

Bottleneck Bandwidth Sharing

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Lab № 1

Outline

- 1 Transport layer protocols
- 2 How to install ns-2 in Ubuntu
- 3 How to run ns-2 in VMware Player
- 4 UDP vs. TCP
- 5 TCP vs. TCP
- 6 Effect of the RTTs and delayed ACKs

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Transport Layer Protocols

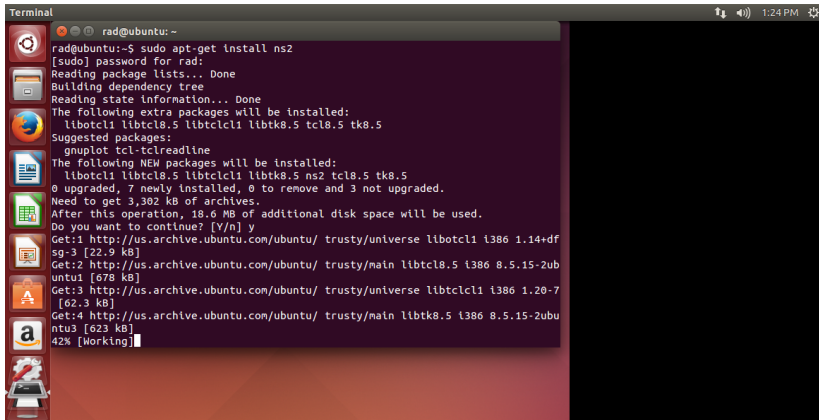
- **User Datagram Protocol (UDP)**
 - Multiplexing/demultiplexing
 - Error control (optional)
- **Transmission Control Protocol (TCP)**
 - Multiplexing/demultiplexing
 - Data segmentation and ordered data transfer
 - Error control (mandatory)
 - Flow control
 - Congestion control

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ns-2 in Ubuntu

- Install ns-2: `sudo apt-get install ns2`
 - Run **Terminal**: <Ctrl>+<Alt>+<T>

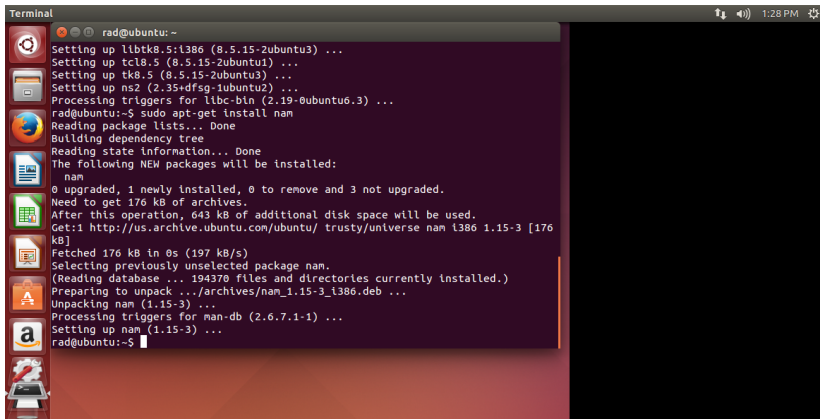


A screenshot of a Linux terminal window titled "Terminal" with a dark purple background. The window shows the command `rad@ubuntu:~$ sudo apt-get install ns2` and its output. The output includes package lists, dependency trees, and the installation progress for `libotcl1`, `libtcl8.5`, `libtk8.5`, and `ns2`. The terminal window has a sidebar on the left with various application icons and a top bar showing the user `rad@ubuntu` and the time `1:24 PM`.

```
rad@ubuntu:~$ sudo apt-get install ns2
[sudo] password for rad:
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following extra packages will be installed:
  libotcl1 libtcl8.5 libtk8.5 tcl8.5 tk8.5
Suggested packages:
  gnuplot tcl-tclreadline
The following NEW packages will be installed:
  libotcl1 libtcl8.5 libtk8.5 ns2 tcl8.5 tk8.5
0 upgraded, 7 newly installed, 0 to remove and 3 not upgraded.
Need to get 3,302 kB of archives.
After this operation, 18.6 MB of additional disk space will be used.
Do you want to continue? [Y/n] y
Get:1 http://us.archive.ubuntu.com/ubuntu/ trusty/universe libotcl1 i386 1.14+df
sg-3 [22.9 kB]
Get:2 http://us.archive.ubuntu.com/ubuntu/ trusty/main libtcl8.5 i386 8.5.15-2ub
untu1 [678 kB]
Get:3 http://us.archive.ubuntu.com/ubuntu/ trusty/universe libtk8.5 i386 8.5.15-2ub
untu3 [623 kB]
Get:4 http://us.archive.ubuntu.com/ubuntu/ trusty/main ns2 i386 2.1.16-1 [42.3
kB]
42% [Working]
```

ns-2 in Ubuntu (cont'd)

