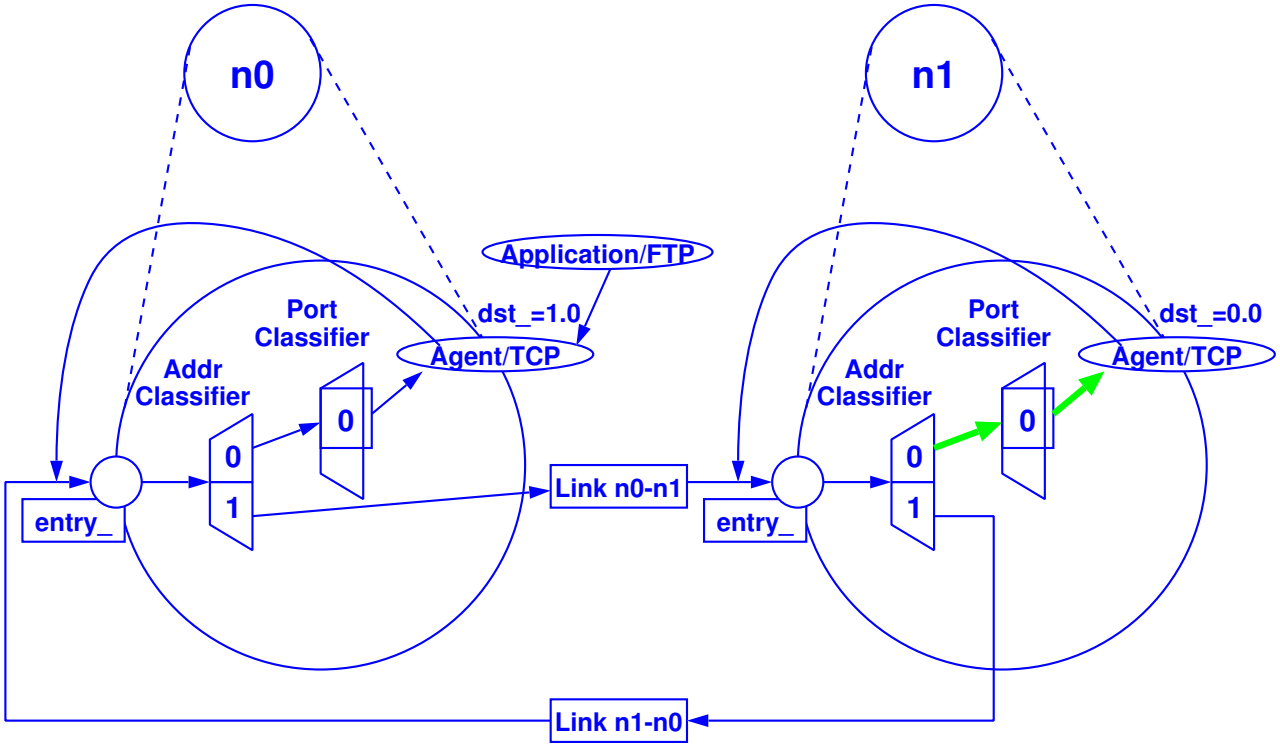


Plumbing: Packet Flow

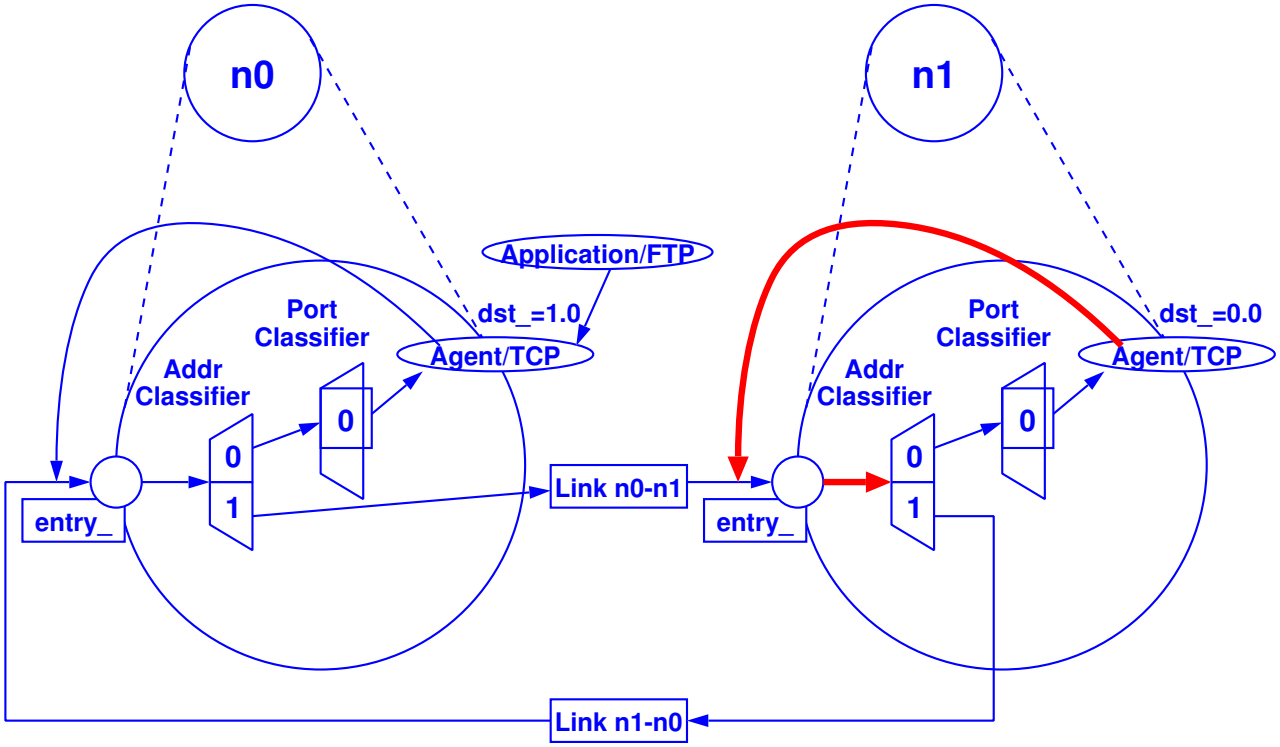




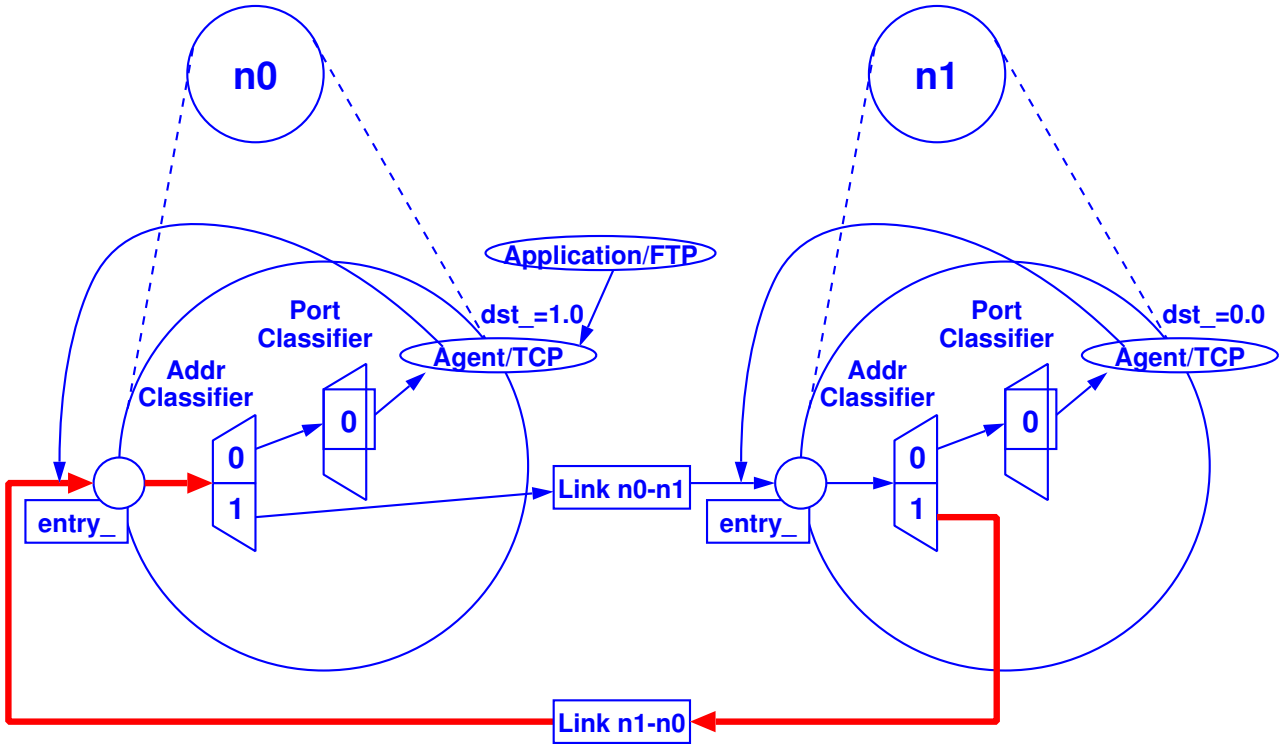
Plumbing: Packet Flow



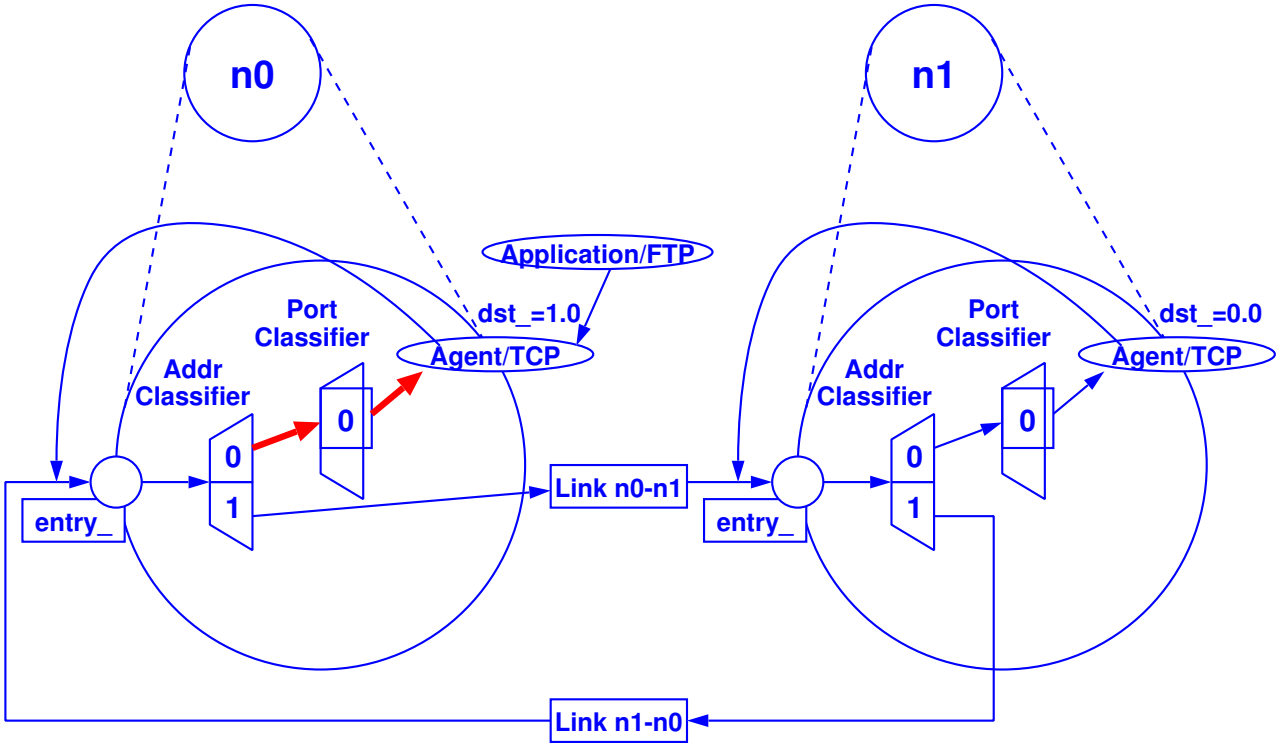
Plumbing: Packet Flow



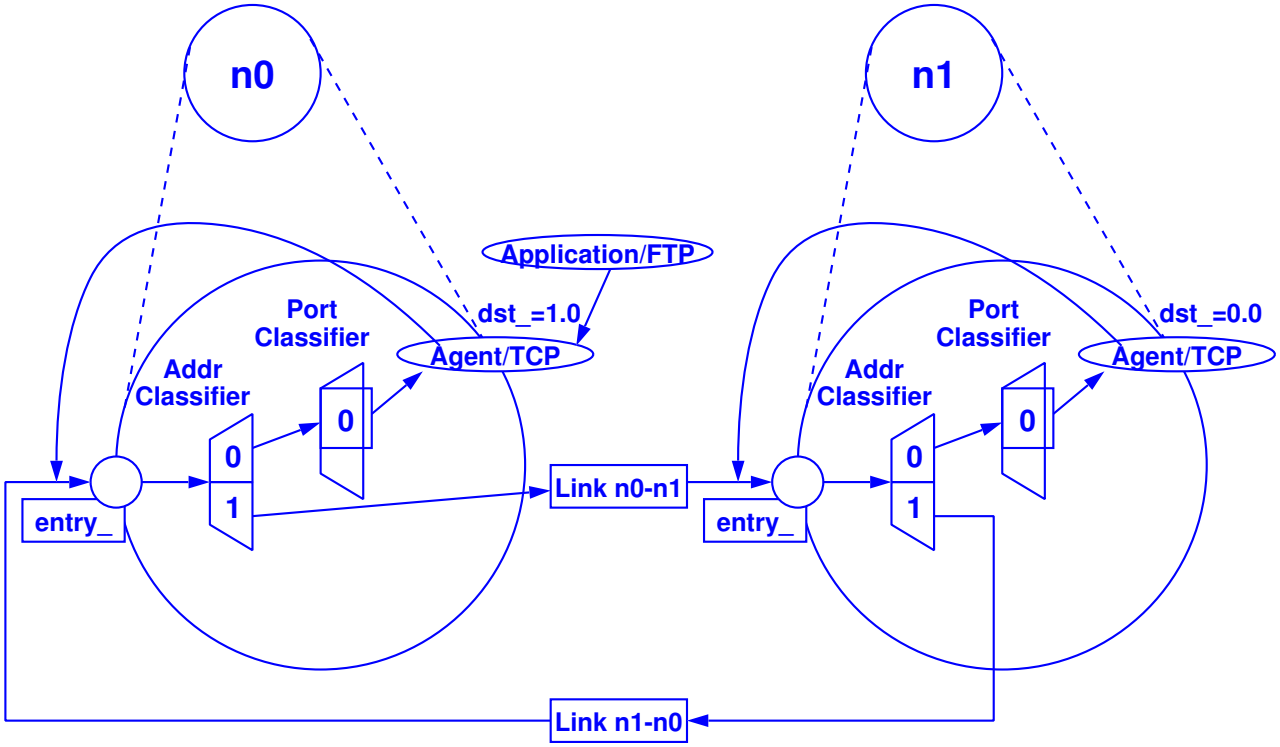
Plumbing: Packet Flow



Plumbing: Packet Flow

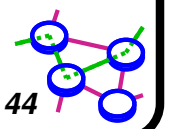


Plumbing: Packet Flow



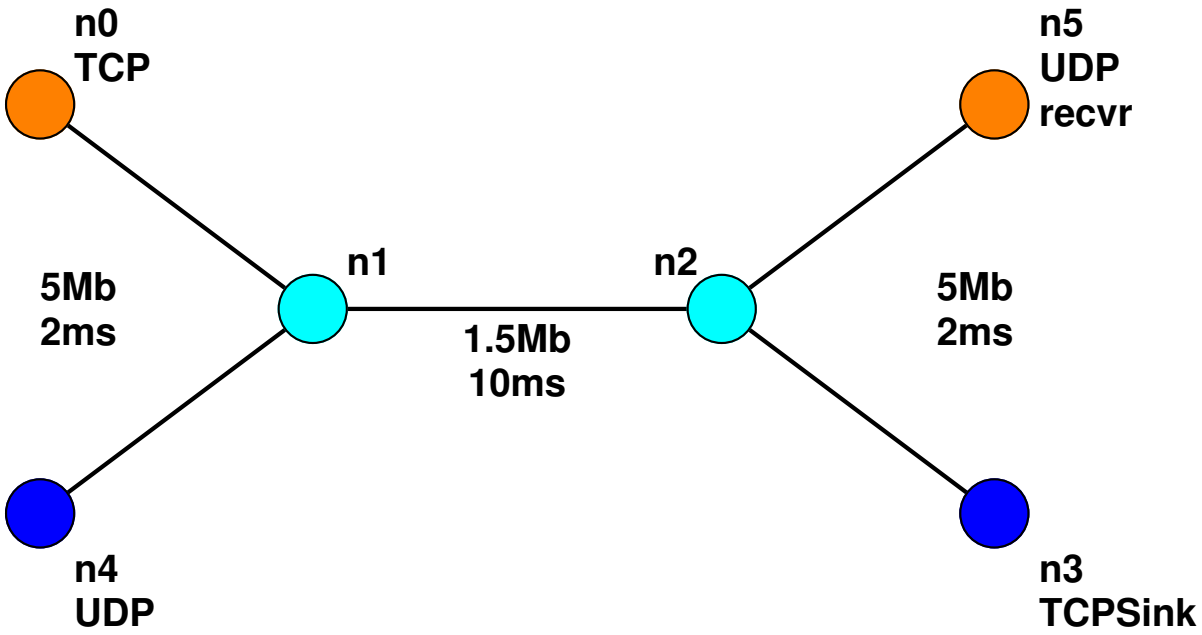
Summary: Generic Script Structure

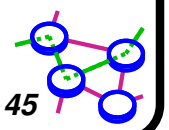
```
set ns [new Simulator]
