Institute of Telecommunications
Warsaw University of Technology
March 2021

EINTE LAB EXERCISES

EINTE TCP LAB

INTRODUCTION

LEARNING TCP

Before starting the exercise, you should refresh your knowledge related to TCP. You are advised to study the following aspects: congestion control, flow control, RTO parameter estimation, conditions that may influence TCP efficiency. To extend the knowledge of TCP you may study the following source documents:

- RFC 793: "Transmission Control Protocol"
- RFC 1122: "Requirements for Internet Hosts - Communication Layers"
- RFC 2581: "TCP Congestion Control" – TCP Reno
- RFC 2988: "Computing TCP's Retransmission Timer"
- RFC 3782: "The NewReno Modification to TCP's Fast Recovery Algorithm"
- RFC 6349: “Framework for TCP Throughput Testing”

SOFTWARE TOOLS

The exercise is executed using the VirtualBox virtual machine (VM) available for download from the course MS Teams group. To run the VM you need to download and install the Oracle VirtualBox and VirtualBox Extension Pack, both available for download at https://www.virtualbox.org/wiki/Downloads

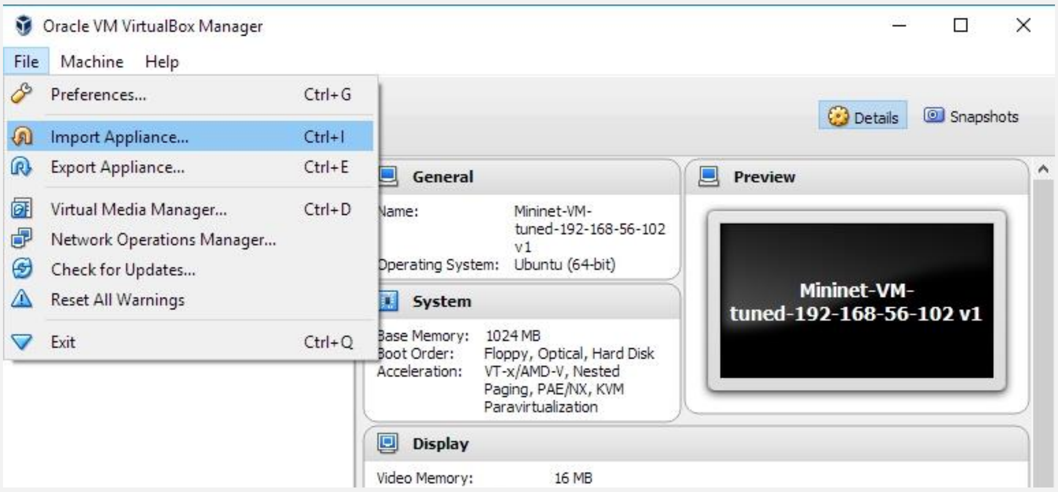
In addition, you should also download and install the free MobaXTerm terminal for Windows, available at https://mobaxterm.mobatek.net/download-home-edition.html.

VIRTUAL MACHINE

The simulations required for the exercise are executed using ns2 (Network Simulator) software, running in VirtualBox virtual machine (VM) with Debian Linux operating system. You should download the VM image from the course MS Teams group file repository.

The following steps are necessary to run and use the virtual router lab environment.

