
**ISSNSM — International Summer School on Network and Service Management**

*2nd ISSNSM's Tutorial on*

# Simulating Networks with Network Simulator 2 (ns-2)

(Tutorial T2)

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*June 3, 2008*

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der Bundeswehr Universität München

NS-2 Network Simulator 2

# Tutorial – Emanics Summer School, Zurich 3rd June, 2008

This tutorial/training course was supported in part by the EC IST-EMANICS Network of Excellence (#26854).



## ToC

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## ToC

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- **LANs**
  - Exercises 4
- **Unicast Routing and Network Dynamics**
  - Exercises 5
- **Outlook**
  - What had to be skipped in this tutorial



## Introduction

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  - Information Systems Laboratory
  - Faculty for Computer Science
  - Universität der Bundeswehr, Munich

## Basics (1/3)

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- **ns-2**
  - Discrete event driven simulator
  - (O)Tcl-script describes simulation flow
  - For all kinds of packet-based networks
  - Most Unix-like systems / cygwin
  - Packets are only events
    - No real data (payload) is transferred!
  - Each packet is simulated
    - Scalability issue!
    - “Careful” logging



## Basics (2/3)

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- **Support for**
  - TCP
  - Routing
  - Multicast-Protocols
  - Wired
  - wireless (WLAN and satellite) networks
  - Energy and movement models
- **Lots of extensions in the internet**
  - Mostly badly maintained
  - Only for one special ns-2 version

## Basics (3/3)

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- **License Simulator**
  - Freely distributable, Open-Source
- **Modules**
  - Type of license different, depending on author
  - mainly:
    - GNU GPL (GNU General Public License)
    - Berkley similar license
    - modified Berkley license
    - And compatible (e.g. Apache 2.0)
  - Use without any warranty



## Simulation Control

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- **With OTcl-Script**
  - Describes network topology and configuration
    - nodes
    - links
    - protocols
    - applications
  - Describes simulation flow (Course of actions)
    - Starting and stopping of data sources
    - Loss of communication
    - Duration of simulation
    - Firing of periodical events

## „Data processing“

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- **ns-2 does not transport any data!**
  - Simulated by events
  - Bigger packets arrive “later”
- **Works on packet level**
  - Every single packet is simulated
- **Everything what happens for each packet**
  - implemented in C++, Runtime advantages
- **Additionally some helper classes (Algorithms) in C++**



## Elements of a simulation

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- **Simulator**
  - Main class
  - Configuration of the simulation
  - Creating objects
  - Creating events and their scheduling
- **Nodes**
  - Nodes in a network (end or intermediate)
  - Attached list of agents (~protocols)
  - Attached list of neighbors (=> Links)
  - Unique ID (~address)

## Elements of a Simulation

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- **Links**
  - connecting nodes („physically“)
  - simplex-, duplex links
  - multiple access LANs, including wireless
  - bandwidth
  - delay
  - queue object
  - different trace-objects
    - enqueue, dequeue,
    - drop
    - receive (implemented in next node)



## Elements of a simulation

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- **Queues**
  - “part of” link
  - store, drop packets if necessary
  - Decide which packet is dropped
    - Drop-tail (FIFO)
    - Random Early Detect (RED)
    - Class Based Queuing (CBQ, priority + Round Robin)
    - Several Fair Queuing mechanisms (SFQ, DRR,...)
  - „Drop Destination“
    - Object all dropped packets are forwarded to

## Elements of a simulation

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- **Agents**
  - Endpoint of (logical) connections
  - ~ OSI level 3 (network)
  - Create and receive packets
  - implement protocols
  - Sometimes additional sender and receiver necessary
  - TCP, TCPSink in div. „flavors“
  - UDP
  - RTP, RTCP
  - ... (see ns manual, Chapter 10.3)