# [Turn on tracing]
# Create topology
# Setup packet loss, link dynamics
# Create routing agents
# Create:
# - multicast groups
# - protocol agents
# - application and/or setup traffic sources
# Post-processing procs
# Start simulation
```



Example - TCP

- Simple scenario with TCP and UDP connections

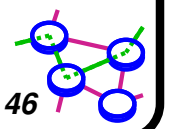




TCP : Step 1

Scheduler & tracing

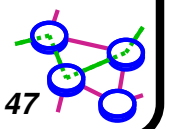
```
#Create scheduler
set ns [new Simulator]
#Turn on tracing
set f [open out.tr w]
$ns trace-all $f
set nf [open out.nam w]
$ns namtrace-all $nf
```



TCP : Step 2

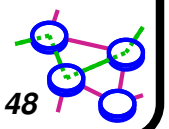
Create topology

```
#create nodes
set n0 [$ns node]
set n1 [$ns node]
set n3 [$ns node]
set n4 [$ns node]
```



TCP : Step 3

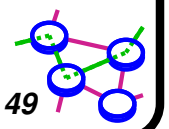
```
#create links
$ns duplex-link $n0 $n1 5Mb 2ms DropTail
$ns duplex-link $n1 $n2 1.5Mb 10ms DropTail
$ns duplex-link $n2 $n3 5Mb 2ms DropTail
$ns queue-limit $n1 $n2 25
$ns queue-limit $n2 $n1 25
```



TCP : Step 4

Create TCP agents

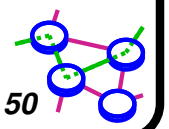
```
set tcp [new Agent/TCP]
