

# The Square Root Formula

Roman Dunaytsev

Department of Communications Networks and Data Transmission  
Saint-Petersburg State University of Telecommunications

[roman.dunaytsev@spbgut.ru](mailto:roman.dunaytsev@spbgut.ru)

Lab № 3

# Outline

1 VMware Player

2 The square root formula

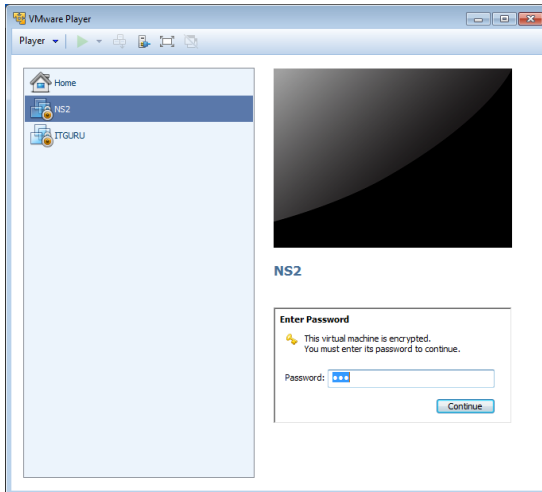
# Outline

1 VMware Player

2 The square root formula

# VMware Player

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



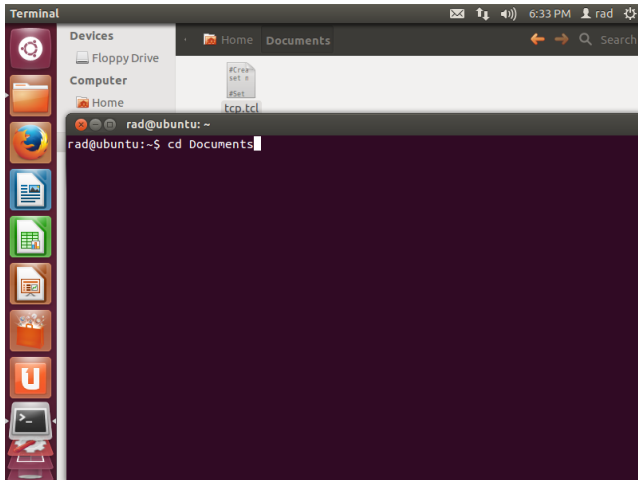
# Outline

1 VMware Player

2 The square root formula

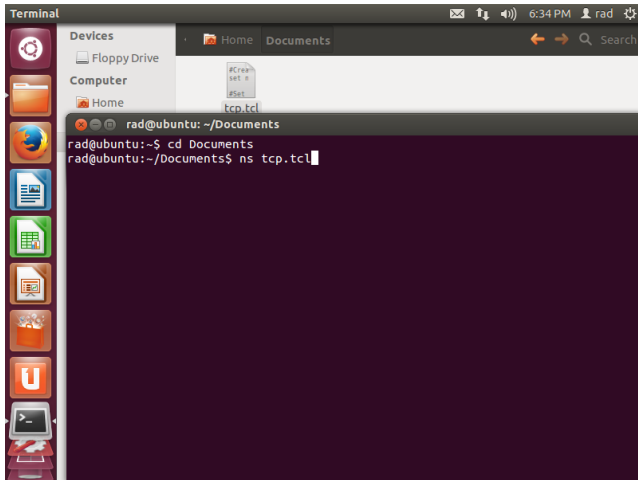
# The Square Root Formula

- Change directory: **cd Documents**



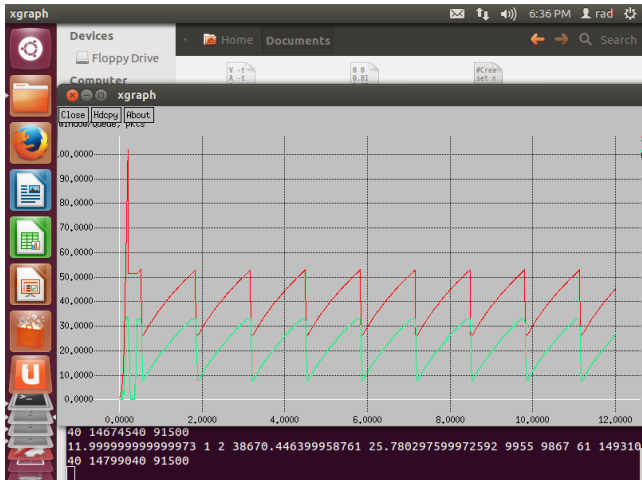
# The Square Root Formula (cont'd)

- Run simulation: **ns tcp.tcl**



# The Square Root Formula (cont'd)

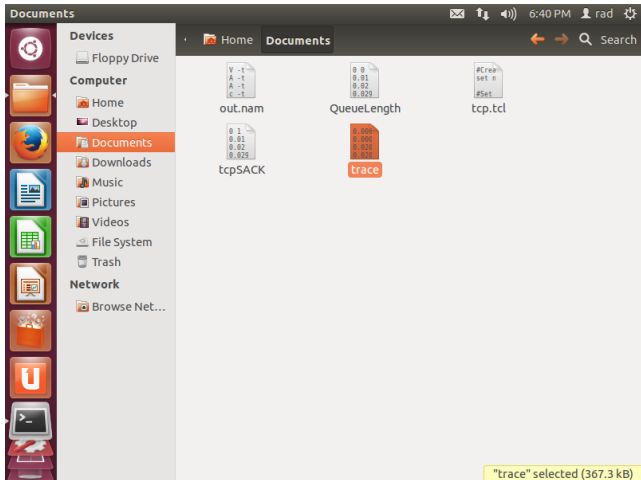
- AIMD (Additive Increase/Multiplicative Decrease)





