Wireless Networks
(CSC-7602)
Lecture 2 & 3
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Network Simulator ns-2

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Agenda

- Introduction
- Interface
  - Tcl and OTcl
  - TclCL
- Simulator
  - Wired network
  - Wireless network

Introduction

- NS-2: network simulator version 2
  - Discrete event simulator
  - Packet level simulation
- Features
  - Open source
  - Scheduling, routing and congestion control
  - Wired networks: P2P links, LAN
  - Wireless networks: terrestrial (ad-hoc, cellular; GPRS, UMTS, WLAN, Bluetooth), satellite
  - Emulation and trace

NS-2: Evolution

- REAL network simulator (Cornell), 1989
  - Study the dynamic behavior of flow and congestion control schemes in packet-switched data networks (written in C)
- NS (NS-1), 1995
  - Adopt the Tcl / C++ architecture
- NS-2, 1996
  - Object-oriented Tcl (Otcl)
- Wireless extensions
  - UC Berkeley Daedalus project
  - CMU Monarch project
  - Sun Microsystems

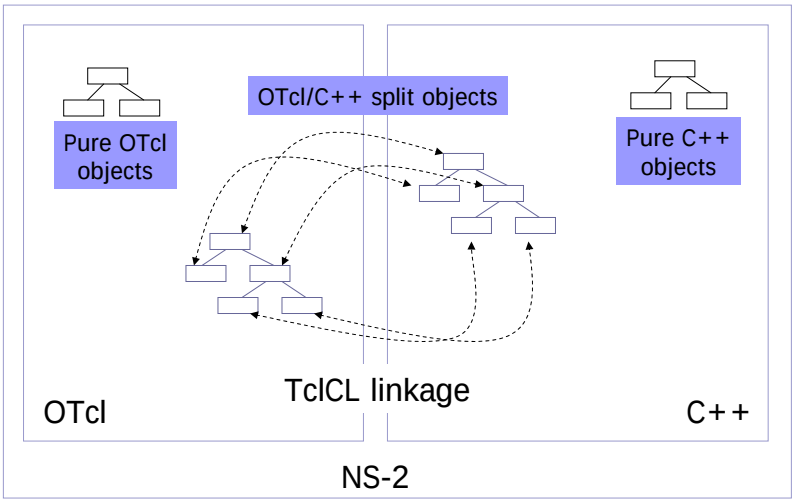
NS-2: Paradigm

- Object-oriented programming
  - Protocol layering
    - Modularity and extensibility
  - Large scale simulation
    - Maintenance and reusability
- Split-language programming
  - Scripting language (Tcl)
  - System programming language (C)

NS-2: Split Languages

- Tcl scripts (Tcl/OTcl)
  - Interpreted (interactive)
  - Setup and configuration
- C codes (C/C++)
  - Compiled (efficient)
  - Algorithms and protocols
- TclCL (OTcl/C++)
  - Link Tcl/OTcl scripts and C/C++ codes
  - Provide a layer of C++ glue over OTcl

NS-2: Split Objects



NS-2: A Tcl Script Example

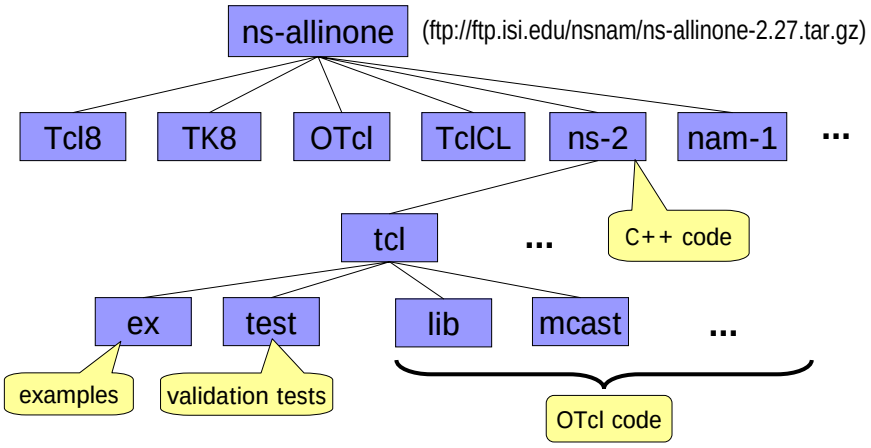
```
#!/home/hsieh/ns-allinone-2.27/bin/ns

set ns [new Simulator]
set nf [open out.tr w];$ns trace-all $nf

for {set i 0} {$i<2} {incr i} {    ;# create the nodes
        set n($i) [$ns node]}
$ns duplex-link $n(0) $n(1) 1Mb 10ms DropTail

# Create a UDP agent
set udp(src) [new Agent/UDP]
$udp(src) set packetSize_ 500
$ns attach-agent $n(0) $udp(src)

proc finish {} {
        global ns nf
        $ns flush-trace; close $nf
}

$ns at 5.0 "finish"
$ns run
```

```
/home>ns  abc.tcl
/home>abc.tcl
```


NS-2: A C++ Code Example

```
static class UdpAgentClass : public TclClass {
public:
        UdpAgentClass() : TclClass("Agent/UDP") {}
        TclObject* create(int, const char*const*) {
                return (new UdpAgent());
        }
} class_udp_agent;

UdpAgent::UdpAgent() : Agent(PT_UDP), seqno_(-1)
{
        bind("packetSize_", &size_);
}

void UdpAgent::sendmsg(int nbytes, AppData* data, const char* flags)
{
        Packet *p;
        p = allocpkt();
        hdr_cmn::access(p)->size() = size_;
        hdr_rtp::access(p)->seqno() = ++seqno_;
        p->setdata(data);
        target_->recv(p);
}
```

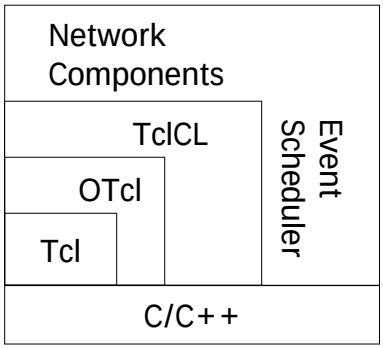
NS-2: Directory Structure



Network Simulator ns-2

Part I: Tcl, OTcl and TclCL

NS-2: A Tcl Extension



ns-2

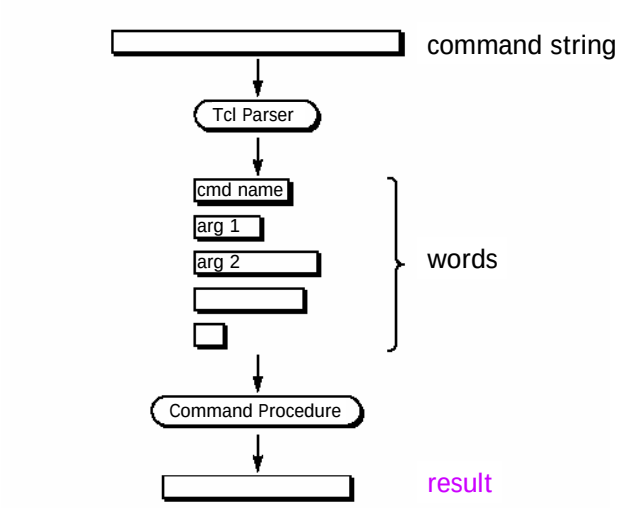
Tcl: Overview

- Tcl: Tool command language
- Tcl is extensible and embeddable
  - NS-2 is also a Tcl interpreter (`tclsh` or `ns`)
- Tcl is a scripting language
  - Ideal for network configuration
- A Tcl script consists of commands
- To write Tcl scripts, you need to learn
  - Tcl command
  - Tcl syntax (how commands are parsed)

Tcl: Command

- A command consists of words
  cmdName arg1 arg2 …
  - *cmdName*: core command or procedure
    - set, puts, expr, open, if, for, …
  - All words are considered as strings
  - White space (space/tab) separates arguments
  - Newline or semicolon (;) terminates a command
- Command evaluation: parsing and execution
  - The interpreter does “substitution” and “grouping” (parsing) before running a command
  - Every command returns a result string after execution

Tcl: Command



Tcl: Command Example

```
puts hello
puts “hello”
open test.tcl w

set a 3
set b 4; set c \
5
set a

expr 1+2
expr 1 + 2
expr “1” “+2”
```

What is the use of the double quote?