set sink [new Agent/TCPSink]
$ns attach-agent $n0 $tcp
$ns attach-agent $n3 $sink
$ns connect $tcp $sink
```



TCP : Step 5

Attach traffic

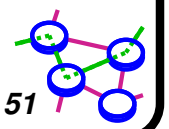
```
set ftp [new Application/FTP]
$ftp attach-agent $tcp
#start application traffic
$ns at 1.1 "$ftp start'
```



TCP : Step 6

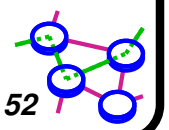
End of simulation wrapper (as usual)

```
$ns at 2.0 "finish"
Proc finish {} {
    global ns f
    close $f
    close $nf
    puts "Running nam..."
    exec nam out.nam &
    exit 0
}
$ns run
```



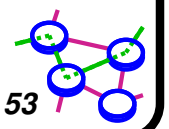
Viz Tools

- Nam-1 (Network AniMator Version 1)
  - Packet-level animation
  - Well-supported by ns
- Xgraph
  - Convert trace output into xgraph format



Ns-nam Interface

- Color
- Node manipulation
- Link manipulation
- Topology layout
- Protocol state
- Misc



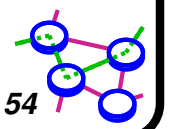
Nam Interface: Color

Color mapping

```
$ns color 40 red
$ns color 41 blue
$ns color 42 chocolate
```

Color ↔ flow id association

```
$tcp0 set fid_ 40 ;# red packets
$tcp1 set fid_ 41 ;# blue packets
```