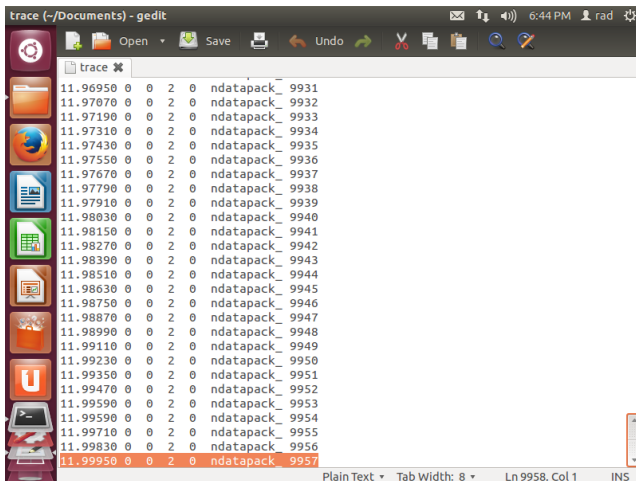
# The Square Root Formula (cont'd)

- Open: **trace**



# The Square Root Formula (cont'd)

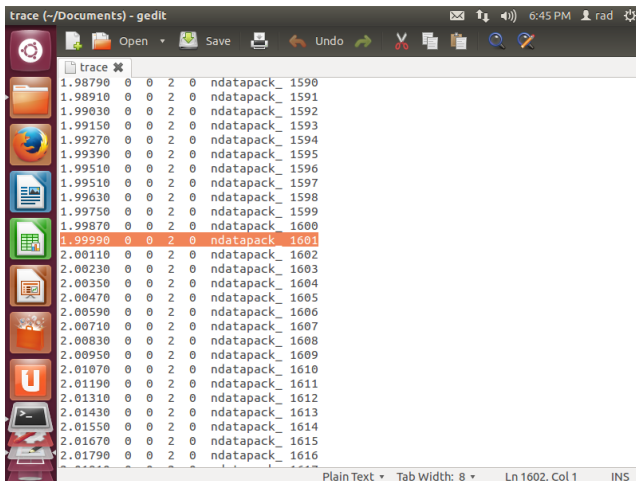
- Time: from 2 to 12



```
trace (~/.Documents) - gedit
11.96950 0 0 2 0 ndatapack_ 9931
11.97070 0 0 2 0 ndatapack_ 9932
11.97190 0 0 2 0 ndatapack_ 9933
11.97310 0 0 2 0 ndatapack_ 9934
11.97430 0 0 2 0 ndatapack_ 9935
11.97550 0 0 2 0 ndatapack_ 9936
11.97670 0 0 2 0 ndatapack_ 9937
11.97790 0 0 2 0 ndatapack_ 9938
11.97910 0 0 2 0 ndatapack_ 9939
11.98030 0 0 2 0 ndatapack_ 9940
11.98150 0 0 2 0 ndatapack_ 9941
11.98270 0 0 2 0 ndatapack_ 9942
11.98390 0 0 2 0 ndatapack_ 9943
11.98510 0 0 2 0 ndatapack_ 9944
11.98630 0 0 2 0 ndatapack_ 9945
11.98750 0 0 2 0 ndatapack_ 9946
11.98870 0 0 2 0 ndatapack_ 9947
11.98990 0 0 2 0 ndatapack_ 9948
11.99110 0 0 2 0 ndatapack_ 9949
11.99230 0 0 2 0 ndatapack_ 9950
11.99350 0 0 2 0 ndatapack_ 9951
11.99470 0 0 2 0 ndatapack_ 9952
11.99590 0 0 2 0 ndatapack_ 9953
11.99590 0 0 2 0 ndatapack_ 9954
11.99710 0 0 2 0 ndatapack_ 9955
11.99830 0 0 2 0 ndatapack_ 9956
11.99950 0 0 2 0 ndatapack_ 9957
```