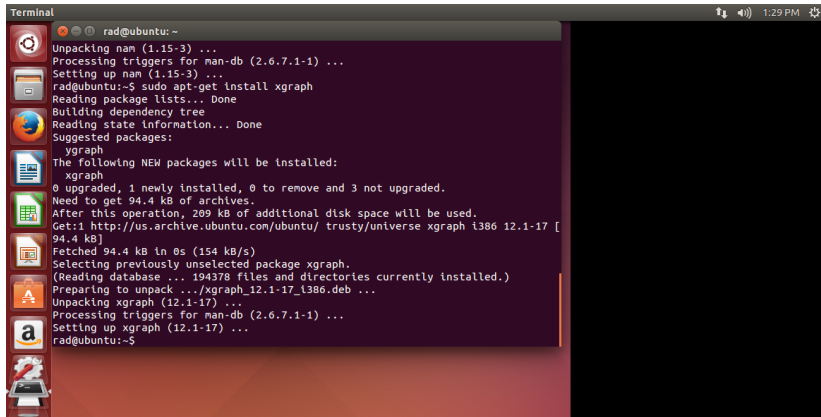
- Install nam: **sudo apt-get install nam**
 - See <http://askubuntu.com/questions/467901/segmentation-fault-core-dumped-in-ns2-ubuntu-14-04> ☹
 - Or use **ubuntu-12.04.5** instead of ubuntu-14.04.2



```
Terminal
rad@ubuntu: ~
Setting up libtk8.5:i386 (8.5.15-2ubuntu3) ...
Setting up tcl8.5 (8.5.15-2ubuntu1) ...
Setting up tk8.5 (8.5.15-2ubuntu3) ...
Setting up ns2 (2.35+dfsg-1ubuntu2) ...
Processing triggers for libc-bin (2.19-0ubuntu6.3) ...
rad@ubuntu:~$ sudo apt-get install nam
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following NEW packages will be installed:
  nam
0 upgraded, 1 newly installed, 0 to remove and 3 not upgraded.
Need to get 176 kB of archives.
After this operation, 643 kB of additional disk space will be used.
Get:1 http://us.archive.ubuntu.com/ubuntu/ trusty/universe nam i386 1.15-3 [176
kB]
Fetched 176 kB in 0s (197 kB/s)
Selecting previously unselected package nam.
(Reading database ... 194370 files and directories currently installed.)
Preparing to unpack .../archives/nam_1.15-3_i386.deb ...
Unpacking nam (1.15-3) ...
Processing triggers for man-db (2.6.7.1-1) ...
Setting up nam (1.15-3) ...
rad@ubuntu:~$
```

ns-2 in Ubuntu (cont'd)

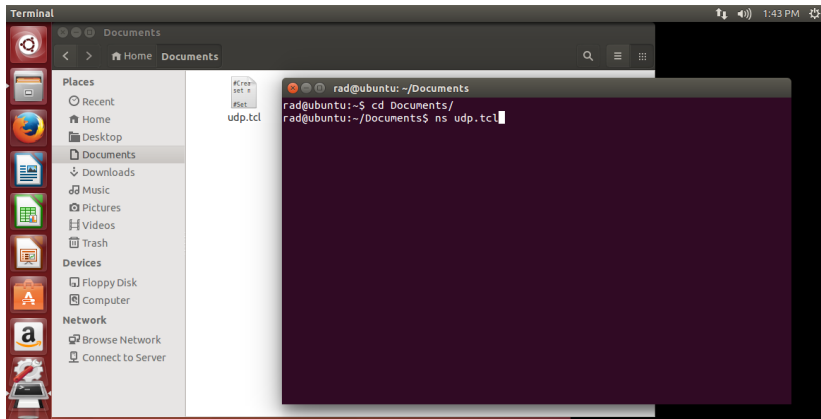
- Install xgraph: `sudo apt-get install xgraph`

A terminal window titled "Terminal" with a dark background and a light-colored text. The window shows the command "sudo apt-get install xgraph" being executed. The output displays the progress of the installation, including reading package lists, building a dependency tree, and fetching the xgraph package. The terminal window is part of a desktop environment with a sidebar on the left containing various application icons like a gear, a folder, a globe, a document, a calendar, a mail icon, a shopping cart, and a laptop. The top of the window shows system status icons like volume, network, and a clock indicating 1:29 PM.

```
Terminal
rad@ubuntu: ~
Unpacking nam (1.15-3) ...
Processing triggers for man-db (2.6.7.1-1) ...
Setting up nam (1.15-3) ...
rad@ubuntu:~$ sudo apt-get install xgraph
Reading package lists... Done
Building dependency tree
Reading state information... Done
Suggested packages:
  ygraph
The following NEW packages will be installed:
  xgraph
0 upgraded, 1 newly installed, 0 to remove and 3 not upgraded.
Need to get 94.4 kB of archives.
After this operation, 209 kB of additional disk space will be used.
Get:1 http://us.archive.ubuntu.com/ubuntu/ trusty/universe xgraph i386 12.1-17 [
94.4 kB]
Fetched 94.4 kB in 0s (154 kB/s)
Selecting previously unselected package xgraph.
(Reading database ... 194378 files and directories currently installed.)
Preparing to unpack .../xgraph_12.1-17_i386.deb ...
Unpacking xgraph (12.1-17) ...
Processing triggers for man-db (2.6.7.1-1) ...
Setting up xgraph (12.1-17) ...
rad@ubuntu:~$
```


ns-2 in Ubuntu (cont'd)