Double quotes are used to group words into a single argument to a command. Dollar signs and square brackets are interpreted inside double quotes.

Tcl: Substitution

- Variable substitution **$**
  - **$***varName* will be replaced by its value
  - Variables are created automatically when assigned to (no declaration is necessary)
- Command substitution **[]**
  - **[***Tcl script***]** will be replaced by its result
  - Nesting and multiple commands
- Backslash substitution \
  - \n, \t, \67, \x67, ... and \$, \[, \\, \”, \{
  - *newline*, *space*
- A single pass of substitution

Tcl: Substitution Example

```
set a 3
puts $a
puts a
puts $z

set b [expr 2+3]
set c [puts hi]
set e [set d [expr $b/2]]
set f [expr 3][set e]
set g [expr 3;set e]

expr 31 + 3
expr 031 + 3
expr 0x31 + 3
expr \x31 + 3
```


Tcl: Grouping (Quoting)

- Group words into a single word
  - Space, newline and semicolon are not interpreted (lose their functions when quoted)
- Grouping before substitution
  - Allow substitution: double quotes “”
  - Prevent substitution: braces {}

Tcl: Grouping Example

```
set msg This Is A Wrong Example
set msg This\ Is\ A\ Correct\ Example
set msg “This Is A Correct Example”
set msg {This Is A Correct Example}
set msg ‘This Is A Wrong Example’

puts "hello; puts hi"
puts "hello
John"

set a 3
puts “$a+2 is\t [expr $a+2]”
puts {$a+2 is\t [expr $a+2]}

for {set i 0} {$i<5} {incr i} {puts $i}
```


Tcl: Variable

- Variable name
  - `varName` can consist of any character
  - By default Tcl assumes *`varName`* contains only letters, digits and the underscore
  - Use of **`${`***`varName`***`}`** for delimiting the name
- Simple variable
  - The variable is always stored as a string
- Associative array ()
  - Variables with a string-valued index (mapping)
    - Array name and element name
  - Multi-dimensional array
  - `array` command

Tcl: Variable Example (1)

```
set  c 122; set 122 c
set  d value; set e d
set  e
set  $e
set [set e]
set “link bandwidth" 3
expr ${link bandwidth} * 5
expr $”link bandwidth” * 5
set rate [expr 5*2]
set bandwidth $rateMb
set bandwidth ${rate}Mb
set bandwidth $rate.5Mb
```


Tcl: Variable Example (2)

```
set  x  3
set "x" "3"
expr $x * "10"
set arr(0) 7
set arr(1) hello
set arr(two) 3
set arr(the\ name) {the value}
array names arr;array size arr
set mat(1,1) 10
set mat(1,2) 5
set x 1;set y 2
puts $mat($x,$y)
```

```
set mat(1, 1) 10
```

Tcl: Procedure

- Define a procedure
  proc *prcName arg body*
  - Procedure name and variable name are in different name spaces
  - Procedure nesting
  - Global scope for procedure name
  - Default argument value (quoting with {})
  - Variable length argument list `args`
  - Return value of a procedure

Tcl: Procedure Example

```
proc add {a b} {expr $a + $b}


proc inc {var {dv 1}} {
        set a [expr $var+$dv]
        return $a
}
proc greet {} {puts “hello there”}
proc add args {
    set s 0
    foreach i $args {incr s $i}
    return $s
}
```

Tcl: Scope

- Local scope inside the procedure
  - Variables defined outside the procedure (global variable) are invisible to the procedure
- **`global`** *`varName1 varName2 …`*
  - Use array for a collection of global variables
- **`upvar`** *`?level? varName localName`*
  - Level: 1 (relative level), #0 (absolute/global level)
  - Call by reference
- Static variable
  - Use global variable

Tcl: Scope Example

```
proc topology {link} {
        global node
        for {set i 0} {$i<$link} {incr i} {
                set node($i) [new Node]
}       }

proc topology-2 {var link} {
        upvar $var nn
        for {set i 0} {$i<$link} {incr i} {
                set nn($i) [new Node]
}       }

topology 3
topology-2 node 3
```

Tcl: Miscellaneous

- Comment (#)
  - Comment is also a command
  - It is placed where a command is expected
- Evaluation (`eval`)
- Command line arguments
  - `argc`, `argv`, `argv0`
- Script files
  - `source`

Tcl: Miscellaneous Examples

```
set x 2        # not a comment
set x 2       ;# a comment

if {$x==2} {   # a comment
  puts "x is 2”}

set bw [expr $x==1 ? 3 : 5]
set bw [expr {[info exists z] ? $z : 0}]
set bw [expr $x ? 3Mb : 5Mb]

set x “puts hello”
eval $x
```

Tcl: Core Commands

- Control flow
  - `if`, `switch`, `while`, `for`, `foreach`
- File access
  - `open`, `close`, `flush`, `puts`, `gets`
- String manipulation
  - glob-style and regular expression
- List manipulation
  - `llength`, `lindex`, `linsert`, `lreplace`
  - `lappend`
- `string` and `array` commands

NS-2: A Tcl Script (Recap)

```
#!/home/hsieh/ns-allinone-2.27/bin/ns

set ns [new Simulator]
set nf [open out.tr w];$ns trace-all $nf

for {set i 0} {$i<2} {incr i} {    ;# create the nodes
        set n($i) [$ns node]}
$ns duplex-link $n(0) $n(1) 1Mb 10ms DropTail

# Create a UDP agent
set udp(src) [new Agent/UDP]
$udp(src) set packetSize_ 500
$ns attach-agent $n(0) $udp(src)

proc finish {} {
        global ns nf
        $ns flush-trace; close $nf
}

$ns at 5.0 "finish"
$ns run
```

OTcl: Overview

- OTcl: Object Tcl
  - Object-oriented
    - Class and inheritance
  - Dynamic
    - Class can be defined incrementally
    - Methods and classes can be modified at any time
    - Instance can behave differently from the class itself
  - Object command approach
    - Each object is registered as a command to the parser
    - Each subcommand is an “argument” to the object
- OTcl intepreter: `otclsh` or `ns`

OTcl: Class

- `Class` command
  - **`Class`** *`clsName`* to create a class
  - *`clsName`* **`instproc`** to define a class method
- `Class` variable
  - *`clsName`* **`set`** *`varName varValue`*
  - *`clsName`* **`instvar`** to link to a class variable
- All instance variables and methods of the class are public
- Inheritance
  - *`clsName`* **`superclass`** to set parent class