1. Run the VirtualBox and select “*File/Import Appliance*” from the main menu

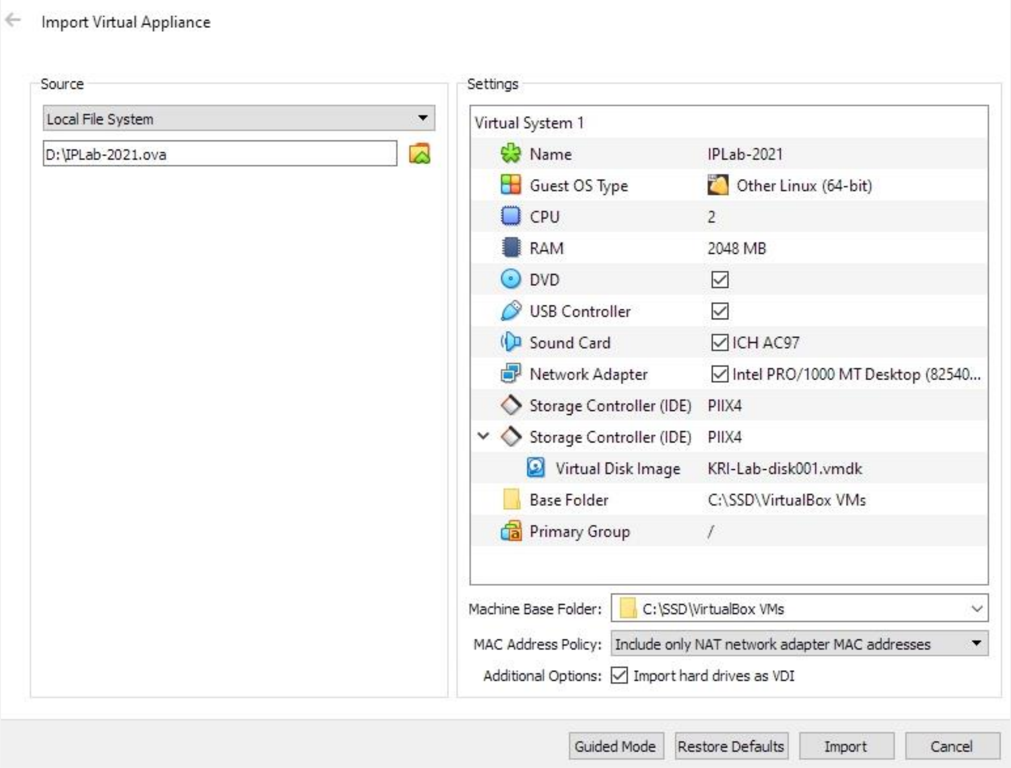


Name: Mininet-VM-tuned-192-168-56-102 v1
Operating System: Ubuntu (64-bit)

Base Memory: 1024 MB
Boot Order: Floppy, Optical, Hard Disk
Acceleration: VT-x/AMD-V, Nested Paging, PAE/NX, KVM Paravirtualization

Video Memory: 16 MB

2. Select the downloaded VM image file (note that *IPlab-2021.ova* in the screenshot below is only an example - the actual name of the downloaded file may be different) and click the "*Import*" button.



Import Virtual Appliance

Source

Local File System

D:\IPLab-2021.ova

Settings

Virtual System 1

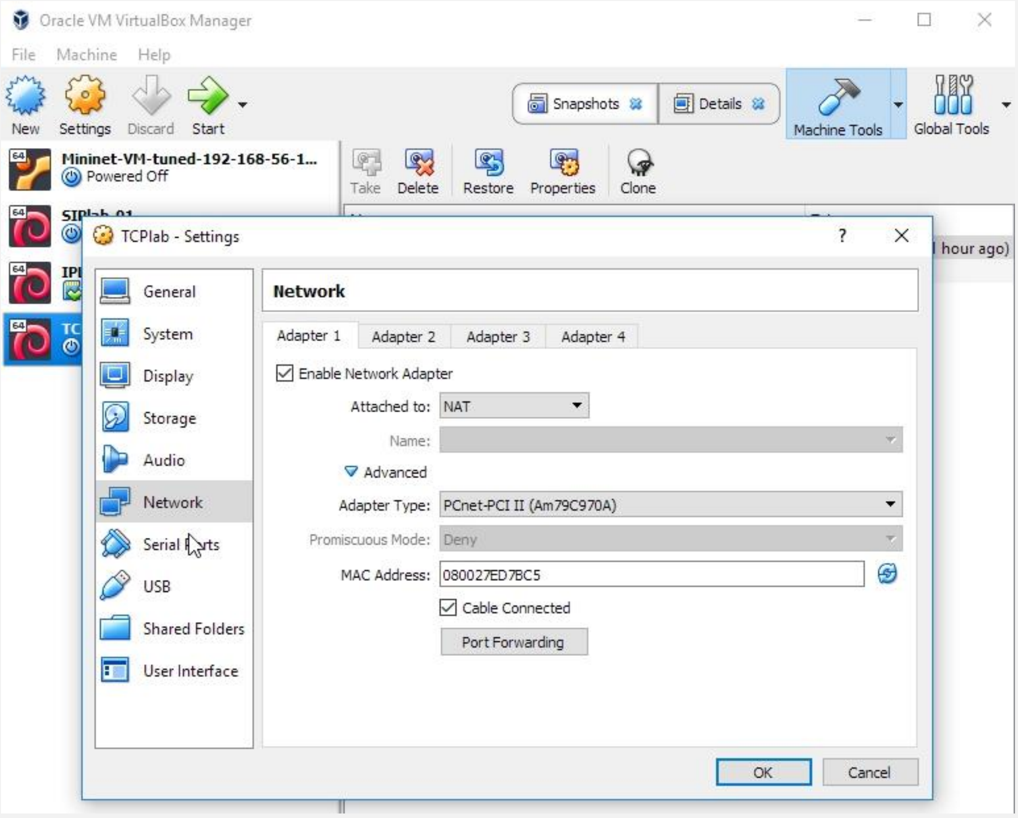
Name	IPLab-2021
Guest OS Type	Other Linux (64-bit)
CPU	2
RAM	2048 MB
DVD	☑
USB Controller	☑
Sound Card	☑ ICH AC97
Network Adapter	☑ Intel PRO/1000 MT Desktop (82540...
Storage Controller (IDE)	PIIX4
Storage Controller (IDE)	PIIX4
Virtual Disk Image	KRI-Lab-disk001.vmdk
Base Folder	C:\SSD\VirtualBox VMs
Primary Group	/