- Run simulation: `ns <name>.tcl`

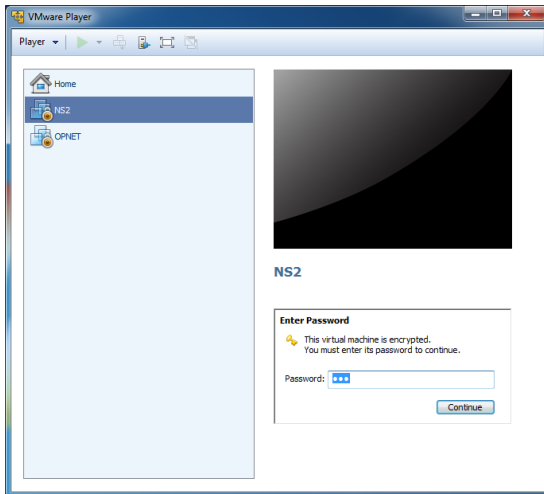


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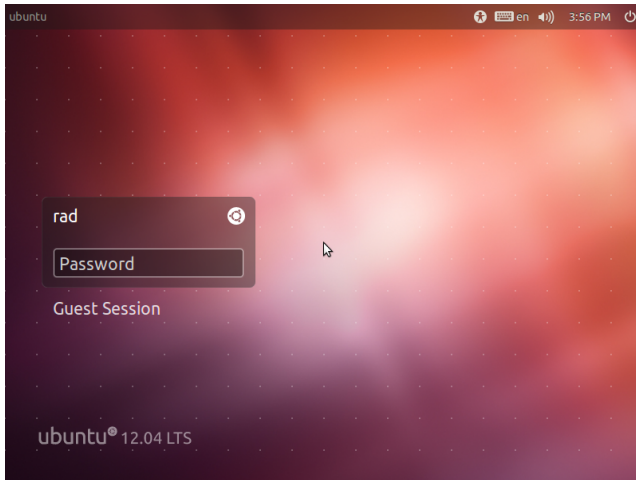
VMware Player

- Virtual machine: **NS2**
- Password to run: **123**



VMware Player (cont'd)

- Password: 123
- Or run **Guest Session**

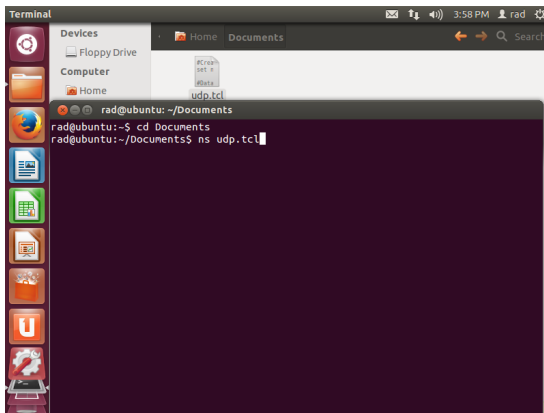


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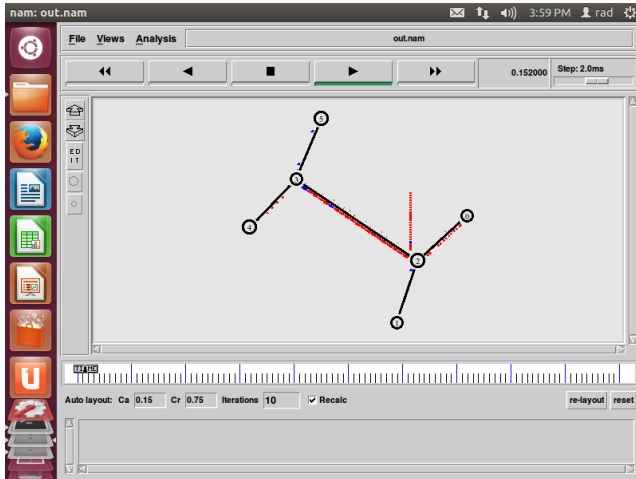
UDP vs. TCP

- Open **Terminal**: <Ctrl>+<Alt>+<T>
- Change directory: **cd Documents**
- Run simulation: **ns udp.tcl**



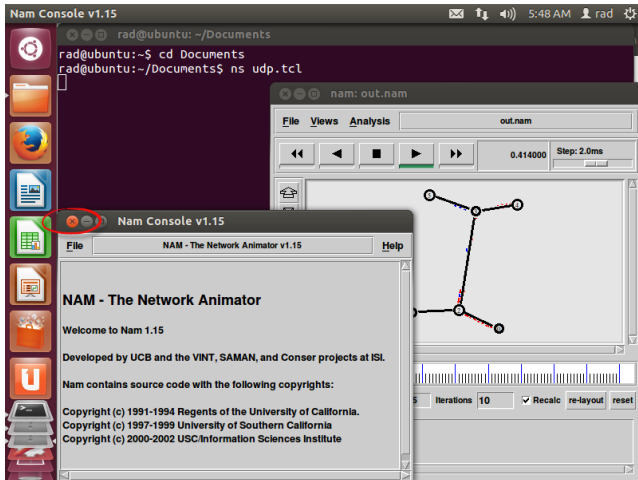
UDP vs. TCP (cont'd)

- **nam:** UDP (blue) vs. TCP (red)



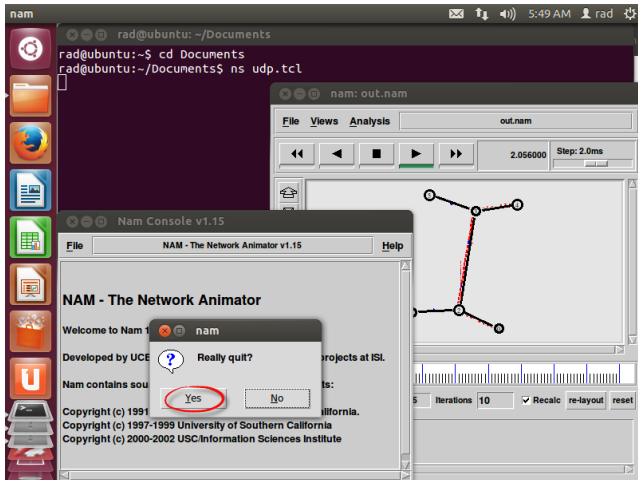
UDP vs. TCP (cont'd)