OTcl: Class

- Comparison with C++
  - Class definition
    - `instproc` and `instvar` (set)
  - Constructor and destructor
    - `init` and `destroy`
  - Method shadowing and combination
    - `next`
  - Method invocation
    - `self`
  - Static variable
  - Instance lifecycle
    - `new` and `delete`

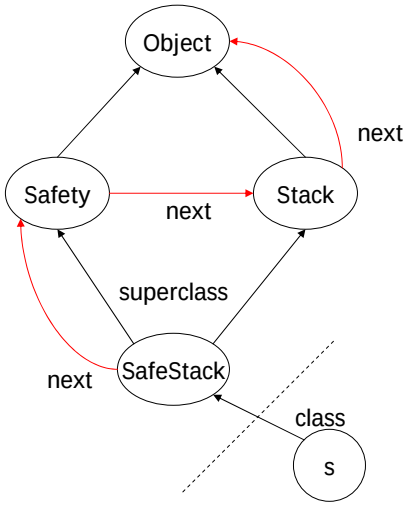
OTcl: An Example

```
Class Safety
Safety instproc init {} {
  $self next
  $self set count 0
}
Safety instproc put {thing} {
  $self instvar count
  incr count
  $self next $thing
}
Safety instproc get {} {
  $self instvar count
  if {$count==0} {return {empty!}}
  incr count -1
  $self next
}
```

```
Class Stack
Stack instproc init {} {
  $self next
  $self set pile {}
}
Stack instproc put {thing} {
  $self instvar pile
  set pile [concat [list $thing] \
            $pile]
  return $thing
}
Stack instproc get {} {
  $self instvar pile
  set top  [lindex $pile 0]
  set pile [lrange $pile 1 end]
  return $top
}
```

```
Class SafeStack -superclass {Safety Stack}
SafeStack s
```

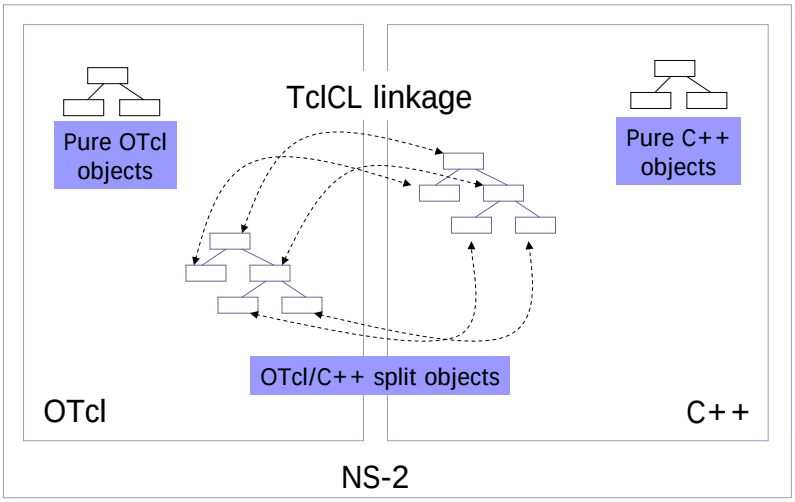
OTcl: Inheritance



TclCL: Overview

- TclCL: Tcl with Classes
- NS-2 is written in C++ with OTcl interpreter as a front end
- Class hierarchy
  - Compiled hierarchy and interpreted hierarchy
  - One-to-one correspondence of objects from users' perspective
  - Simulator objects are implemented in the compiled hierarchy, but instantiated through the interpreter
  - TclObject is the root of the hierarchy

TclCL: NS-2 Objects



TclCL: OTcl/C++ Linkage

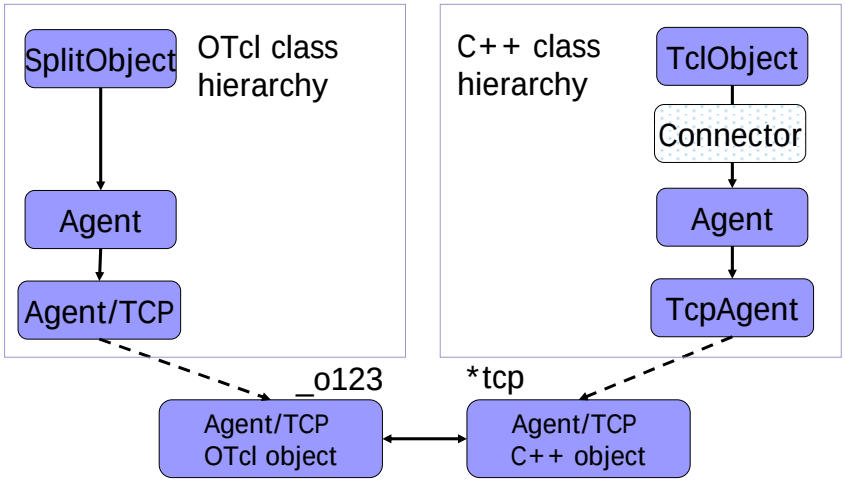
TclObject	Root of NS-2 object hierarchy
	bind(): link variable values between C++ and OTcl
	command(): link OTcl methods to C++ implementations
TclClass	Create and initialize TclObject's
Tcl	C++ methods to access the OTcl interpreter
TclCommand	Standalone global commands
EmbeddedTcl	NS-2 script initialization

TclCL: Class TclObject

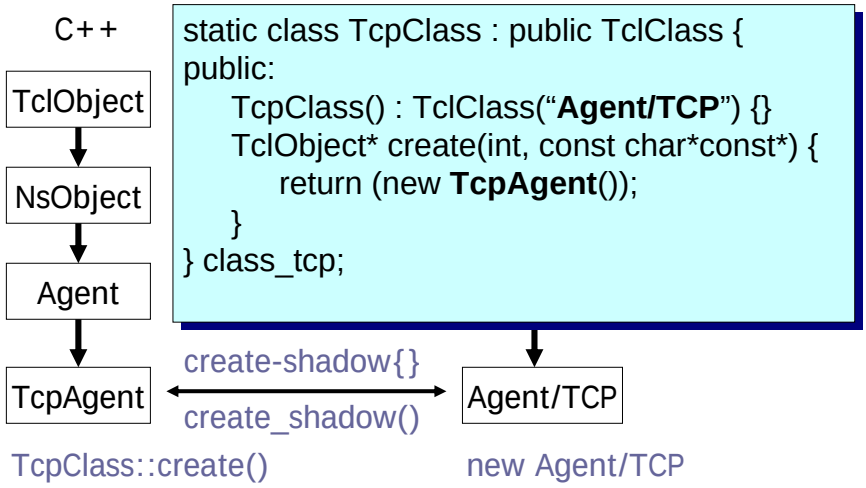
- Base class in NS-2 for split objects
  - Mirrored in both C++ (TclObject) and OTcl (SplitObject)
- Usage
  - Instantiation, bind and command
- Example

```
set tcp [new Agent/TCP]
$tcp set window_ 30
$tcp advanceby 5000
```


Class TclObject: Hierarchy



TclCL: Class TclClass



Class TclObject: Binding

- Bi-directional variable bindings
  - Link C++ member variables (compiled) to OTcl instance variables (interpreted)
- Initialization through the closest OTcl class variable

```
Agent/TCP set window_ 50
```

- Do all initialization of bound variables in ~ns/tcl/lib/ns-default.tcl
  - Otherwise a warning will be issued when the shadow compiled object is created