Machine Base Folder: C:\SSD\VirtualBox VMs

MAC Address Policy: Include only NAT network adapter MAC addresses

Additional Options: ☑ Import hard drives as VDI

3. Select the imported VM on the panel, click "*Settings*" and then "*Network*". On "*Adapter 1*" tab click "*Advanced*" and then click the "*Port Forwarding*" button.



Oracle VM VirtualBox Manager

Mininet-VM-tuned-192-168-56-1...
Powered Off

SIPlab_01

hour ago)

TCPlab - Settings

Network

☑ Enable Network Adapter

Attached to: NAT

Name:

Advanced

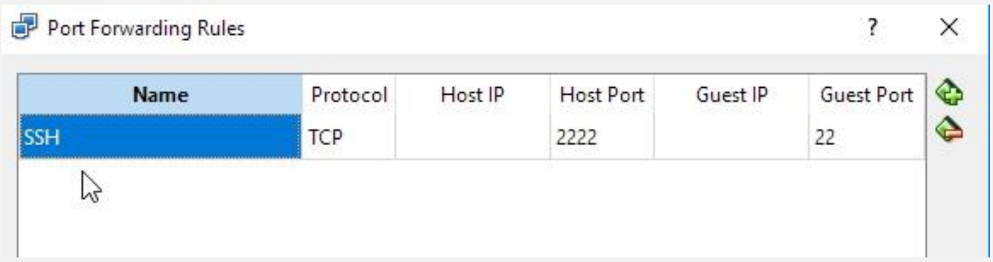
Adapter Type: PCnet-PCI II (Am79C970A)