# The Square Root Formula (cont'd)

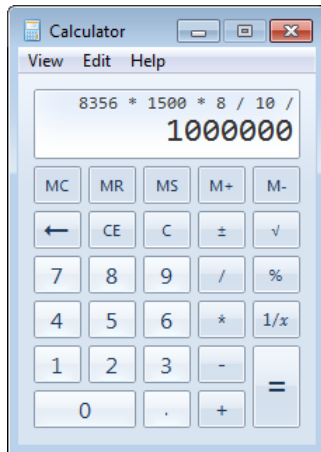
- Time: from 2 to 12



```
trace x
1.98790 0 0 2 0 ndatapack_ 1590
1.98910 0 0 2 0 ndatapack_ 1591
1.99030 0 0 2 0 ndatapack_ 1592
1.99150 0 0 2 0 ndatapack_ 1593
1.99270 0 0 2 0 ndatapack_ 1594
1.99390 0 0 2 0 ndatapack_ 1595
1.99510 0 0 2 0 ndatapack_ 1596
1.99510 0 0 2 0 ndatapack_ 1597
1.99630 0 0 2 0 ndatapack_ 1598
1.99750 0 0 2 0 ndatapack_ 1599
1.99870 0 0 2 0 ndatapack_ 1600
1.99990 0 0 2 0 ndatapack_ 1601
2.00110 0 0 2 0 ndatapack_ 1602
2.00230 0 0 2 0 ndatapack_ 1603
2.00350 0 0 2 0 ndatapack_ 1604
2.00470 0 0 2 0 ndatapack_ 1605
2.00590 0 0 2 0 ndatapack_ 1606
2.00710 0 0 2 0 ndatapack_ 1607
2.00830 0 0 2 0 ndatapack_ 1608
2.00950 0 0 2 0 ndatapack_ 1609
2.01070 0 0 2 0 ndatapack_ 1610
2.01190 0 0 2 0 ndatapack_ 1611
2.01310 0 0 2 0 ndatapack_ 1612
2.01430 0 0 2 0 ndatapack_ 1613
2.01550 0 0 2 0 ndatapack_ 1614
2.01670 0 0 2 0 ndatapack_ 1615
2.01790 0 0 2 0 ndatapack_ 1616
```

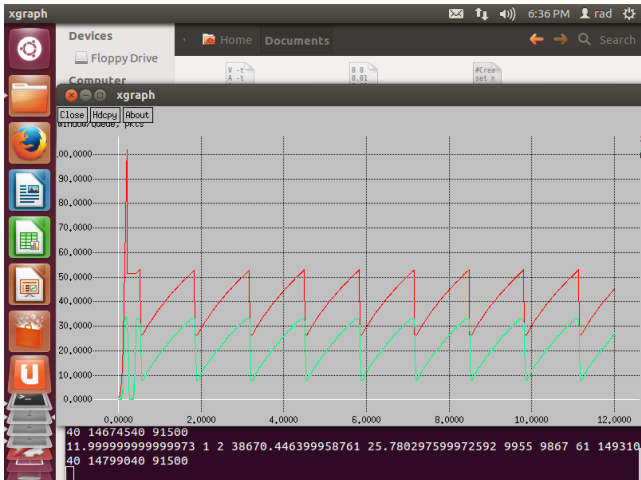
# The Square Root Formula (cont'd)

- Packets sent:  $9957 - 1601 = 8356$
- Throughput: 10.03 Mb/s



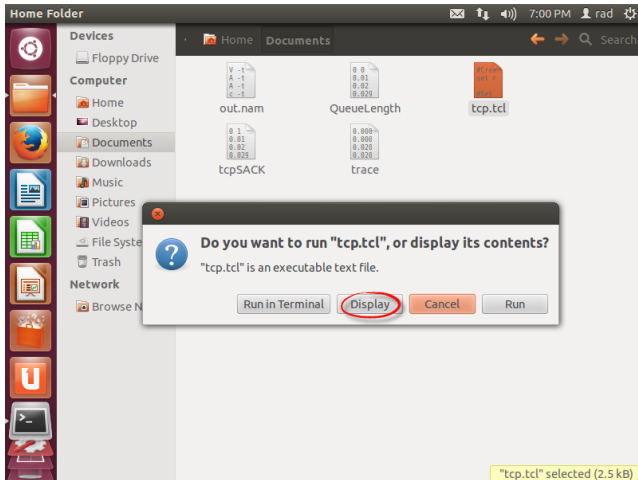
# The Square Root Formula (cont'd)

- Mathis model =  $f(RTT, p) = f(rtt\_ , ncwndcuts\_ / ndatapack\_)$



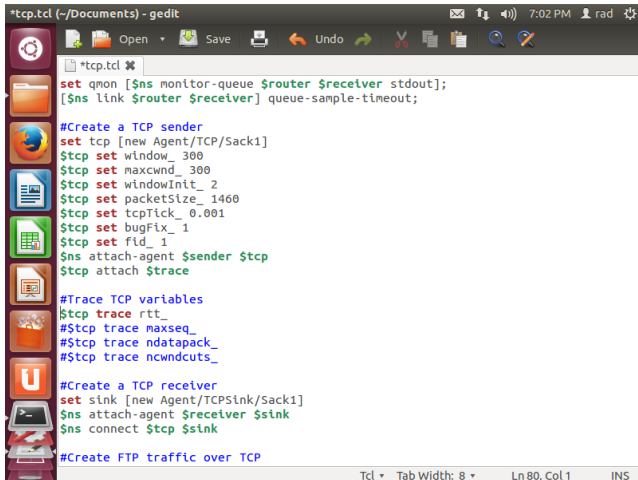
# The Square Root Formula (cont'd)