## Simplified scenario

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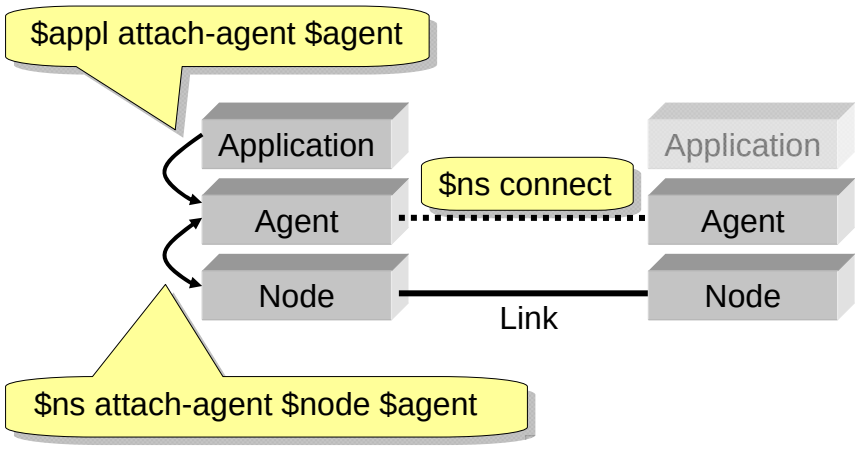

## First simulation (OTcl-Script)

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

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

#Define a 'finish' procedure
proc finish {} {
        global ns nf
        $ns flush-trace
        close $nf;              #Close the trace file

        exec nam out.nam &      #Execute nam on the trace file
                                #(optional)
        exit 0
}
```



## First simulation

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- **Place your code here**

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

#Run the simulation
$ns run
```

## General approach

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- ❑Create the simulator
- ❑Activate tracing
- ❑Create the nodes and topology
- ❑Create the links
- ❑Activate routing
- ❑Chose error model, if necessary
- ❑Create the traffic
- ❑Send application data



## Exercise

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- ❑**Exercise 1.1**
- ❑**Exercise 1.2**
- ❑**Exercise 1.3**
- ❑**Exercise 1.4**
- ❑**Exercise 1.5**

## Trace support

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- **Two types of output**
  - namtrace
  - trace
- **nam**
  - Graphical user interface for “Replaying” the simulation
  - Auto-layout or define node positions in script
  - Color packets
  - Graphical queue monitoring
  - (Limited) editor for creating simulations
  - namtrace only usable for nam



## Trace support

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- **Two ways to collect data:**
  - Traces with trace objects
  - Counters with monitor objects
- **Trace objects**
  - For each single packet writes to trace file:
  - Time of arrival, sending, dropping
  - For links or queues
- **Tracing of all links to one file is easy:**
  - $ns trace-all $tf
  - Not for bigger simulations!

## Example trace file

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```
- 0.84824 2 3 tcp 1040 ------- 0 0.0 3.0 29 46
r 0.85408 2 3 tcp 1040 ------- 0 0.0 3.0 28 44
+ 0.85656 2 3 tcp 1040 ------- 0 0.0 3.0 30 47
- 0.85656 2 3 tcp 1040 ------- 0 0.0 3.0 30 47
r 0.8624 2 3 tcp 1040 ------- 0 0.0 3.0 29 46
+ 0.86488 2 3 tcp 1040 ------- 0 0.0 3.0 31 49
- 0.86488 2 3 tcp 1040 ------- 0 0.0 3.0 31 49
r 0.87072 2 3 tcp 1040 ------- 0 0.0 3.0 30 47
+ 0.8732 2 3 tcp 1040 ------- 0 0.0 3.0 32 50
- 0.8732 2 3 tcp 1040 ------- 0 0.0 3.0 32 50
r 0.87904 2 3 tcp 1040 ------- 0 0.0 3.0 31 49
+ 0.88152 2 3 tcp 1040 ------- 0 0.0 3.0 33 52
- 0.88152 2 3 tcp 1040 ------- 0 0.0 3.0 33 52
r 0.88736 2 3 tcp 1040 ------- 0 0.0 3.0 32 50
+ 0.88984 2 3 tcp 1040 ------- 0 0.0 3.0 34 53
```



## Creating trace objects

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- **different trace objects**
  - Trace/*Enque*: packet arrival (at a queue)
  - Trace/*Deque* packet departure (at a queue)
  - Trace/*Drop* packet drop (packet delivered to drop-target)
  - Trace/*Recv* packet receive event at the destination node of a link

  **`$ns create-trace {type file src dst}`**
- **Needs to be included in simulation afterwards (Regularly very complex)!**
  - Not feasible

## Tracing of links

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- **Record all events**