Promiscuous Mode: Deny

MAC Address: 080027ED7BC5

☑ Cable Connected

4. Make sure that the port forwarding rules contain the following entry:

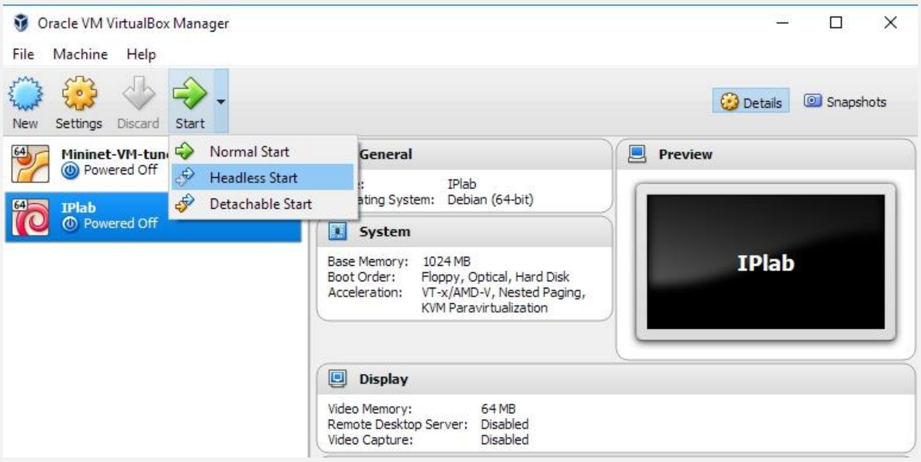


Port Forwarding Rules

Name	Protocol	Host IP	Host Port	Guest IP	Guest Port
SSH	TCP		2222		22

If not, add the entry using the green + button on the right.

5. Select the TCPlab VM on the panel, click the right side of the "*Start*" button and select "*Headless Start*" from the drop-down menu.



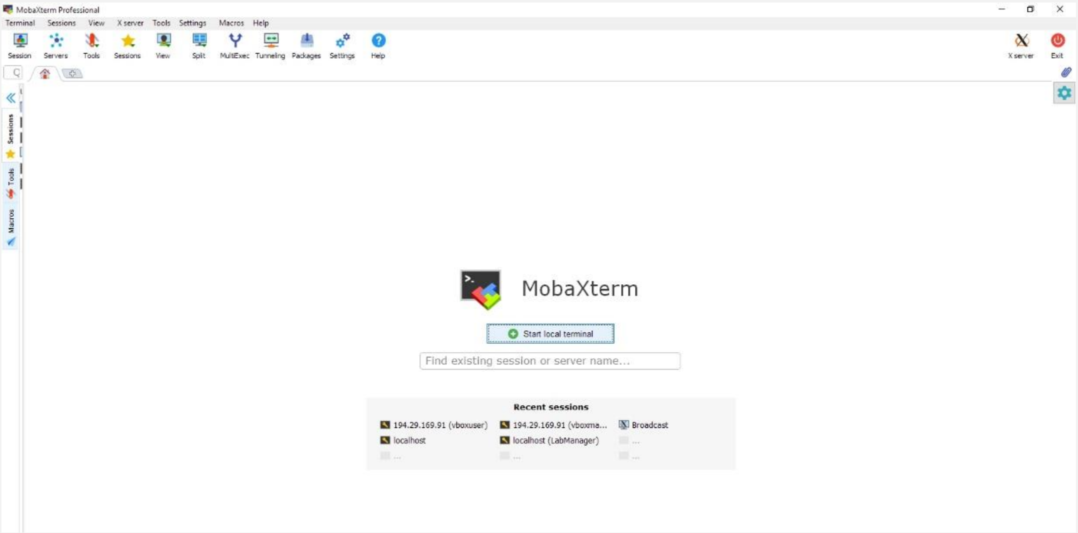
General
: IPlab
ating System: Debian (64-bit)

System
Base Memory: 1024 MB
Boot Order: Floppy, Optical, Hard Disk
Acceleration: VT-x/AMD-V, Nested Paging, KVM Paravirtualization

Display
Video Memory: 64 MB
Remote Desktop Server: Disabled
Video Capture: Disabled

The VM is based on Debian Linux without any graphical interface.

6. Start the MobaXTerm software and click the "*Start local terminal*" button – this will open the terminal first tab.



7. In terminal window, run the following command: `ssh -p 2222 tcp@localhost`
8. Log in to the VM using password *`tcplab`*. The ns-2 simulator is already installed on the VM.