- Edit: **tcp.tcl**



# The Square Root Formula (cont'd)

- Trace: `rtt_`



The screenshot shows a Gedit editor window titled '\*tcp.tcl (~/.Documents) - gedit'. The window contains a Tcl script for network simulation. The script includes comments and commands for setting up a TCP sender, a TCP receiver, and tracing variables. The status bar at the bottom indicates 'Tcl', 'Tab Width: 8', 'Ln 80, Col 1', and 'INS'.

```
*tcp.tcl (~/.Documents) - gedit
set qmon [$ns monitor-queue $router $receiver stdout];
[$ns link $router $receiver] queue-sample-timeout;

#Create a TCP sender
set tcp [new Agent/TCP/Sack1]
$tcp set window_ 300
$tcp set maxcwnd_ 300
$tcp set windowInit_ 2
$tcp set packetSize_ 1460
$tcp set tcpTick_ 0.001
$tcp set bugFix_ 1
$tcp set fid_ 1
$ns attach-agent $sender $tcp
$tcp attach $trace

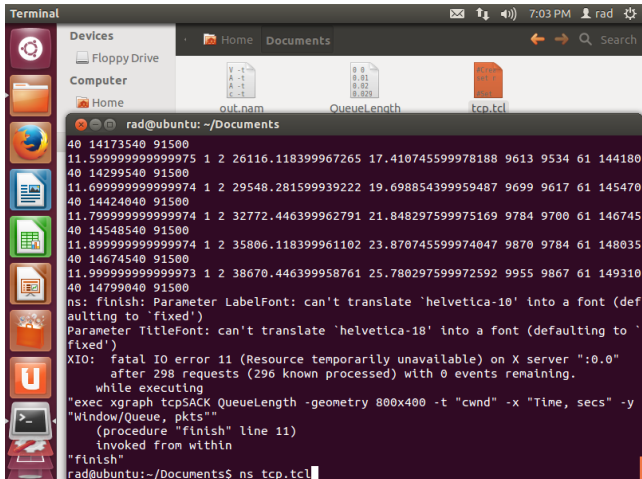
#Trace TCP variables
$tcp trace rtt_
#$tcp trace maxseq_
#$tcp trace ndatpack_
#$tcp trace ncwndcuts_

#Create a TCP receiver
set sink [new Agent/TCPSink/Sack1]
$ns attach-agent $receiver $sink
$ns connect $tcp $sink

#Create FTP traffic over TCP
```

# The Square Root Formula (cont'd)

- Rerun: **tcp.tcl**



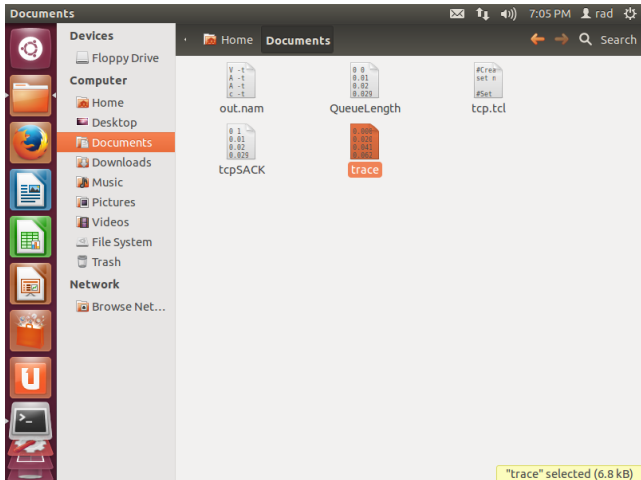
The image shows a terminal window titled "Terminal" with a Ubuntu desktop background. The terminal displays the output of running the `tcp.tcl` script. The output consists of several lines of numerical data, followed by error messages and a final command prompt.

```
rad@ubuntu: ~/Documents
40 14173540 91500
11.599999999999997 1 2 26116.118399967265 17.410745599978188 9613 9534 61 144180
40 14299540 91500
11.699999999999997 1 2 29548.281599939222 19.698854399959487 9699 9617 61 145470
40 14424040 91500
11.799999999999997 1 2 32772.446399962791 21.848297599975169 9784 9700 61 146745
40 14548540 91500
11.899999999999997 1 2 35806.118399961102 23.870745599974047 9870 9784 61 148035
40 14674540 91500
11.999999999999997 1 2 38670.446399958761 25.780297599972592 9955 9867 61 149310
40 14799040 91500
ns: finish: Parameter LabelFont: can't translate 'helvetica-10' into a font (def
aulting to 'fixed')
Parameter TitleFont: can't translate 'helvetica-18' into a font (defaulting to '
fixed')
XIO: fatal IO error 11 (Resource temporarily unavailable) on X server ":0.0"
after 298 requests (296 known processed) with 0 events remaining.
while executing
"exec xgraph tcpSACK QueueLength -geometry 800x400 -t "cwnd" -x "Time, secs" -y
"Window/Queue, pkts"
(procedure "finish" line 11)
invoked from within
"finish"
rad@ubuntu:~/Documents$ ns tcp.tcl
```



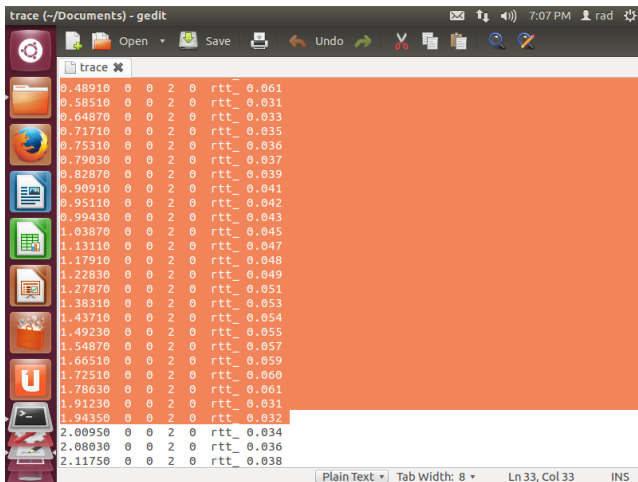
# The Square Root Formula (cont'd)