Nam Interface: Nodes

Color

```
$node color red
```

Shape (can't be changed after sim starts)

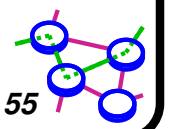
```
$node shape box        ;# circle, box, hexagon
```

Marks (concentric *shapes*)

```
$ns at 1.0 "$n0 add-mark m0 blue box"
$ns at 2.0 "$n0 delete-mark m0"
```

Label (single string)

```
$ns at 1.1 "$n0 label \"web cache 0 \""
```



Nam Interfaces: Links

- **Color**

```
$ns duplex-link-op $n0 $n1 color "green"
```

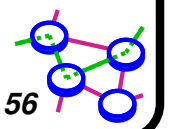
- **Label**

```
$ns duplex-link-op $n0 $n1 label "abced"
```

- **Dynamics (automatically handled)**

```
$ns rtmodel Deterministic {2.0 0.9 0.1} $n0 $n1
```

- **Asymmetric links not allowed**

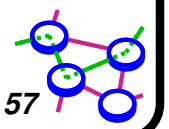


Nam Interface: Topo Layout

- ***Manual*** **layout: specify everything**

```
$ns duplex-link-op $n(0) $n(1) orient right
$ns duplex-link-op $n(1) $n(2) orient right-up
$ns duplex-link-op $n(2) $n(3) orient down
$ns duplex-link-op $n(3) $n(4) orient 60deg
```

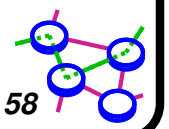
- **If anything missing -> automatic layout**



Nam Interface: Protocol State

Monitor values of agent variables

```
$ns add-agent-trace $srm0 srm_agent0
$ns monitor-agent-trace $srm0
$srm0 tracevar C1_
$srm0 tracevar C2_
# ... ...
$ns delete-agent-trace $tcp1
```



Nam Interface: Misc

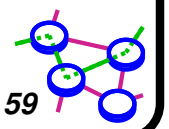
Annotation

- Add textual explanation to your sim

```
$ns at 3.5 "$ns trace-annotate \"packet drop\""
```

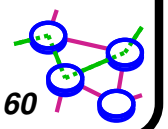
Set animation rate

```
$ns at 0.0 "$ns set-animation-rate 0.1ms"
```



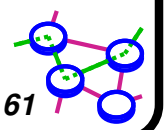
Other Utilities in Ns

- Nam editor
  - Available as part of nam-1
- Tcl debugger
  - For source and documentation, see
    http://www.isi.edu/nsnam/ns/ns-debugging.html
- Topology generator
  - *http://www.isi.edu/nsnam/ns/ns-topogen.html*
- Scenario generator
  - *http://www.isi.edu/nsnam/ns/ns-scengeneration.html*



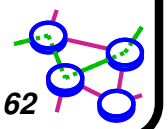
Other Ns Features

- Other areas in wired domain
  - LANs
  - Diffserv
  - Multicast
  - Full TCP
  - Applications like web-caching
- Wireless domain
  - Ad hoc routing
  - Mobile IP
  - Satellite networking
  - Directed diffusion (sensor networks)



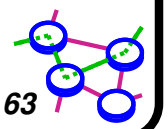
Other Ns Features

- Emulator
  - Connect simulator in a real network
  - Can receive and send out live packets from/into the real world



Resources

- Ns distribution download
  - *http://www.isi.edu/nsnam/ns/ns-build.html*
- Installation problems and bug-fix
  - *http://www.isi.edu/nsnam/ns/ns-problems.html*
- Ns-users mailing list
  - Ns-users@isi.edu
  - See *http://www.isi.edu/nsnam/ns/ns-lists.html*
  - Archives from above URL



Resources (cont...)

- Marc Greis' tutorial
  - *http://www.isi.edu/nsnam/ns/tutorial*
- Ns-users archive
- Ns-manual
  - *http://www.isi.edu/nsnam/ns/nsdocumentation.html*
- Tcl (Tool Command Language)
  - *http://dev.scriptics.com/scripting*
  - Practical programming in Tcl and Tk, Brent Welch
- Otcl (MIT Object Tcl)
  - ~otcl/doc/tutorial.html (in distribution)