Class TclObject: Binding

- C++

```
TcpAgent::TcpAgent() {
    bind("window_", &wnd_);
    … …
}
```

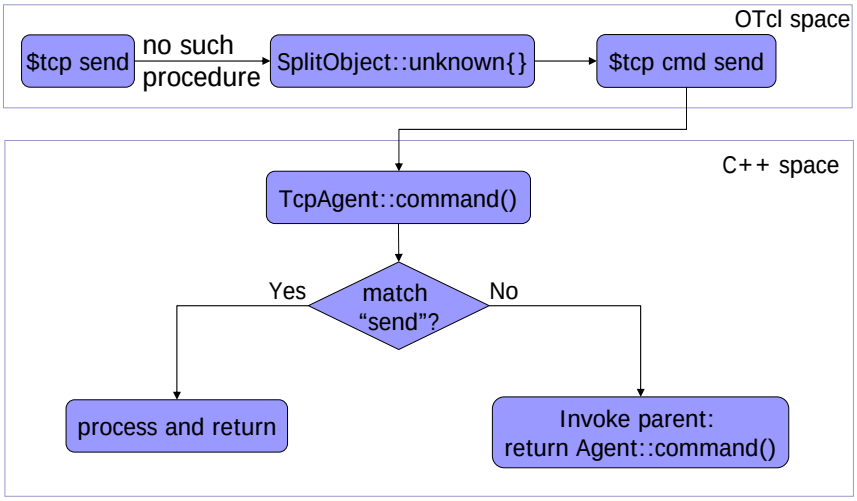
  - bind(), bind_time(), bind_bool(), bind_bw()
- OTcl

```
Agent/TCP set window_ 50
set tcp [new Agent/TCP]
$tcp set window_ 100
```


Class TclObject: Command

- Invoke C++ compiled functions through OTcl interpreted methods
  - A way of implementing OTcl methods in C++
- Hook point
  - Tcl method `unknown{}`
  - OTcl method `cmd{}`
- Send all arguments after `cmd{}` call to `TclObject::command()`
  - Use `Tcl::resultf()` in C++ to pass back results

Class TclObject: Command



Class TclObject: Command

- OTcl

```
set tcp [new Agent/TCP]
$tcp advance 100
```

- C++

```
int TcpAgent::command(int argc,
                      const char*const* argv) {
  if (argc == 3) {
    if (strcmp(argv[1], "advance") == 0) {
      int newseq = atoi(argv[2]);
      ……
      return TCL_OK;
    }
  }
  return (Agent::command(argc, argv);
}
```

TclCL: Class Tcl

- Class Tcl encapsulates the instance of the OTcl interpreter
  - It provides methods in C++ to access and communicate with the interpreter
- Usage
  - Obtain a reference to the OTcl instance
  - Invoke OTcl procedure
  - Obtain or pass back OTcl evaluation results
  - Return success/failure code to OTcl

Class Tcl: Example

- C++ (app.cc)

```
Tcl& tcl = Tcl::instance();
if (argc == 2) {
  if (strcmp(argv[1], "agent") == 0) {
    tcl.resultf("%s", agent_->name());
    return TCL_OK;
   }  else if (strcmp(argv[1], “start”) == 0) {
    tcl.evalf("[%s info class] info instprocs",
              name_);
    sprintf(result, " %s ", tcl.result());
     …
  }
  tcl.error(“unknown command”);
 }
```

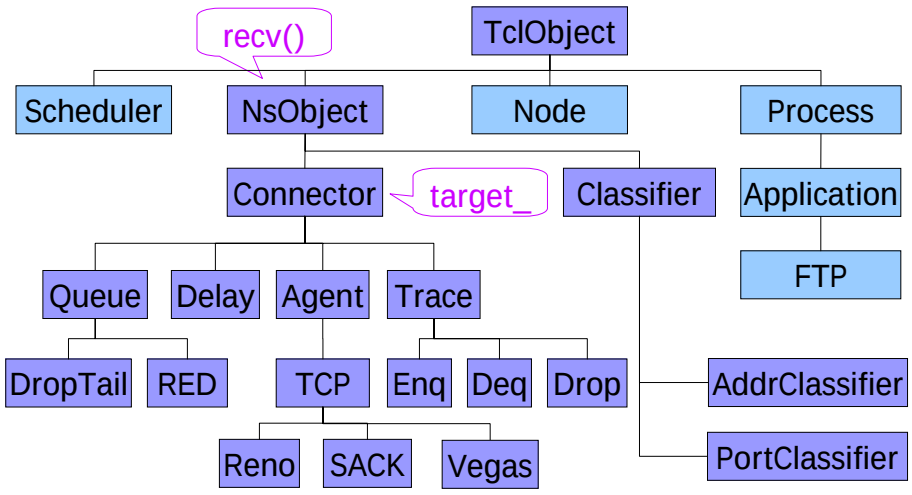
TclCL: Summary

- Class TclObject
  - Unified interpreted (OTcl) and compiled (C++) class hierarchies
  - Seamless access (procedure call and variable access) between OTcl and C++
- Class TclClass
  - Mechanism that makes TclObject work
- Class Tcl
  - Primitives to access OTcl interpreter

Network Simulator ns-2

Part II: Wired Network

Class Hierarchy



Simulation Elements

- Create the event scheduler (simulator)
- [Setup tracing]
- Create network topology
- [Setup routing]
- [Insert error modules/network dynamics]
- Create connection (transport)
- Create traffic (application)
- Start the scheduler
- Post-process data

Event Scheduler

- Create event scheduler
  - `set ns [new Simulator]`
- Schedule events (OTcl)
  - OTcl: `$ns at <time> <TCL_command>`
  - C++: `Scheduler::schedule(h,e, delay)`
- Obtain simulation time
  - OTcl: `$ns now`
  - C++: `Scheduler::clock()`
- Start scheduler
  - `$ns run`
  - The last line of your OTcl script

Trace

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

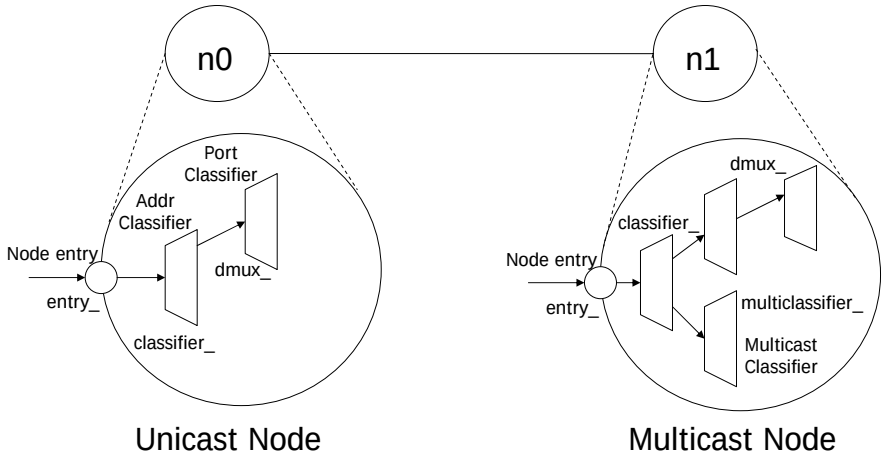
```
<event> <t>  <from> <to>  <pkt> <size> -- <fid> <src> <dst> <seq> <uid>
      + 1      0     2    cbr   210 ------- 0   0.0   3.1    0    0
      - 1      0     2    cbr   210 ------- 0   0.0   3.1    0    0
      r 1.00234 0    2    cbr   210 ------- 0   0.0   3.1    0    0
```