- Open: **trace**



# The Square Root Formula (cont'd)

- Cut: first 2 seconds



trace (~/.Documents) - gedit

Open Save Undo

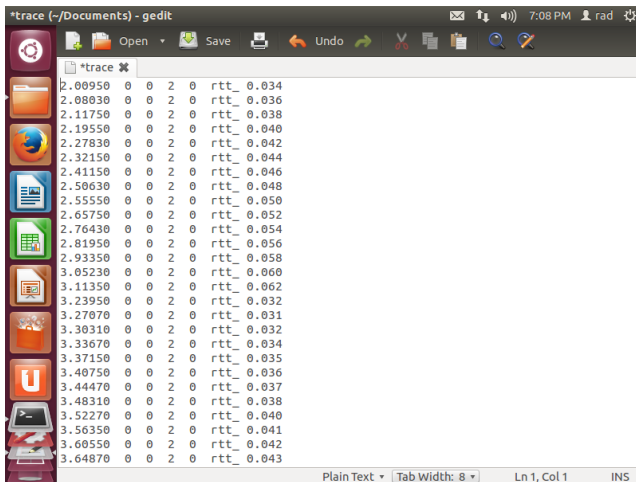
trace x

0.48910	0	0	2	0	rtt_	0.061
0.58510	0	0	2	0	rtt_	0.031
0.64870	0	0	2	0	rtt_	0.033
0.71710	0	0	2	0	rtt_	0.035
0.75310	0	0	2	0	rtt_	0.036
0.79030	0	0	2	0	rtt_	0.037
0.82870	0	0	2	0	rtt_	0.039
0.90910	0	0	2	0	rtt_	0.041
0.95110	0	0	2	0	rtt_	0.042
0.99430	0	0	2	0	rtt_	0.043
1.03870	0	0	2	0	rtt_	0.045
1.13110	0	0	2	0	rtt_	0.047
1.17910	0	0	2	0	rtt_	0.048
1.22830	0	0	2	0	rtt_	0.049
1.27870	0	0	2	0	rtt_	0.051
1.38310	0	0	2	0	rtt_	0.053
1.43710	0	0	2	0	rtt_	0.054
1.49230	0	0	2	0	rtt_	0.055
1.54870	0	0	2	0	rtt_	0.057
1.66510	0	0	2	0	rtt_	0.059
1.72510	0	0	2	0	rtt_	0.060
1.78630	0	0	2	0	rtt_	0.061
1.91230	0	0	2	0	rtt_	0.031
1.94350	0	0	2	0	rtt_	0.032
2.00950	0	0	2	0	rtt_	0.034
2.08030	0	0	2	0	rtt_	0.036
2.11750	0	0	2	0	rtt_	0.038

Plain Text Tab Width: 8 Ln 33, Col 33 INS

# The Square Root Formula (cont'd)

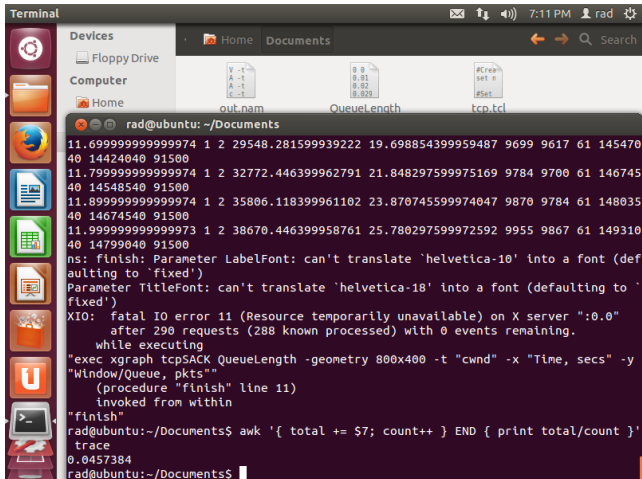
- Save: **trace**



```
*trace (~/.Documents) - gedit
2.00950 0 0 2 0 rtt_ 0.034
2.08030 0 0 2 0 rtt_ 0.036
2.11750 0 0 2 0 rtt_ 0.038
2.19550 0 0 2 0 rtt_ 0.040
2.27830 0 0 2 0 rtt_ 0.042
2.32150 0 0 2 0 rtt_ 0.044
2.41150 0 0 2 0 rtt_ 0.046
2.50630 0 0 2 0 rtt_ 0.048
2.55550 0 0 2 0 rtt_ 0.050
2.65750 0 0 2 0 rtt_ 0.052
2.76430 0 0 2 0 rtt_ 0.054
2.81950 0 0 2 0 rtt_ 0.056
2.93350 0 0 2 0 rtt_ 0.058
3.05230 0 0 2 0 rtt_ 0.060
3.11350 0 0 2 0 rtt_ 0.062
3.23950 0 0 2 0 rtt_ 0.032
3.27070 0 0 2 0 rtt_ 0.031
3.30310 0 0 2 0 rtt_ 0.032
3.33670 0 0 2 0 rtt_ 0.034
3.37150 0 0 2 0 rtt_ 0.035
3.40750 0 0 2 0 rtt_ 0.036
3.44470 0 0 2 0 rtt_ 0.037
3.48310 0 0 2 0 rtt_ 0.038
3.52270 0 0 2 0 rtt_ 0.040
3.56350 0 0 2 0 rtt_ 0.041
3.60550 0 0 2 0 rtt_ 0.042
3.64870 0 0 2 0 rtt_ 0.043
```