- Close **nam** (step 1)



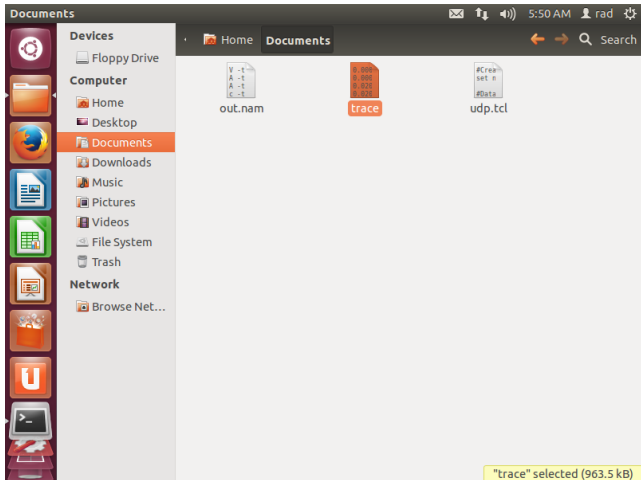
UDP vs. TCP (cont'd)

- Close **nam** (step 2)



UDP vs. TCP (cont'd)

- Open trace



UDP vs. TCP (cont'd)

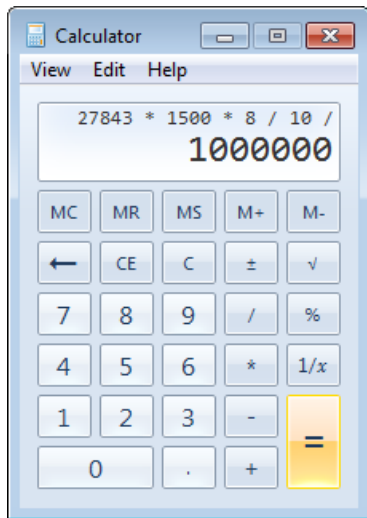
- trace: TCP goodput

```
trace (~/.Documents) - gedit
9.93617 0 0 4 0 maxseq_ 27817
9.93647 0 0 4 0 maxseq_ 27818
9.93677 0 0 4 0 maxseq_ 27819
9.93707 0 0 4 0 maxseq_ 27820
9.93737 0 0 4 0 maxseq_ 27821
9.93767 0 0 4 0 maxseq_ 27822
9.93827 0 0 4 0 maxseq_ 27823
9.93857 0 0 4 0 maxseq_ 27824
9.93887 0 0 4 0 maxseq_ 27825
9.93917 0 0 4 0 maxseq_ 27826
9.93947 0 0 4 0 maxseq_ 27827
9.93977 0 0 4 0 maxseq_ 27828
9.94007 0 0 4 0 maxseq_ 27829
9.94037 0 0 4 0 maxseq_ 27830
9.94067 0 0 4 0 maxseq_ 27831
9.94127 0 0 4 0 maxseq_ 27832
9.94157 0 0 4 0 maxseq_ 27833
9.94187 0 0 4 0 maxseq_ 27834
9.94217 0 0 4 0 maxseq_ 27835
9.94247 0 0 4 0 maxseq_ 27836
9.94277 0 0 4 0 maxseq_ 27837
9.94307 0 0 4 0 maxseq_ 27838
9.94337 0 0 4 0 maxseq_ 27839
9.94367 0 0 4 0 maxseq_ 27840
9.94397 0 0 4 0 maxseq_ 27841
9.98537 0 0 4 0 maxseq_ 27842
9.98537 0 0 4 0 maxseq_ 27843
```

Plain Text ▾ Tab Width: 8 ▾ Ln 27845, Col 1 INS

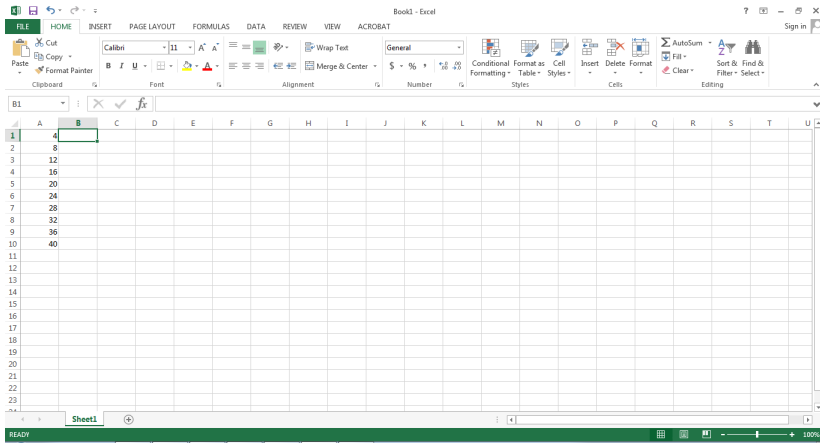
UDP vs. TCP (cont'd)

- **Calculator:** TCP goodput in "Mb/s"