```
$ns trace-queue <n1> <n2>
                    <optional:file>
$ns trace-queue $n2 $n3 $tf
```

- **Record only the drops**

```
$ns drop-trace $n2 $n3 [$ns
  create-trace Drop $tf $n2 $n3]
```



## Trace support

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- **Monitor objects**
  - Count variable (e.g. number of arrived packets or bytes)
  - for all packets or
  - only for one flow (flow monitor)
  - Advantage: Statistical data without long post processing

## Monitoring of Queues

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- `$ns monitor-queue <n1> <n2> <opt:qtrace> <opt:sampleinterval>`
  - qtrace: Channel-ID, optional only when Channel-ID was set in trace-all
  - Returns QueueMonitor object
  - Is configured over attached link
  - `$ns simplex-link` and `$ns duplex-link` have no return value
  - Retrieve link object from simulator:

```
set monitoredLink [$ns link $n2 $n3]
```



## Monitoring of Queues

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- **Time based**
  - All *sampleInterval* seconds
  - `$monitoredLink queue-sample-timeout`
  - `$monitoredLink start-tracing`
  - Uses for output: `sample-queue-size`
  - starts each time new period!
- **Call directly**
  - **`$monitoredLink sampe-queue-size`**
  - returns string:
  - $meanBytesQ $meanPktsQ $parrivals_ $pdepartures_ $pdrops_ $barrivals_ $bdepartures_ $bdrops_

## Monitoring of Queues

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❑**Read all values manually (packets)**

`$qmon set parrivals_` (# packet arrival)
`$qmon set pdepartures_` (# p. depart.)
`$qmon set pdrops_` (# packet drops)
`$qmon set pkts_` (# packet in queue now)

```
set pktint [$qmon get-pkts-
                        integrator]
```

`$pktint set sum_` (Integral of queue size)



## Monitoring of Queues

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❑**Read all values manually (Bytes)**

`$qmon set barrivals_` (bytes arrival)
`$qmon set bdepartures_` (bytes depart.)
`$qmon set bdrops_` (bytes dropped)
`$qmon set size_` (bytes in queue now)