# The Square Root Formula (cont'd)

- RTT average: **0.046 s**

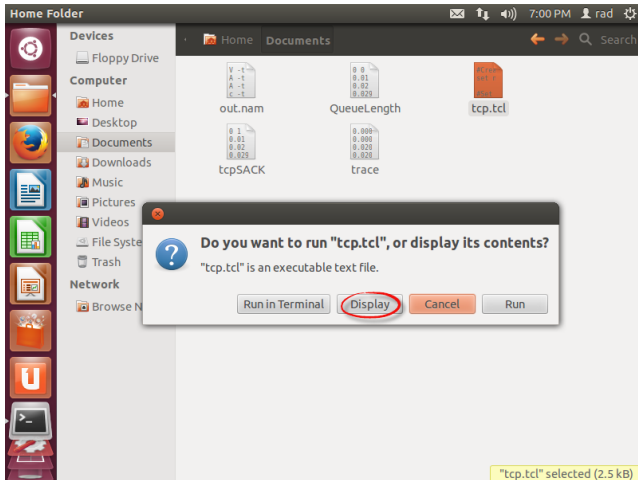


The screenshot shows a terminal window titled "Terminal" with a sidebar on the left containing icons for various applications. The main window displays the output of a network test. The output consists of several lines of data, including timestamps, sequence numbers, and packet counts. There are also error messages from the X server and a warning about the 'finish' procedure. The terminal prompt is "rad@ubuntu: ~/Documents\$".

```
rad@ubuntu: ~/Documents$
11.6999999999999974 1 2 29548.281599939222 19.698854399959487 9699 9617 61 145470
40 14424040 91500
11.7999999999999974 1 2 32772.446399962791 21.848297599975169 9784 9700 61 146745
40 14548540 91500
11.8999999999999974 1 2 35806.118399961102 23.870745599974047 9870 9784 61 148035
40 14674540 91500
11.9999999999999973 1 2 38670.446399958761 25.780297599972592 9955 9867 61 149310
40 14799040 91500
ns: finish: Parameter LabelFont: can't translate 'helvetica-10' into a font (def
aulting to 'fixed')
Parameter TitleFont: can't translate 'helvetica-18' into a font (defaulting to '
fixed')
XIO: fatal IO error 11 (Resource temporarily unavailable) on X server ":0.0"
after 290 requests (288 known processed) with 0 events remaining.
while executing
"exec xgraph tcpSACK QueueLength -geometry 800x400 -t "cwnd" -x "Time, secs" -y
"Window/Queue, pkts"
(procedure "finish" line 11)
invoked from within
"finish"
rad@ubuntu:~/Documents$ awk '{ total += $7; count++ } END { print total/count }'
trace
0.0457384
rad@ubuntu:~/Documents$
```

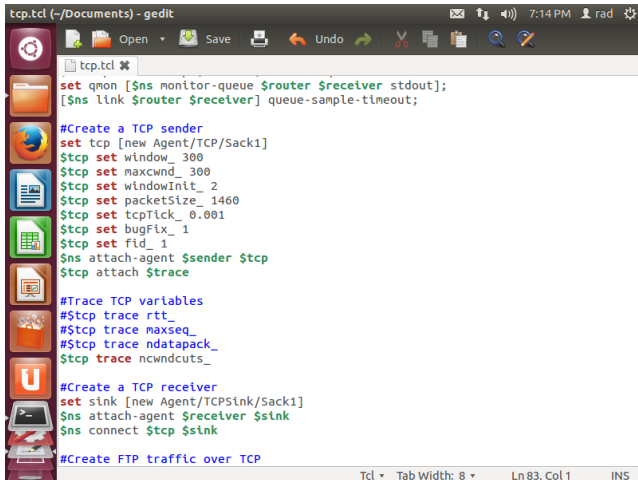
# The Square Root Formula (cont'd)