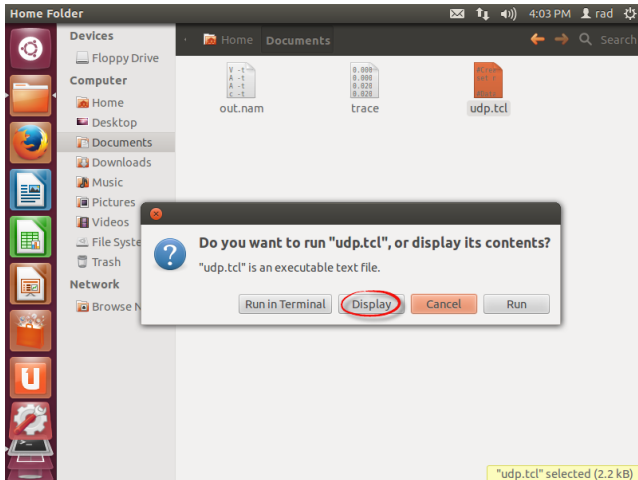
UDP vs. TCP (cont'd)

- Excel: UDP vs. TCP graph



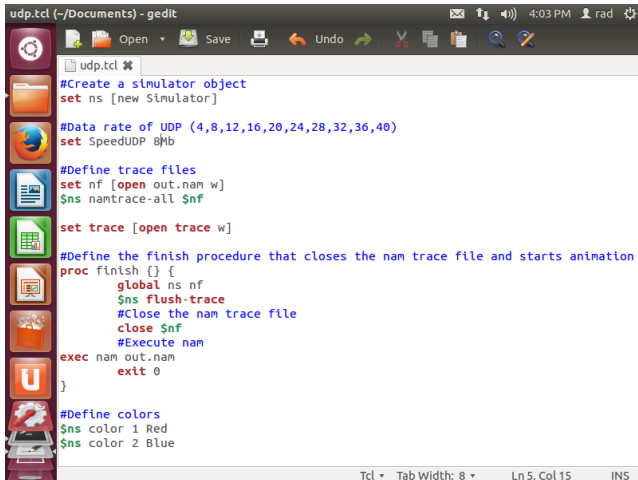
UDP vs. TCP (cont'd)

- **udp.tcl**: increase the data rate of UDP



UDP vs. TCP (cont'd)

- **udp.tcl**: 4, 8, 12, 16, 20, 24, 28, 32, 36, 40 Mb/s



```
udp.tcl (~/.Documents) - gedit
#Create a simulator object
set ns [new Simulator]

#Data rate of UDP (4,8,12,16,20,24,28,32,36,40)
set SpeedUDP 8Mb

#Define trace files
set nf [open out.nam w]
$ns namtrace-all $nf

set trace [open trace w]

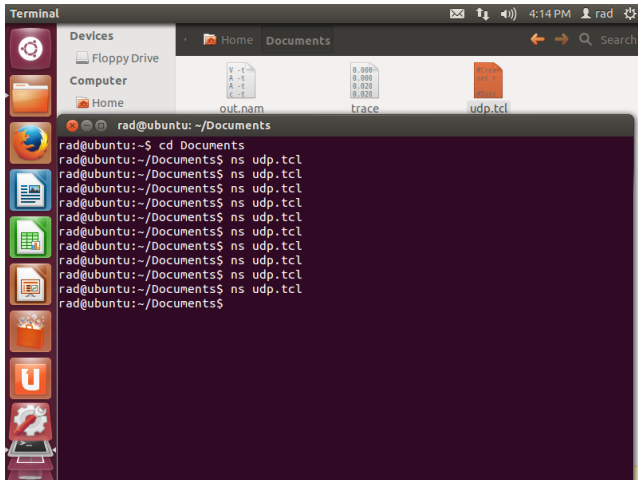
#Define the finish procedure that closes the nam trace file and starts animation
proc finish {} {
    global ns nf
    $ns flush-trace
    #Close the nam trace file
    close $nf
    #Execute nam
    exec nam out.nam
    exit 0
}

#Define colors
$ns color 1 Red
$ns color 2 Blue
```

Tcl Tab Width: 8 Ln 5, Col 15 INS

UDP vs. TCP (cont'd)

- **udp.tcl**: 4, 8, 12, 16, 20, 24, 28, 32, 36, 40 Mb/s

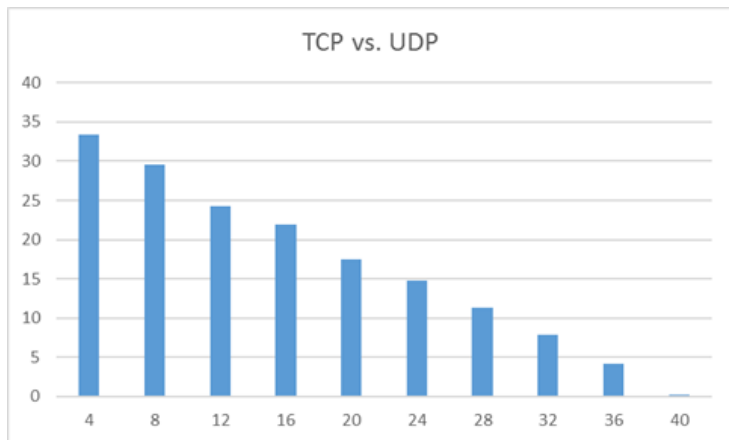


The screenshot shows a terminal window titled "Terminal" with a dark background. The window has a sidebar on the left with icons for Devices, Computer, and Home. The main area shows the file manager view of the "Documents" directory, with files "out.nam", "trace", and "udp.tcl" visible. The terminal output shows the user "rad@ubuntu" navigating to the "Documents" directory and running the command "ns udp.tcl" multiple times. The output of each command is a single line of text: "rad@ubuntu:~/Documents\$ ns udp.tcl".

```
rad@ubuntu: ~/Documents
rad@ubuntu:~$ cd Documents
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$ ns udp.tcl
rad@ubuntu:~/Documents$
```