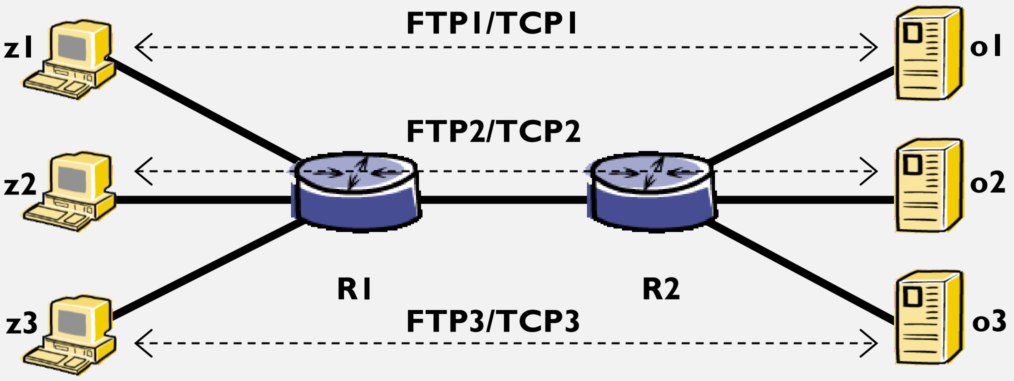
LAB EXERCISE - SIMULATIONS

Simulations for the exercise are done using the popular public-domain network simulation software **ns-2.** After logging in to the VM, in the *tcp* user home directory you should find a **tcp.tcl** script, describing the simulated network. The simulation parameters can be modified within the script to adjust them to requirements of subsequent tasks, defined for this exercise. You can edit the script using the *pico* text editor (*pico tcp.tcl*). To run the simulation, you need to issue the **ns tcp.tcl** command.

Please ignore the following notification displayed after starting the simulation.

```
When configured, ns found the right version of tclsh in /home/dukat/ns-allinone-
2.28/tcl8.4.5/unix/tclsh but it doesn't seem to be there anymore, so ns will fall back on
running the first tclsh in your path. The wrong version of tclsh may break the test suites.
Reconfigure and rebuild ns if this is a problem.
```

The simulated network consists of two routers (nodes R1, R2). The hosts attached to the routers represent TCP sources (z1, z2, z3) and receivers (o1, o2, o3), respectively. There are TCP connections set up between each source-receiver pair (z1-o1, etc.). These connections are used by FTP applications.



At the beginning of the tcp.tcl script there's a section where the simulation parameters are defined:

sim_time	- total simulation time [s]
ini_time	- simulation startup time [s]
interval	- sampling interval [s]
enable_tcp1	- enable/disable TCP source 1 [1 - on, 0 - off]
enable_tcp2	- enable/disable TCP source 2 [1 - on, 0 - off]
enable_tcp3	- enable/disable TCP source 3 [1 - on, 0 - off]
window_tcp1	- max. TCP window size of source 1 [segments]
window_tcp2	- max. TCP window size of source 2 [segments]
window_tcp3	- max. TCP window size of source 3 [segments]
delay_R1R2	- delay on R1-R2 link (propagation time) [ms, e.g., 10ms]
capacity_R1R2	- R1-R2 link capacity [Mbps, e.g., 10Mb]
buffer_R1R2	- R1-R2 link buffer size [packets]
segment_size	- TCP segment data size [bytes]

The values of these parameters must be set according to the content of each subtask.

When the simulation ends, the program displays the throughput of TCP connections. For each connection, two values are displayed: mean throughput for the total simulation time (Average Throughput) and mean throughput calculated for the period excluding the simulation startup time (Stable Throughput). You should write down these values.

Other simulation results are written to **out.csv** file (the file will be created in *einte* home directory, the same that hosts the tcp.tcl script). The following data is written to the output file:

Time	– sampling time
cwnd1	– TCP1 window size [bytes]
cwnd2	– TCP2 window size [bytes]
cwnd3	– TCP3 window size [bytes]]
rtt1	– rtt for TCP1 [s]
rtt2	– rtt for TCP2 [s]
rtt3	– rtt for TCP3 [s]
bytes1	– bytes received over TCP1
bytes2	– bytes received over TCP2
bytes3	– bytes received over TCP3

This file must be downloaded from the VM for further analysis using a spreadsheet software (e.g., Microsoft Excel, or any freeware equivalent). Note that after each simulation the old file will be overwritten if you don't change its name in the simulation script. Therefore, you can either download the file after each simulation and rename it such that you can recognize to which simulation/task the results belong, or you can modify the name of the output file in the tcp.tcl before each simulation.

To download the output files from the VM to your host PC you need to establish the sftp session with the VM. Using MobaXTerm, you need to click the "*Session*" button and then "*SFTP*". In the "*Remote host*" field enter *localhost*, the username is *tcp,* the password is *tcplab*, the port number should be set to 2222.