  - `$ns namtrace-all [open namtr.out w]`
- Turn on tracing on specific links
  - `$ns trace-queue $n0 $n1`
  - `$ns namtrace-queue $n0 $n1`
- Output trace to `/dev/null` if not desired

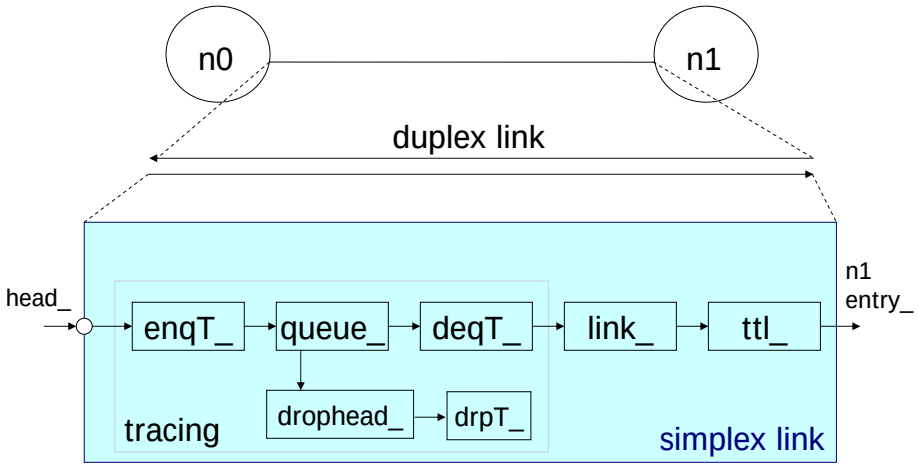
Network Topology

- Nodes
  - `set n0 [$ns node]`
    `set n1 [$ns node]`
- Links and queues
  - `$ns duplex-link $n0 $n1 \`
    `<bandwidth> <delay> <queue>`
  - `bandwidth`: bind_bw(), `delay`: bind_time()
    `queue`: DropTail, RED, CBQ, FQ, ...
  - Link delay = *f* (`bandwidth`, `delay`)
    = packet transmission time + propagation delay

Network Topology: Node



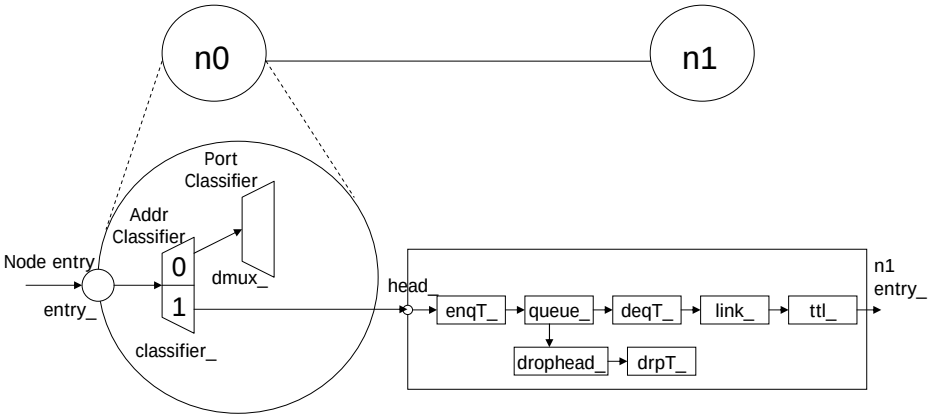
Network Topology: Link



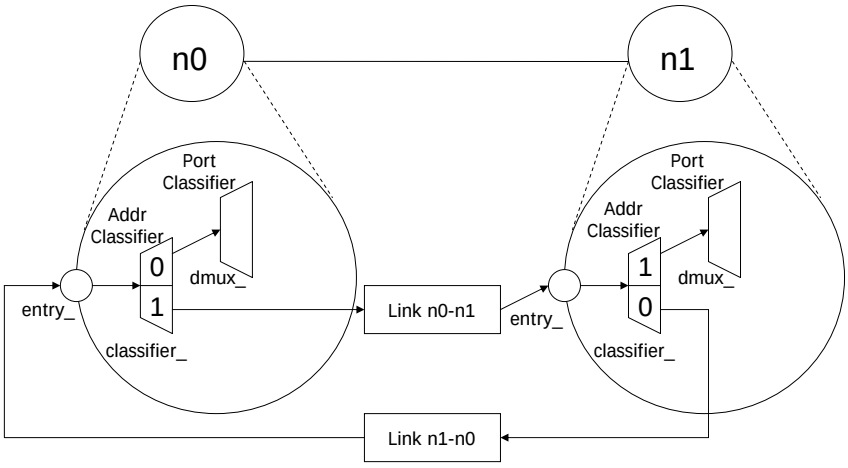
Routing

- Unicast routing
  - `$ns rtproto <type> <nodes>`
  - `type`: Static (default), Session, DV, LS, Manual
    `nodes`: default entire topology
- Default static routing
  - Dijkstra's all-pairs shortest path first algorithm
  - Route calculation is done before simulation starts
- Link cost
  - `$ns cost $n0 $n1 <cost>`
  - default link cost = 1

Routing



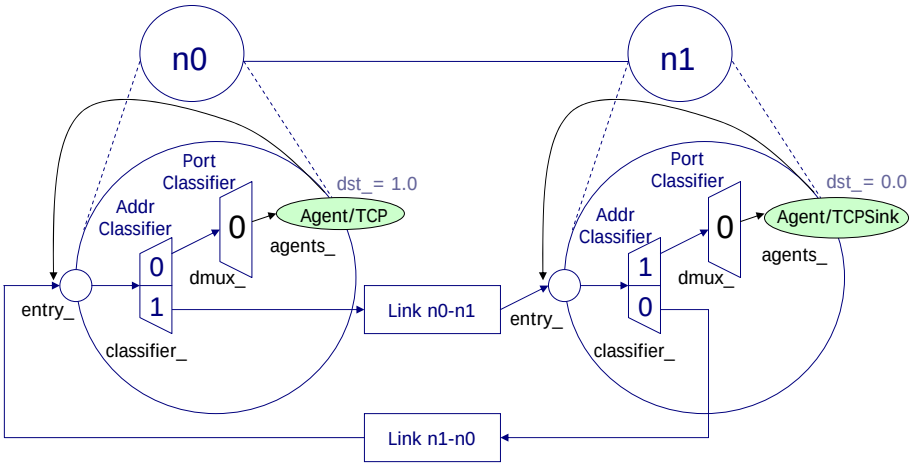
Routing



Transport: 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 $tcpsink`
  - Use `create-connection{}`
- Customization
  - `$agent set fid <fid>`
  - `$agent set packetSize_ <size>`

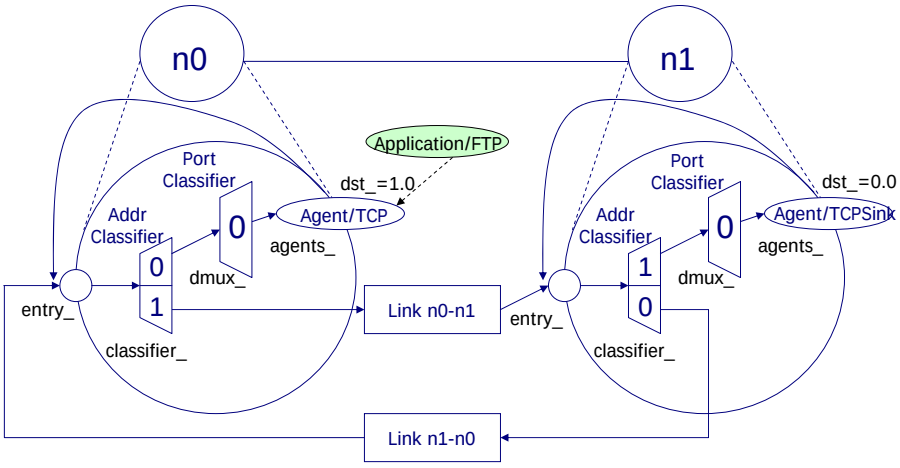
Transport



Application

- FTP
  - `set ftp [new Application/FTP]`
    `$ftp attach-agent $tcp`
  - `$tcp attach-app FTP`
- CBR
  - `set cbr [new Application/Traffic/CBR]`
  - `$cbr set packetSize_ 1000`
    `$cbr set rate_ 16000`
- Start traffic generation
  - `$ns at <time> “$app start”`