UDP vs. TCP (cont'd)

- UDP vs. TCP

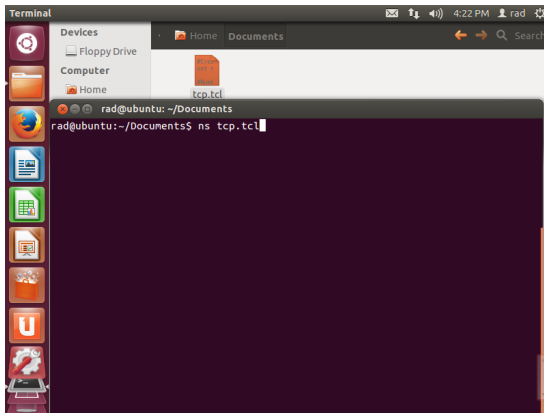


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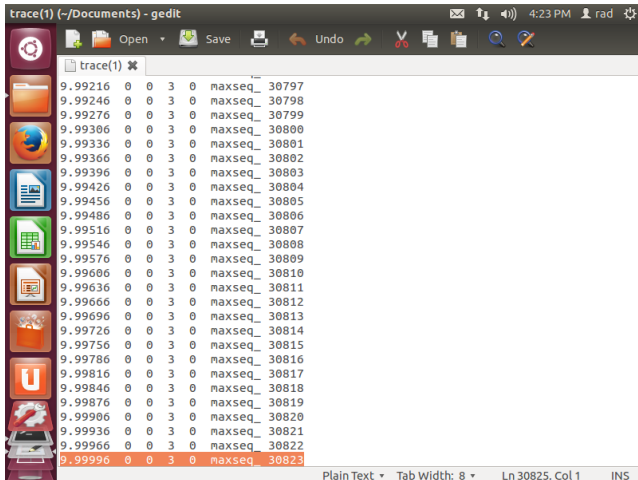
TCP vs. TCP

- Open **Terminal**: <Ctrl>+<Alt>+<T>
- Change directory: **cd Documents**
- Run simulation: **ns tcp.tcl**



TCP vs. TCP (cont'd)

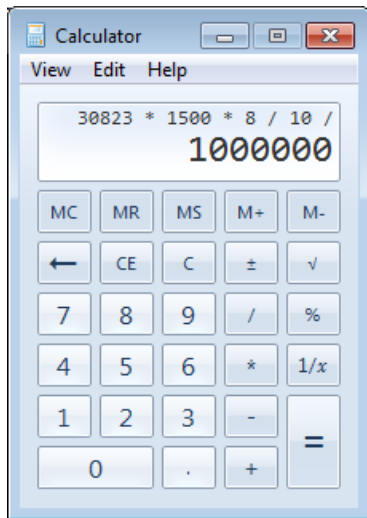
- trace(1): TCP1 goodput



```
9.99216 0 0 3 0 maxseq_ 30797
9.99246 0 0 3 0 maxseq_ 30798
9.99276 0 0 3 0 maxseq_ 30799
9.99306 0 0 3 0 maxseq_ 30800
9.99336 0 0 3 0 maxseq_ 30801
9.99366 0 0 3 0 maxseq_ 30802
9.99396 0 0 3 0 maxseq_ 30803
9.99426 0 0 3 0 maxseq_ 30804
9.99456 0 0 3 0 maxseq_ 30805
9.99486 0 0 3 0 maxseq_ 30806
9.99516 0 0 3 0 maxseq_ 30807
9.99546 0 0 3 0 maxseq_ 30808
9.99576 0 0 3 0 maxseq_ 30809
9.99606 0 0 3 0 maxseq_ 30810
9.99636 0 0 3 0 maxseq_ 30811
9.99666 0 0 3 0 maxseq_ 30812
9.99696 0 0 3 0 maxseq_ 30813
9.99726 0 0 3 0 maxseq_ 30814
9.99756 0 0 3 0 maxseq_ 30815
9.99786 0 0 3 0 maxseq_ 30816
9.99816 0 0 3 0 maxseq_ 30817
9.99846 0 0 3 0 maxseq_ 30818
9.99876 0 0 3 0 maxseq_ 30819
9.99906 0 0 3 0 maxseq_ 30820
9.99936 0 0 3 0 maxseq_ 30821
9.99966 0 0 3 0 maxseq_ 30822
9.99996 0 0 3 0 maxseq_ 30823
```

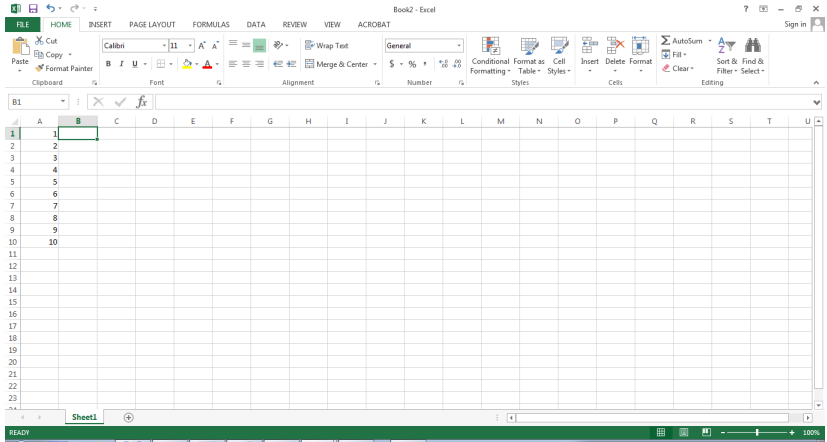
TCP vs. TCP (cont'd)