- Edit: **tcp.tcl**



# The Square Root Formula (cont'd)

- Trace: `ncwndcuts_`



The screenshot shows a Gedit editor window titled "tcp.tcl (~/.Documents) - gedit". The window contains a Tcl script for simulating a TCP connection. The script includes comments and commands for setting up a monitor, creating a TCP sender, attaching an agent, creating a TCP receiver, and connecting them. The script is as follows:

```
tcp.tcl
set qmon [$ns monitor-queue $router $receiver stdout];
[$ns link $router $receiver] queue-sample-timeout;

#Create a TCP sender
set tcp [new Agent/TCP/Sack1]
$tcp set window_ 300
$tcp set maxcwnd_ 300
$tcp set windowInit_ 2
$tcp set packetSize_ 1460
$tcp set tcpTick_ 0.001
$tcp set bugFix_ 1
$tcp set fid_ 1
$ns attach-agent $sender $tcp
$tcp attach $trace

#Trace TCP variables
#$tcp trace rtt_
#$tcp trace maxseq_
#$tcp trace ndatpack_
$tcp trace ncwndcuts_

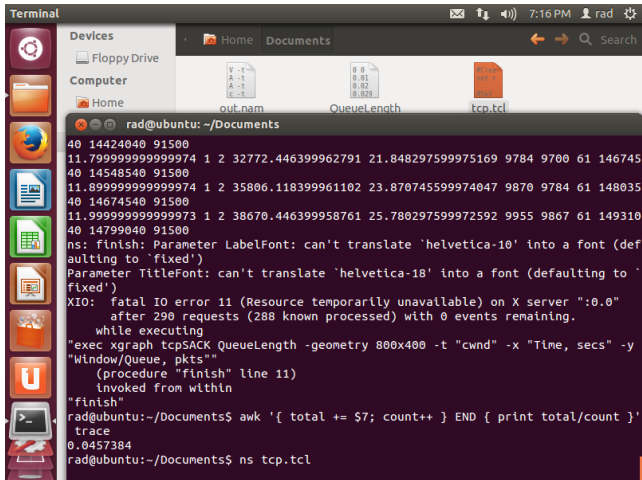
#Create a TCP receiver
set sink [new Agent/TCPSink/Sack1]
$ns attach-agent $receiver $sink
$ns connect $tcp $sink

#Create FTP traffic over TCP
```

The status bar at the bottom of the window indicates "Tcl", "Tab Width: 8", "Ln 83, Col 1", and "INS".

# The Square Root Formula (cont'd)

- Rerun: **tcp.tcl**

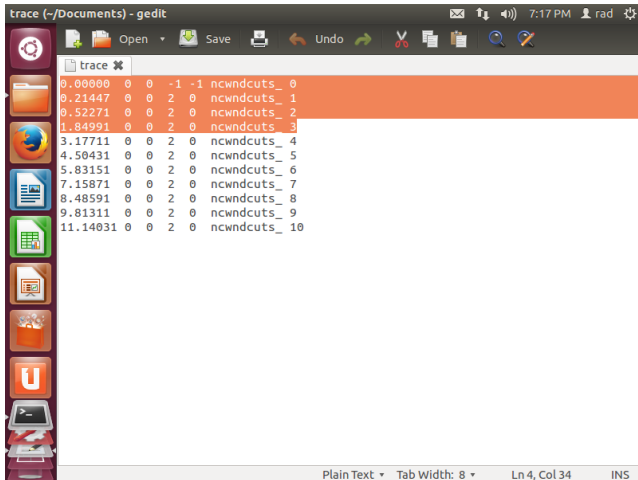


The image shows a terminal window titled "Terminal" with a sidebar on the left containing icons for various applications. The main window displays the file manager view of the "/Documents" directory, showing files "out.nam", "QueueLength", and "tcp.tcl". Below this, a terminal window is open, showing the execution of "tcp.tcl" and subsequent error messages.

```
rad@ubuntu: ~/Documents
40 14424040 91500
11.799999999999974 1 2 32772.446399962791 21.848297599975169 9784 9700 61 146745
40 14548540 91500
11.899999999999974 1 2 35806.118399961102 23.870745599974047 9870 9784 61 148035
40 14674540 91500
11.999999999999973 1 2 38670.446399958761 25.780297599972592 9955 9867 61 149310
40 14799040 91500
ns: finish: Parameter LabelFont: can't translate 'helvetica-10' into a font (def
aulting to 'fixed')
Parameter TitleFont: can't translate 'helvetica-18' into a font (defaulting to '
fixed')
XIO: fatal IO error 11 (Resource temporarily unavailable) on X server ":0.0"
after 290 requests (288 known processed) with 0 events remaining.
while executing
"exec xgraph tcpSACK QueueLength -geometry 800x400 -t "cwnd" -x "Time, secs" -y
"Window/Queue, pkts"
(procedure "finish" line 11)
invoked from within
"finish"
rad@ubuntu:~/Documents$ awk '{ total += $7; count++ } END { print total/count }'
trace
0.0457384
rad@ubuntu:~/Documents$ ns tcp.tcl
```

# The Square Root Formula (cont'd)

- Open: **trace**



The screenshot shows a gedit window titled "trace (~/.Documents) - gedit". The window contains a file named "trace" with the following content:

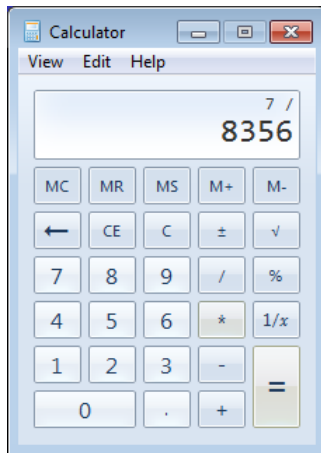
Time	Source IP	Destination IP	Source Port	Destination Port	Protocol	Interface
0.00000	0	0	-1	-1	ncwndcuts_	0
0.21447	0	0	2	0	ncwndcuts_	1
0.52271	0	0	2	0	ncwndcuts_	2
1.84991	0	0	2	0	ncwndcuts_	3
3.17711	0	0	2	0	ncwndcuts_	4
4.50431	0	0	2	0	ncwndcuts_	5
5.83151	0	0	2	0	ncwndcuts_	6
7.15871	0	0	2	0	ncwndcuts_	7
8.48591	0	0	2	0	ncwndcuts_	8
9.81311	0	0	2	0	ncwndcuts_	9
11.14031	0	0	2	0	ncwndcuts_	10

The status bar at the bottom indicates "Plain Text", "Tab Width: 8", "Ln 4, Col 34", and "INS".