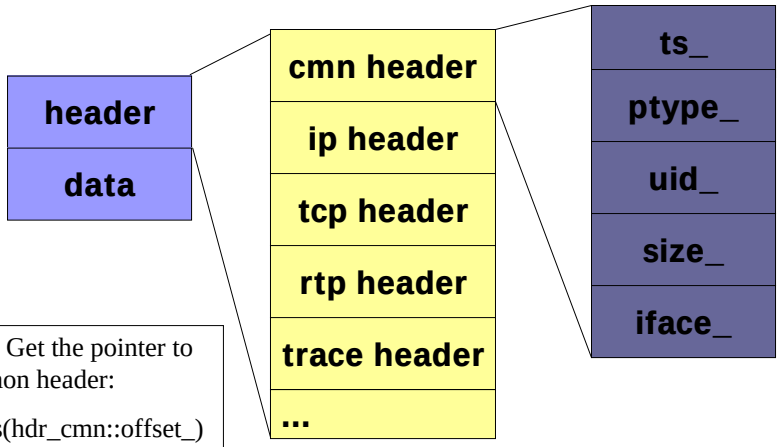
Application



Packet

- Packets are events
  - Can be scheduled to “arrive”
- Packets contain header section and data
  - Header section is a cascade of all in-use headers
- Each packet contains a common header
  - packet size (used to compute transmission time)
  - packet type
  - timestamp, uid, ...
- All in-use headers are included when simulation starts
  - Change packet size to reflect header cascading

Packet Header

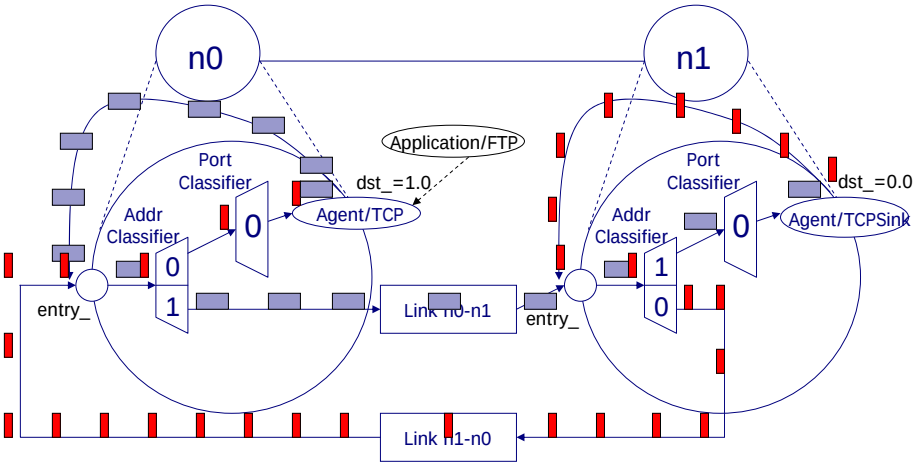


Example: Get the pointer to the common header:

p->access(hdr_cmn::offset_)

or, HDR_CMN(p)

Packet Flow



Simple code (I)

```
set ns [new Simulator]

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

$ns duplex-link $n0 $n1 1Mb 10ms DropTail

set tcp0 [new Agent/TCP]
$ns attach-agent $n0 $tcp0
set sink0 [new Agent/TCPSink]
$ns attach-agent $n1 $sink0
$ns connect $tcp0 $sink0

set ftp0 [new Application/FTP]
$ftp0 attach-agent $tcp0

$ns at 0.5 "$ftp0 start"
$ns at 4.5 "$ftp0 stop"
$ns at 5.0 "stop"

$ns run
```

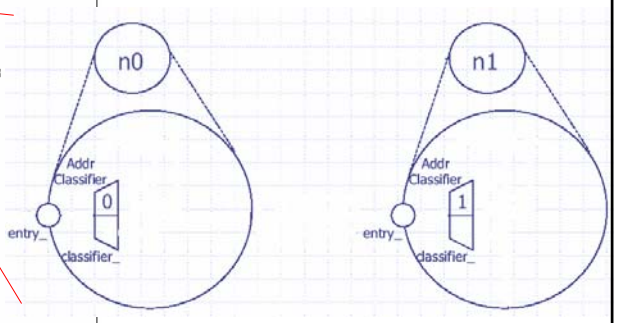
Simple.tcl

```
Simulator instproc init args {
        $self create_packetformat

        $self use-scheduler Calendar

        $self set nullAgent_ [new Agent/Null]
        $self set-address-format def

        eval $self next $args
}
```

Run your program →
% ns Simple.tcl

Simple code (II)

```
set ns [new Simulator]

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

$ns duplex-link $n0 $n1 1Mb 10ms

set tcp0 [new Agent/TCP]
$ns attach-agent $n0 $tcp0
set sink0 [new Agent/TCPSink]
$ns attach-agent $n1 $sink0
$ns connect $tcp0 $sink0

set ftp0 [new Application/FTP]
$ftp0 attach-agent $tcp0

$ns at 0.5 "$ftp0 start"
$ns at 4.5 "$ftp0 stop"
$ns at 5.0 "stop"

$ns run
```



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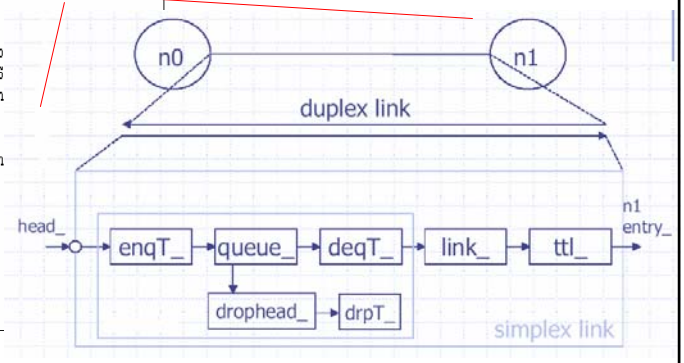
Simple code (III)

```
set ns [new Simulator]

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

$ns duplex-link $n0 $n1 1Mb 10ms DropTail

set tcp0 [new Agent/TCP]
$ns attach-agent $n0 $tcp
set sink0 [new Agent/TCPS
$ns attach-agent $n1 $sin
$ns connect $tcp0 $sink0

set ftp0 [new Application
$ftp0 attach-agent $tcp0

$ns at 0.5 "$ftp0 start"
$ns at 4.5 "$ftp0 stop"
$ns at 5.0 "stop"

$ns run
```