```
set byteint [$qmon get-bytes-
                        integrator]
```

`$byteint set sum_` (Integral queue size)
`$samples mean` (Average queue delay)

## Monitoring of Queues

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- **Time in queue**
  - `Samples` as extension to `QueueMonitor`
  - `set samples [new Samples]`
  - `$qMon set-delay-samples $samples`
- **Samples Klasse**
  - Siehe ~ns/tools/integrator.{h | cc}
  - `newPoint (delay)`
  - `cnt`
  - `mean`
  - `variance`
  - `reset`



## Monitoring of connections

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- **for UDP connections**
  - Special agent
  - Instead of `Agent/Null`
  - Set `Agent/LossMonitor`
- **Read variables**

`[set $lossMon nlost_]` # **not** arrived packets
`[set $lossMon npkts_]` # arrived packets
`[set $lossMon bytes_]` # arrived bytes

## Tracing of RED Queues

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- **Queue/RED derived from Queue**
- **additionally**
  - ave_ average queue size
  - prob1_ dropping probability
  - curq_ current queue size
  - cur_max_p_ current max. drop prob.
  - `set redq [[$ns link $n2 $n3] queue]`
    - Queue of link between n2 and n3
  - `redq trace variable`
    - Variables see above
  - `redq attach $tf` ($tf=trace file)



## Monitoring of Flows

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- **Special monitor**
  - Common and
  - Flow-based information

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

  - Fid: Name of a classifier (Classifier/Hash/ )
  - $link: Link object
- **Prints values only on call of dump**
  - To use **Fid classifier** have agent mark flows with **`set class_`**

## Exercise 2

- **Exercise 2.1**
- **Exercise 2.2**
- **Exercise 2.3**
- **Exercise 2.4**
- **Exercise 2.5**



## Evaluate Traces

- **Two applications included**
  - nam
  - xgraph
- **other**
  - Everything that can handle long tables
  - Delimiter is „ “ (Blank)
  - Spread sheets unsuitable (Traces too long, e.g., Excel can handle max. 64k lines)
  - Dependencies between lines, requires programming/scripting language

## Best practice Trace

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- **During simulation**
  - Output only relevant data
  - Less is more!
  - Do not write nam trace if not needed
- **Post-Processing**
  - Filter (e.g., grep)
  - Calculate derived data (e.g., calculate delay from two timestamps)
  - If necessary create new data file
  - visualize (xgraph or gnuplot)



## Best practice Monitor

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- **During simulation**
  - Read statistical data periodically from monitor
  - Directly write desired format to file
- **Post-Processing**
  - Filter (e.g., grep)
  - Calculate further derived values
  - Visualize (xgraph or gnuplot)

## xgraph

- **Part of ns-2**
- **Data set:**
  - Two columns, separated by blanks
  - Empty line starts new data set
  - Or store data sets in separate files
- **Lots of possibilities to customize output**
  - See `man xgraph`



## Xgraph - example

```
TitleText: Sample Data
0.5 7.8
1.0 6.2
"set one
1.5 8.9

"set two"
2.2 12.8
2.4 -3.3
2.6 -32.2
2.8 -10.3
```

Options as *option*: *value*

Name of data set, anywhere, starts with ”

Empty line or new file starts new data set

## gnuplot

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- **Plots functions**
  - Available for almost all operating systems
- **Interactive mode**

```
plot „filename“ using RowX:RowY,
       „filename“ using RowX:RowY2
       {axes x1y2} {with lines}
```

- **Plots even millions of points**
- **`man gnuplot`**
- **Good tutorials for gnuplot available in Internet**



## Useful (unix) commands

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- **grep**
  - Filters based on simple regular expression

```
grep –e “regex” filename
```

- **sed**
  - Filter with more complex regular expressions

```
sed –n –e “/regex/p” filename
```

- **awk**
  - Execute arbitrary commands for each line
  - Columns in parameters $1 $2 …

`awk '{ commands }'` (e.g. if, printf)

## Exercise

- **Exercise 3.1**
- **Exercise 3.2**
- **Exercise 3.3**



## Multipoint Links (LANs)

- **LAN (multi-access)**
  - Shared medium
  - Concurrent access