# The Square Root Formula (cont'd)

- Packet loss rate:  $\text{ncwndcuts\_} / \text{ndatapack\_} = 0.00084$



# The Square Root Formula (cont'd)

- Throughput simulated: **10.03 Mb/s**
- Throughput estimated: **11.02 Mb/s**

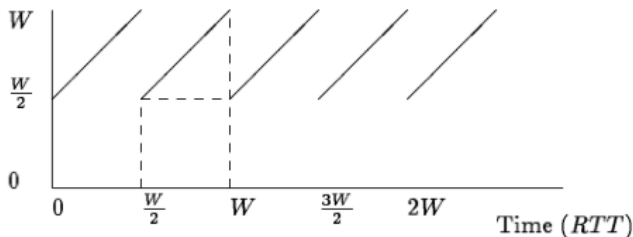
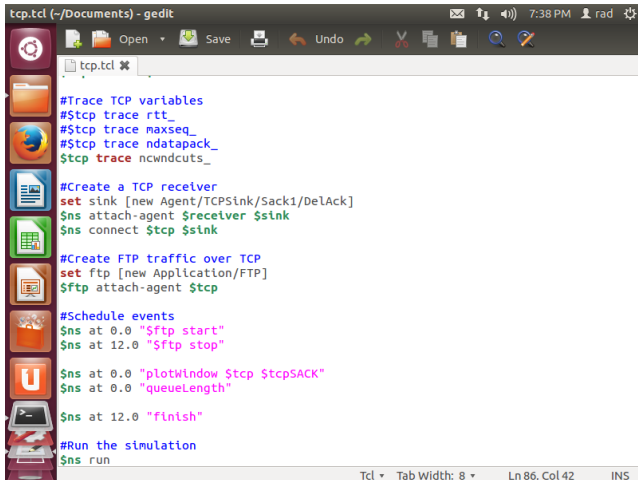


Figure 1: TCP window evolution under periodic loss  
Each cycle delivers  $(\frac{W}{2})^2 + \frac{1}{2}(\frac{W}{2})^2 = 1/p$  packets and takes  $W/2$  round trip times.

# The Square Root Formula (cont'd)

- Agent/TCPSink/Sack1  $\Rightarrow$  Agent/TCPSink/Sack1/DelAck



```
tcp.tcl (~/Documents) - gedit
#Trace TCP variables
#$tcp trace rtt_
#$tcp trace maxseq_
#$tcp trace ndatapack_
#$tcp trace ncwndcuts_

#Create a TCP receiver
set sink [new Agent/TCPSink/Sack1/DelAck]
$ns attach-agent $receiver $sink
$ns connect $tcp $sink

#Create FTP traffic over TCP
set ftp [new Application/FTP]
$ftp attach-agent $tcp

#Schedule events
$ns at 0.0 "$ftp start"
$ns at 12.0 "$ftp stop"

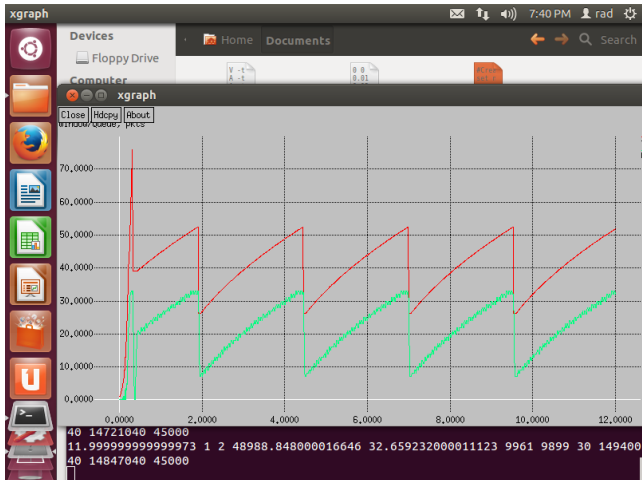
$ns at 0.0 "plotWindow $tcp $tcpSACK"
$ns at 0.0 "queueLength"

$ns at 12.0 "finish"

#Run the simulation
$ns run
```

# The Square Root Formula (cont'd)

- Agent/TCPSink/Sack1/DelAck



# The Square Root Formula (cont'd)

- **Agent/TCP/Sack1**

- $RTT = 0.046 \text{ s}$
- $p = 0.00084$
- Throughput simulated: **10.03 Mb/s**
- Throughput estimated: **11.02 Mb/s**

- **Agent/TCPSink/Sack1/DelAck**

- $RTT = 0.045 \text{ s}$
- $p = 0.00036$
- Throughput simulated: **10.03 Mb/s**
- Throughput estimated: **12.17 Mb/s**