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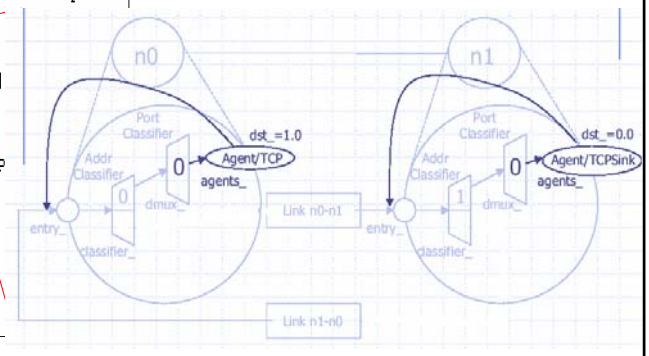
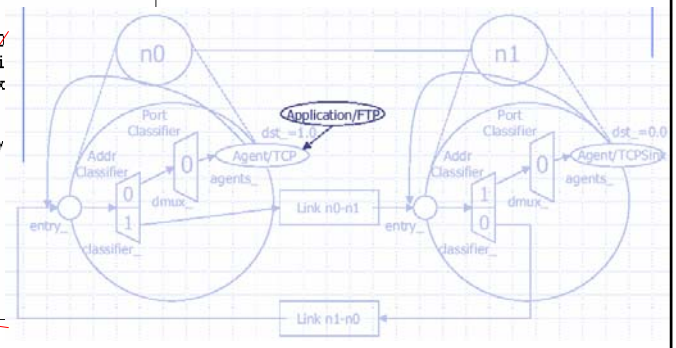
Simple code (IV)

```
set ns [new Simulator]

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

$ns duplex-link $n0 $n1 1Mb 10ms DropTail

set tcp0 [new Agent/TCP]
$ns attach-agent $n0 $tcp0
set sink0 [new Agent/TCPSink]
$ns attach-agent $n1 $sink0
$ns connect $tcp0 $sink0

set ftp0 [new Application/FTP
$ftp0 attach-agent $tcp0

$ns at 0.5 "$ftp0 start"
$ns at 4.5 "$ftp0 stop"
$ns at 5.0 "stop"

$ns run
```



Simple code (V)

```
set ns [new Simulator]

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

$ns duplex-link $n0 $n1 1Mb 10ms DropTail

set tcp0 [new Agent/TCP]
$ns attach-agent $n0 $tcp0
set sink0 [new Agent/TCPSi
$ns attach-agent $n1 $sink
$ns connect $tcp0 $sink0

set ftp0 [new Application/
$ftp0 attach-agent $tcp0

$ns at 0.5 "$ftp0 start"
$ns at 4.5 "$ftp0 stop"
$ns at 5.0 "stop"

$ns run
```



Recap

- NsObject: generic receive method `recv()` for packet reception
- Connector: one neighbor `target_`
- Node: collection of classifiers and agents
- Link: encapsulation of queue and delay
- Classifier: packet demultiplexer (routing)
- Agent: protocol endpoint or implementation of routing protocol
- Application: traffic generation

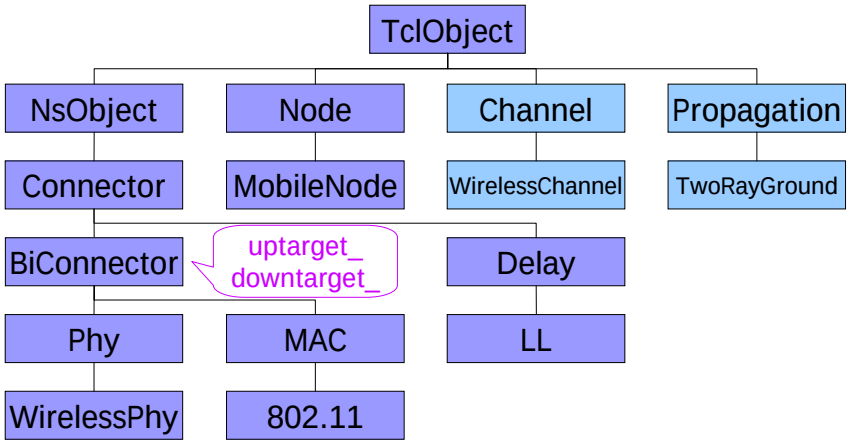
Network Simulator ns-2

Part III: Wireless Network

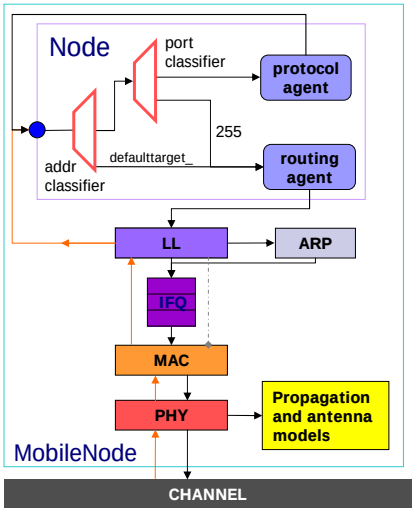
Wireless Network

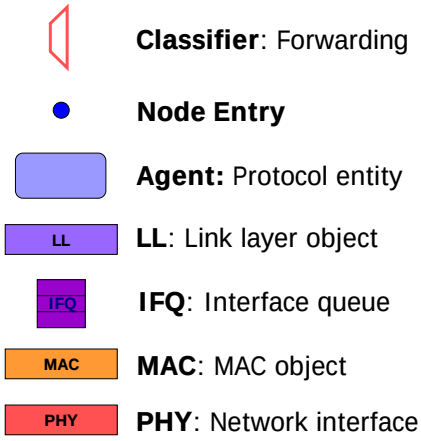
- Wireless network
  - Nodes can move
  - No explicit “links” used to connect nodes
- Wireless network extension
  - Mobile node
  - Wireless channel and propagation model
  - Packet headers
  - Topology and movement
  - Routing and forwarding

Class Hierarchy



Mobile Node: Portrait





Mobile Node: Components

- Link layer and ARP
  - Same as for LAN, but with a separate ARP module
  - ARP holds only one packet to the same destination
- Interface queue
  - Use callback to allow MAC retransmission
  - Use priority queue to give priority to routing protocol packets
- MAC layer
  - IEEE 802.11
  - RTS/CTS/DATA/ACK for all unicast packets
  - Physical and virtual carrier sense

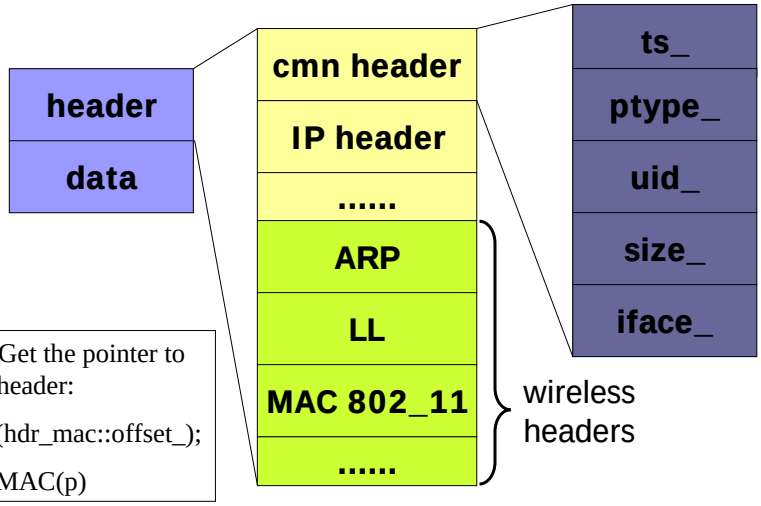
Mobile Node: Components

- Network interface (PHY)
  - Parameters based on DSSS (WaveLAN 914MHz)
  - Interface with antenna and propagation models for packet reception decision
  - Update energy upon transmission and reception
- Radio propagation model
  - Friss-space attenuation ($1/r^2$) at near distance
  - Two-ray ground reflection ($1/r^4$) at far distance
- Antenna
  - Omni-directional antenna with unity gain