```
$ns make-lan "$n1 $n2" $bw $delay
   LL Queue/DropTail MAC/802_3 Channel
```

- **Creates LanNode**
  - Connects the nodes
  - Is a “Node” only from routing perspective
  - Implicitly creates a LanIface per node
  - Implicitly creates a Vlink to all nodes

## Multipoint Links (LANs)

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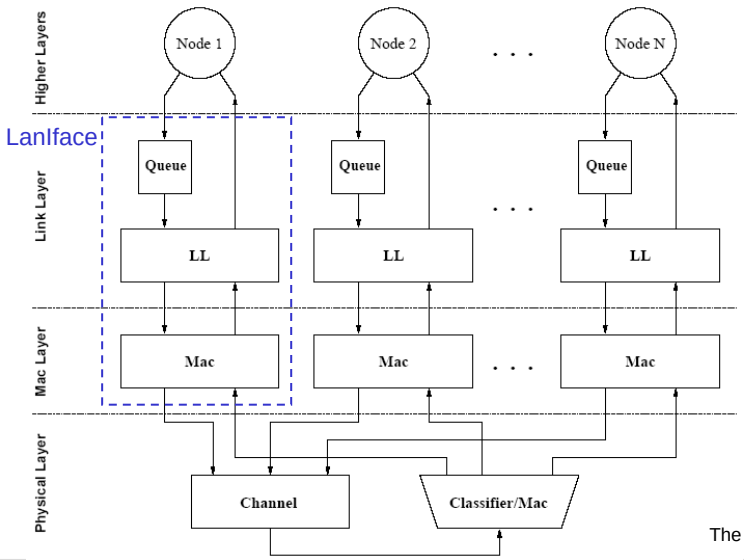


The ns Manual



## Multipoint Links (LANs)

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- **Channel class**
  - Simulates shared medium
  - Allows for MAC layer Carrier Sense and Collision Detection
  - `instvar delay_`
- **MacClassifier Klasse**
  - Delivers Packets, resp.
  - Simple Broadcast mechanism

## Multipoint Links (LANs)

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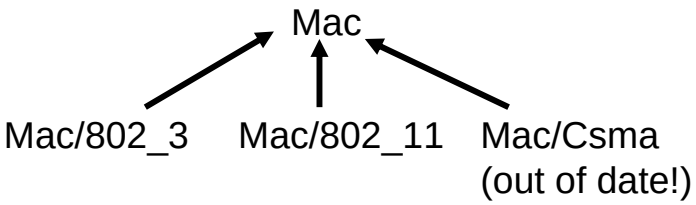
- **Mac class**
  - Simulates medium access protocol
  - `instvar bandwidth_` modulation rate
  - `instvar hlen_` header length
  - `instvar label_` MAC address






## Multipoint Links (LANs)

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- **LL class (Link Layer)**
  a) Determines the IP address of next hop
  – Uses LanRouter Object
  b) Determines related MAC address
  – Simplification: 1:1 of IP to MAC address (i.e. IP address is used as MAC address!)

- **LAN related OTcl files have own folder**
  – ~ns/tcl/lan/*
  – Includes also LAN extension of simulator

## Multipoint Links (LANs)

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- **LanRouter class**
  - One object per LAN
  - Created with LanNode
  - Each link layer object stores pointer to LanRouter
  - Determines next hop in the LAN
  - Uses configured RouteLogic



## protocols in ns-2

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- **Validated! (~ns/tcl/test/*)**
- **IP**
- **UDP**
- **TCP**
  - Taheo, Reno, New Reno, Vegas, ...
  - TFRC
- **RTP/RTCP (Realtime Transport P.)**
- **SRM (Scalable Reliable Multicast)**
- **SCTP (Stream Control Transmission P.)**

## Traffic profiles in ns-2

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- **Out-of-box**
- **CBR (Constant Bit Rate)**
- **Exponential**
- **Pareto**
- **RealAudio**
- **Worm (Simple Worm model)**
- **SctpApp**
- **Web cache**
- **Web traffic**



## Queuing discipline

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- **DropTail (simple FIFO)**
- **RED (Random Early Detect)**
  - PD
  - dsRED (RED for DiffServ)
- **DRR (Deficit Round-Robin)**
- **SFQ (Stochastically Fair Queuing)**
- **CBQ (Class based Queuing)**
- **XCP (Explicit Congestion)**

## Exercise

- **Exercise 4.1**
- **Exercise 4.2**



## Unicast Routing

- **No protocols, only algorithms are implemented**
  `$ns rtproto Protocol Nodelist`
- **Static (Standard)**
  - Dijkstra All-pairs Shortest Path First (SPF)
  - Calculated once before start of simulation
- **Session**
  - also Dijkstra (as static)
  - Recalculation for each topology change
  - Central routing protocol

## Unicast Routing

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- **DV**
  - Dynamic, decentralized, not for LANs!
  - Creates an agent per node
  - Distance Vector (Distributed Bellman-Ford)
  - Supports link costs
    `$ns cost $n2 $n3 costs`
  - Supports multiple paths to the same destination
    `$n2 set multiPath_ 1`
- **Manual**
  - No protocol
  - equivalent to „route“ command



## Network Dynamics

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- **Activate and deactivate**
  - Links
  - Nodes
- **Patterns**
  - Manual (once)