- **Calculator:** TCP goodput in "Mb/s"



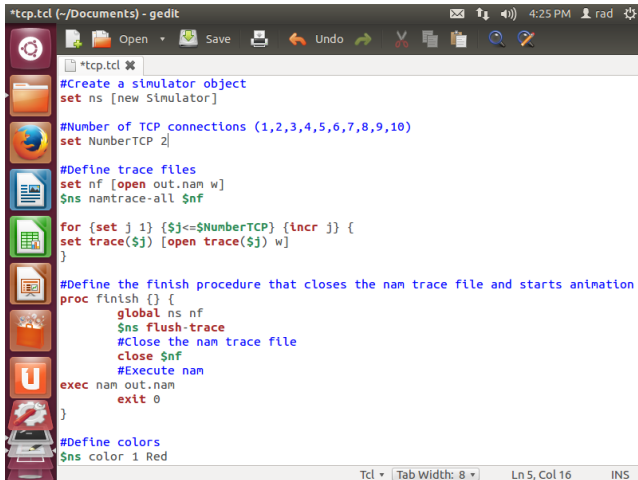
TCP vs. TCP (cont'd)

- Excel: TCP vs. TCP graph



TCP vs. TCP (cont'd)

- **tcp.tcl**: increase the number of TCP connections



```
*tcp.tcl (~/.Documents) - gedit
#Create a simulator object
set ns [new Simulator]

#Number of TCP connections (1,2,3,4,5,6,7,8,9,10)
set NumberTCP 2

#Define trace files
set nf [open out.nam w]
$ns namtrace-all $nf

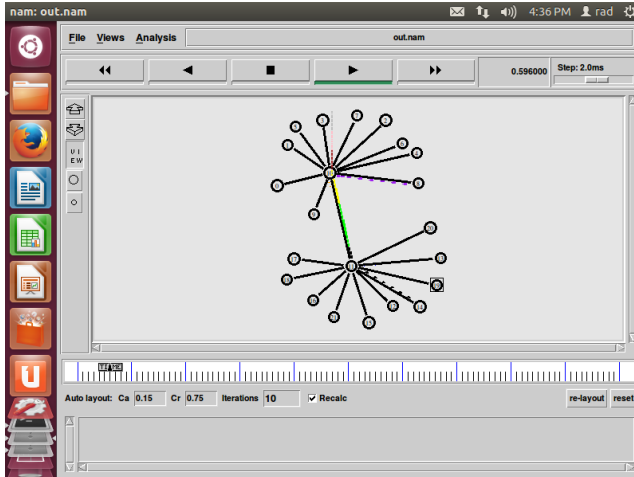
for {set j 1} {$j<=$NumberTCP} {incr j} {
    set trace($j) [open trace($j) w]
}

#Define the finish procedure that closes the nam trace file and starts animation
proc finish {} {
    global ns nf
    $ns flush-trace
    #Close the nam trace file
    close $nf
    #Execute nam
    exec nam out.nam
    exit 0
}

#Define colors
$ns color 1 Red
```

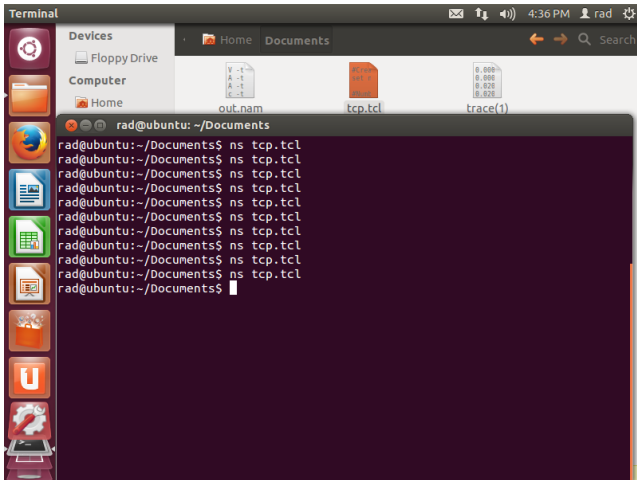
TCP vs. TCP (cont'd)

- **nam:** TCP vs. TCP



TCP vs. TCP (cont'd)