Wireless Channel

- Duplicate packets to all mobile nodes attached to the channel except the sender
  - Propagation delay is included
  - Use of multiple channels is possible
- It is the receiver's responsibility (PHY) to decide if it will accept the packet
  - Decision is based on received signal power
    - Each packet will have the transmission power stamped
    - Currently interference from other transmissions is not included in reception decision
    - Collision is handled at individual receiver

Wireless Packet Header



Example: Get the pointer to the MAC header:

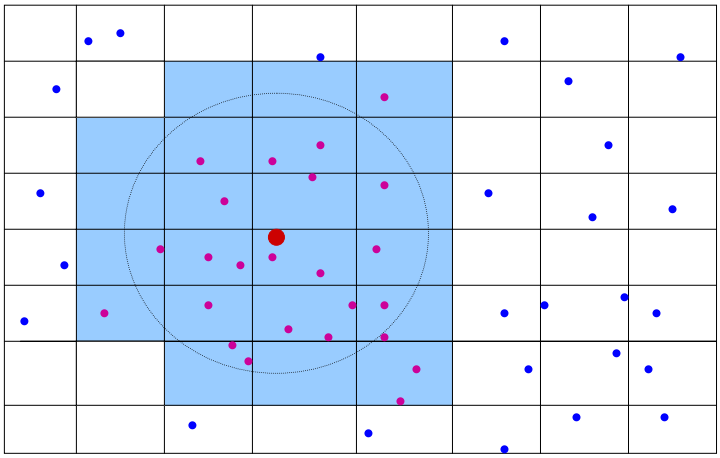
p->access(hdr_mac::offset_);

or, HDR_MAC(p)

Node Movement

- Location
  - Coordinates (x,y,z)
- Movement
  - Waypoint movement model
  - Random destination
  - Random speed [0, maxSpeed]
  - Random pause time or random moving time

Network Topology



Example: Ad Hoc Network

- Scenario
  - 3 mobile nodes
  - Move within a 670m*670m flat topology
  - DSR ad hoc routing protocol
  - Random waypoint mobility model
  - UDP and CBR traffic

An Example – Step 1

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

# Create a topology in a 670m x 670m area
set topo [new Topography]
$topo load_flatgrid 670 670

# ns trace and nam trace
$ns trace-all [open ns.tr w]
$ns namtrace-all-wireless [open ns.nam w] 670 670
```


An Example – Step 2

```
# Create God
set god [create-god 3]
```

- God: General Operations Director
  - Keep the number of nodes in the network
  - Called by 802.11 MAC to keep a sequence number cache of all nodes
  - Store an array of the smallest number of hops required to reach one node to another
  - Used for setdest operation

    `$ns at 100.00 “$god set-dist 2 3 1”`

An Example – Step 3

```
# Define how to create a mobile node
$ns node-config \
     -adhocRouting DSR \
     -llType LL \
     -macType Mac/802_11 \
     -ifqLen 50 \
     -ifqType Queue/DropTail/PriQueue \
     -phyType Phy/WirelessPhy \
     -antType Antenna/OmniAntenna \
     -propType Propagation/TwoRayGround \
     -channel [new Channel/WirelessChannel] \
     -topoInstance $topo
     -agentTrace ON \
     -routerTrace OFF \
     -macTrace OFF \
     -movementTrace OFF
```


Energy Parameters

```
$ns node-config \
      –energyModel       EnergyModel \
      -initialEnergy     100.0 \
      -txPower           0.6 \
      -rxPower           0.2
```

- Node is energy-aware
  - Node status: on / off / sleep
- Pt_ and Pt_consume_

An Example – Step 4

```
# Create mobile nodes
for {set i 0} {$i<3} {incr i} {
  set node($i) [$ns node]
  # disable random motion for static network
  $node($i) random-motion 0
}

# Define movement model (if applicable)
source movement-scenario-files

# Define traffic model (if applicable)
source traffic-scenario-files
```


Scenario: Movement

- Mobile movement generator
  - ~ns/indep-utils/cmu-scen-gen/setdest/setdest

```
setdest -n <numNodes>
-p <pauseTime> -s <maxSpeed>
-t <simTime> -x <maxX> -y <maxY>
```

- Random movement

```
$node random-motion 1
$node start
```

  - Change POSITION_UPDATE_INTERVAL and MAX_SPEED internally

A Movement File

```
$node_(0) set X_ 83.4
$node_(0) set Y_ 239.4
$node_(0) set Z_ 0.0
$node_(1) set X_ 257.1
$node_(1) set Y_ 345.4
$node_(1) set Z_ 0.0
$node_(2) set X_ 591.3
$node_(2) set Y_ 199.4
$node_(2) set Z_ 0.0
$ns_ at 33.0 "$node_(0) setdest 89.7  283.5 19.2“
$ns_ at 51.0 "$node_(1) setdest 221.8  80.9 14.9"
$ns_ at 50.0 "$node_(2) setdest 369.5 170.5  3.4"
```


Scenario: Traffic

- Traffic pattern generator
  - CBR (UDP) or FTP (TCP) traffic
  - ~ns/indep-utils/cmu-scen-gen/cbrgen.tcl

```
ns cbrgen.tcl [-type cbr|tcp]
[-nn nodes] [-seed seed]
[-mc connections] [-rate rate]
```

- Specify in the OTcl script
  - Same as the wired network scenario

A Traffic Scenario

```
set udp_(0)  [new Agent/UDP]
$ns_ attach-agent $node_(0) $udp_(0)
set null_(0) [new Agent/Null]
$ns_ attach-agent $node_(2) $null_(0)

set cbr_(0) [new Application/Traffic/CBR]
$cbr_(0) set packetSize_ 1000
$cbr_(0) set interval_ 4.0
$cbr_(0) set random_ 1
$cbr_(0) set maxpkts_ 10000
$cbr_(0) attach-agent $udp_(0)

$ns_ connect $udp_(0) $null_(0)
$ns_ at 20.0 "$cbr_(0) start"
```


An Example – Step 5

```
# Define node initial position in nam
for {set i 0} {$i < 3} {incr i} {
   $ns initial_node_position $node($i) 20
}

# Tell ns/nam the simulation stop time
$ns at 100.0 “$ns nam-end-wireless 100.0”
$ns at 100.0 “$ns halt”

# Start your simulation
$ns run
```

Summary

- NS-2 is an open source, discrete event, and packet level network simulator
- NS-2 is written in C++ with OTcl interpreter as a front end
- TclCL provides linkage for class hierarchy, object instantiation, variable binding and command dispatching
- NS-2 provides abundant implementations of protocols used in wired and wireless networks

References

- The *ns* Manual, January 2002
- IEC *ns* workshop slides, June 2000
- First *ns* workshop slides, September 1997
- Wetherall and Lindblad, “Extending Tcl for Dynamic Object-Oriented Programming,” Proceedings of the Tcl/Tk Workshop, 1995
- Welch, “Practical Programming in Tcl and Tk”, Prentice-Hall, 1995
- Ousterhout, “Tcl and the Tk Toolkit,” Addison-Wesley, 1994