```
$ns rtmodel Manual operation time
                          node1 {node2}
```

  - *operation*: link-up, link-down
    - Two nodes: Link in between
    - One node: all links to this node

```
$ns rtmodel-at time {up|down} n1 {n2}
```

## Network Dynamics

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– Exponential distribution

```
$ns rtmodel Exponential {start
     uptime downtime finish} n1 {n2}
```

– Deterministic

```
$ns rtmodel Deterministic {start
     uptime downtime finish} n1 {n2}
```

– From *start* sec for *uptime* activated, then for *downtime* deactivated, until *finish* sec.

– *uptime* and *downtime* for exponential documented wrong!



## Network Dynamics

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– Timestamps in file

```
$ns rtmodel Trace filename n1 {n2}
```

- File format

```
v time operation n1 {n2}
```

- Operation: see above
- Not valid lines (e.g., different nodes) are ignored

❑**Recording of events/actions**

```
$rtmodel trace-dynamics $file
```

– Writes above format

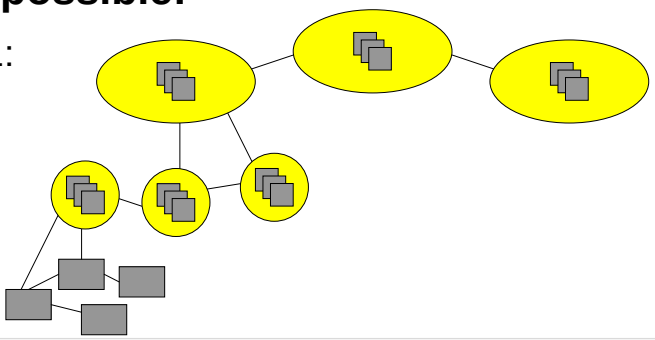
## Hierarchical Routing

- More efficient routing tables
- If number of nodes exceeds several thousands
- 3 layers possible:

Layer 1: domain

Layer 2: cluster

Layer 3: node





## Exercise

- Exercise 5.1
- Exercise 5.2
- Exercise 5.3

## Bug in ns-2.3x

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- **On activating or deactivating of a link:**

```
foreach node [[Simulator instance] all-
  nodes-list]
{
   # XXX using dummy 0 for 'changes'
        $node notify-mcast 0
}
```

  - "LAN" is a node (`LanNode`) but misses `notify-mcast`
  - Hack: find method `notifiy-mcast` of `node`
  - Create an (empty) method stub for `LanNode`
  - Run `make` in folder ns-2.33



## Outlook

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- **Error Model**
- **Wireless**
  - 802.11 MAC
  - Movement model
  - Ad Hoc Routing
  - Antenna
  - Mobil IP
  - Energy consumption
  - Satellite networks

## Outlook

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- **Emulation**
  - Connects simulator to real world networks
- **Topology Generators**
- **Random Variables**



## Further documentation

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- **nsnam Homepage**
  - http://nsnam.isi.edu/nsnam/index.php
  - User Information
- **Marc Greis‘s tutorial**
  - Good starting point
- **ns by Example**
  - Some more examples
- **Ns Manual**
  - The ns-2 bible
  - Reference for development

## Further documentation

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- **Slides of other Tutorials**
  - ISI ns tutorial 2002
  - UCB ns workshop 1999
- **Internet research**
  - Astonishing less helpful
- **Source code**
  - In your own installation directory
  - Doxygen formated
    - Search for “doxygen ns-2”
  - http://www-sop.inria.fr/planete/software/



## ns-2 Internals

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- **Size** **(Yu., H., Salehi, N., IEC Workshop 2000)**
  - 100.000 lines of C++-Code
  - 70.000 lines of OTcl-Code
  - 30.000 lines of Test-Suite
  - 20.000 lines Documentation
- **Fundamental model**
  - „Split object“
  - Binding between C++ and OTcl