TASK 1

The goal of task 1 is to investigate how the window size influences TCP effectiveness. The simulations should be run using the following parameters:

- R1-R2 link delay: 70ms,
- access links delay: 10ms,
- R1-R2 link capacity: 10 Mbps,
- R1-R2 link buffer: 5 packets.

First, calculate the theoretical optimal window size for the above network parameters. You should write down in the report an exact formula that you used to calculate the optimal window size. Note that the *segment_size* parameter does not include the overhead introduced by the ns-2 to the TCP data segment (the overhead in ns-2 is 40 bytes: 20 bytes for TCP header and 20 bytes for IP header; the link layer overhead is not modeled).

Next, simulate a single TCP connection with different maximum window size (set the "window_..." parameter accordingly). The maximum TCP window size should be changed in the range between one segment and the value of 20-30% above the theoretical optimal window size. The report should contain the plot showing the mean TCP connection throughput as a function of window size.

NOTE: the mean TCP throughput should be calculated for a period when the TCP connection works stable, i.e., neglecting the simulation „startup" period (the phase in which TCP stays in the slow start phase). The simulation time should be also set such that it covers at least a few periods of TCP connection being in a *congestion avoidance and retransmission* phases.

Draw two plots showing the *cwnd* parameter as a function of time (for the duration of the simulation) for the following cases:

1) the maximum window sizes are below theoretical optimal window size (e.g., by 10%)

2) the maximum window sizes are above theoretical optimal window size (e.g., by 10%)

Explain the observed differences between these two plots.

TASK 2

The goal of task 2 is to investigate the influence of network buffers on TCP efficiency. The simulation should be run using the following parameters:

- R1-R2 link delay: 70ms,
- access links delay: 10ms,
- R1-R2 link capacity: 10 Mbps,
- max. TCP window size: 5000 packets.

Simulations should be done for a single TCP connection.

The report should contain a plot of TCP connection throughput as a function of buffer size on R1-R2 link. The buffer size should be changed in the range from 5 packets to the value that assures maximum TCP efficiency (close to the link capacity but do not try to reach the link capacity exactly, few percent accuracy is enough).

The report should also contain the plots showing how the following parameters change in time (for two simulations done with the lowest and optimal buffer sizes accordingly):

- cwnd size
- rtt,
- TCP momentary throughput (calculated for 1s periods)
- TCP momentary throughput estimated od the base of cwnd and rtt.

On the base of the obtained results try to find out what is the relation between the optimal buffer size and the network parameters. Can we calculate (at least approximately) the expected optimal buffer size knowing the network parameters like RTT and capacity? Try to make additional simulation varying the R1-R2 link capacity and delay. Note: you don't need to find an exact formula, just find some rough approximation.

TASK 3

The goal of task 3 is to investigate how TCP protocol shares the network bandwidth between competing connections.

First, simulate all 3 TCP connection with equal RTT (do at least 5 simulations with different RTT in the range from 10 to 200ms). Then, change the RTT of the simulated TCP connections by setting different delays on the access links, for example set the delay of access links and R1-R2 link to get 10ms RTT for the first, 50ms for the second and 100ms for the third TCP connection. Try different combinations of RTT settings (at least five).

Include a table with the per connection average throughput for the cases with equal and non-equal RTTs in the report. Evaluate the fairness of the TCP in sharing the network bandwidth.

Note: check that the simulation time is long enough, especially for larger RTT values (you should simulate at least a few TCP congestion avoidance/retransmission phases). If necessary, extend the simulation time.

FINAL REPORT

The final report should be prepared in pdf format and archived together with other required files. The report should contain screenshots with simulation results (one screenshot for each task). The archive should also contain the simulation output files for each simulation (for tasks 1 and 2 only files related to simulations with optimal values of the window size and buffer size are required).

Do not forget to list the authors' names on the first page of the report and use the following template for naming the archive with report and required files: **EINTE_2021Z_FirstAuthorSurname.zip** (example: EINTE_2021Z_Kowalski.zip).

Please note that the clarity of the report will also contribute to your final score.