- **tcp.tcl**: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 connections

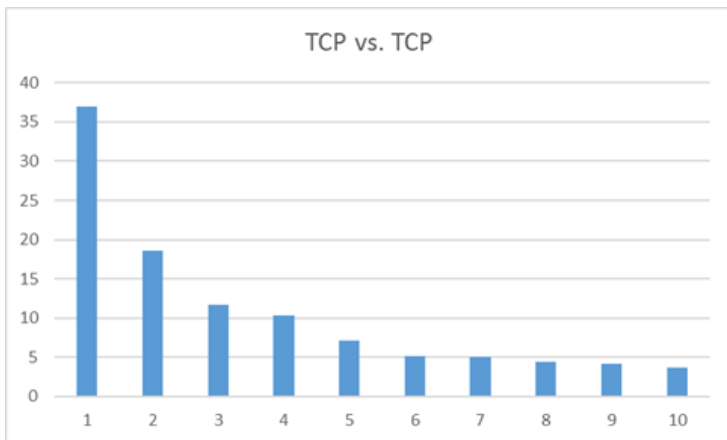


The screenshot shows a terminal window titled "Terminal" with a dark background. The window is open to the "Documents" directory, which contains three files: "out.nam", "tcp.tcl", and "trace(1)". The terminal prompt is "rad@ubuntu: ~/Documents". The user has entered the command "ns tcp.tcl" ten times, and the terminal shows the command being executed on each line. The output of the command is not visible in the screenshot.

```
rad@ubuntu: ~/Documents
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$ ns tcp.tcl
rad@ubuntu:~/Documents$
```

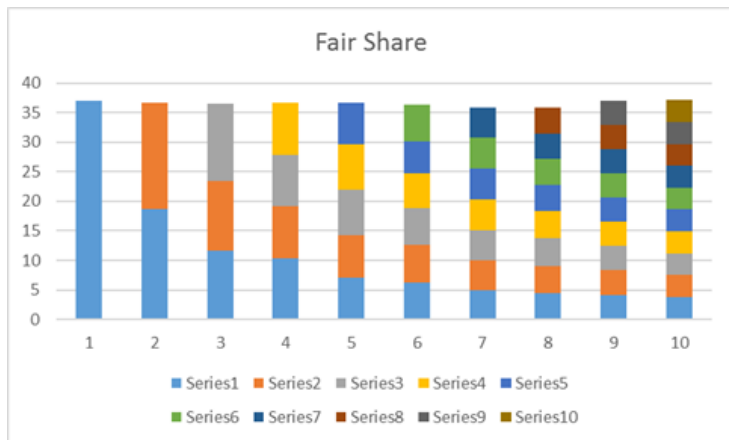
TCP vs. TCP (cont'd)

- TCP vs. TCP



TCP vs. TCP (cont'd)

- Fairness



TCP vs. TCP (cont'd)

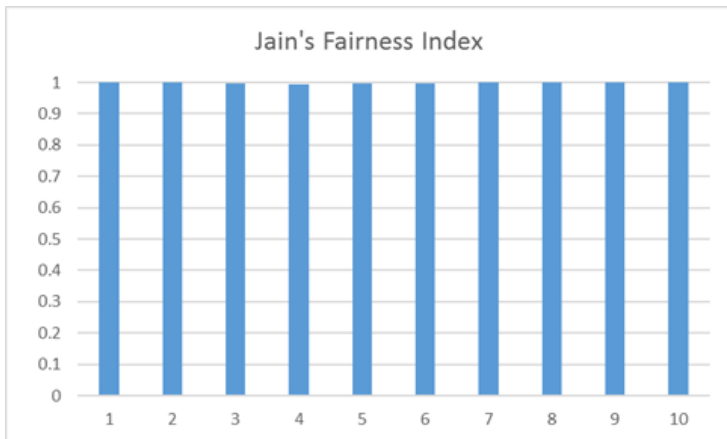
- Fairness can be quantified using **Jain's fairness index**
 - Prof. Raj Jain
- If the system allocates rates to N contending users, such that the i -th user receives a rate allocation x_i , the fairness index $f(x)$ is defined as:

$$f(x) = \frac{(\sum_{i=1}^N x_i)^2}{N * \sum_{i=1}^N (x_i)^2}$$



TCP vs. TCP (cont'd)

- Jain's fairness index



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RTTs and DelAck

- *J. Lee, S. Bohacek, J. Hespanha, K. Obraczka, 'A study of TCP fairness in high-speed networks,' University of Southern California, Technical Report 05-854, 2005*
- 2 TCP connections:
- $RTT_1 = 20 \text{ ms}$, $RTT_2 = 20 \text{ ms}$
 - Goodput1 = ? Mb/s, Goodput2 = ? Mb/s, Jain = ?
- **$RTT_1 = 40 \text{ ms}$** , $RTT_2 = 20 \text{ ms}$
 - Goodput1 = ? Mb/s, Goodput2 = ? Mb/s, Jain = ?
- $RTT_1 = 20 \text{ ms}$, $RTT_2 = 20 \text{ ms}$, $IW = 2$, **TCP1 = DelAck**
 - Goodput1 = ? Mb/s, Goodput2 = ? Mb/s, Jain = ?

RTTs and DelAck (cont'd)

- *J. Lee, S. Bohacek, J. Hespanha, K. Obraczka, 'A study of TCP fairness in high-speed networks,' University of Southern California, Technical Report 05-854, 2005*
- 2 TCP connections:
- $RTT1 = 20 \text{ ms}$, $RTT2 = 20 \text{ ms}$
 - Goodput1 = 19.9 Mb/s, Goodput2 = 19.4 Mb/s, Jain = 1
- **$RTT1 = 40 \text{ ms}$** , $RTT2 = 20 \text{ ms}$
 - Goodput1 = 15.1 Mb/s, Goodput2 = 24.3 Mb/s, Jain = 0.948
- $RTT1 = 20 \text{ ms}$, $RTT2 = 20 \text{ ms}$, $IW = 2$, **TCP1 = DelAck**
 - Goodput1 = 9.8 Mb/s, Goodput2 = 29.8 Mb/s, Jain = 0.797