POLITECNICO DI TORINO

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Lab #2 on Traffic Scheduling

"Computer network design and control" module of
Communication and network systems

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Chapter 1

Laboratory #2

The aim of the lab is to experiment with fairness issues and Quality of Service (QoS) support through scheduling algorithms, in a Mininet SDN network emulator running on a Virtual Machine within Crownlabs. The Linux Traffic Control (`tc`) tool will be used to define and configure QoS algorithms on the virtual switch interfaces.

The lab's primary goal is to familiarize students with QoS techniques, their impact on network performance, and the various scheduling and buffer management algorithms.

1.1 Starting the lab

To start the lab, follow the same procedure outlined in Lab 1 (also provided below for convenience).

For detailed instructions on using Crownlabs, please refer to the guide in Lab 1.

1. Navigate to the Crownlabs website: https://crownlabs.polito.it/
2. Click on the button "Login @Polito"
3. On the web page with the login form, click on the button "PoliTo SSO", which you can find at the bottom of the form
4. Log in using your PoliTo credentials (the same credentials you use to access the "Portale della didattica")
5. You will now be logged in to Crownlabs. Here, you will find yourself on the "Dashboard" tab, and on the UI, you should see the "Communication and Network Systems" workspace on the left of the user interface (UI)
6. Click on that workspace, and a new section will appear where you will find the VM called "Lab"
7. Click on the "Create" button, and a new instance of the VM will be created. Once the creation is complete, the "Connect" button will become active
8. When the "Connect" button is active, click on it, and a new web browser tab will open where you will be connected to the VM, and you will be able to see the VM desktop

1.2 Scheduling algorithms

The objective of this section of the lab is to compare the performance of various scheduling algorithms, including FIFO, Round-Robin (RR), Weighted Round-Robin (WRR), and Strict Priority, across different network topologies.

1.2.1 Two-flows scenario

Let's start with a simple topology featuring two traffic flows under varying input loads.

The topology is shown in Fig. 1.1 and consists of two hosts, `h1` and `h2`, serving as traffic generators, and two hosts, `h3` and `h4`, acting as traffic destinations. The hosts are interconnected through two switches, `s1` and `s2`, in series. All links between hosts and switches operate at 2 Mbps with a delay of 40 ms. The link between the two switches (denoted as the "bottleneck"), runs at 1 Mbps with a delay of 10 ms.

In the folder `lab2/linear_topology`, you find the scripts to configure the topology and run different scheduling algorithms on the output interface connecting `s1` to `s2`:

- `fifo.py` implements FIFO queuing;
- `rr.py` implements a Round-Robin (RR) policy;
- `wrr.py` implements a Weighted Round-Robin (WRR) with weights 4 (for the traffic generated by `h1`) and 1 (for the traffic generated by `h2`);
- `strict-priority.py` implements a strict priority (SP) scheduler, with the traffic generated by `h1` at the highest priority.

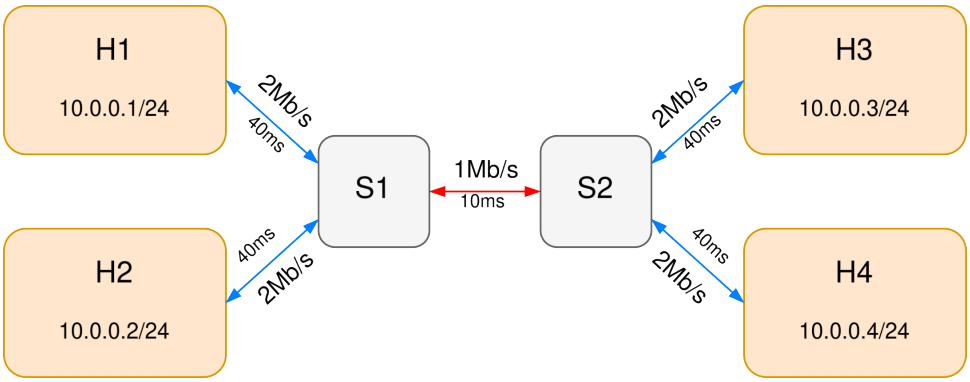


Figure 1.1: Linear topology with two flows

All the commands reported from now on need to be run with the current working directory set to `/home/netlab/Desktop`. If you are not sure which directory your terminal is currently in, you can check it by running `pwd`. Otherwise, simply run `cd /home/netlab/Desktop` to navigate to the correct location.

1.2.1.1 FIFO

Run the first scenario with a FIFO scheduler, using the command:

```
sudo python -m lab2.linear_topology.fifo
```

Open the terminal of all four hosts by typing, within the mininet window:

```
xterm h1 h2 h3 h4
```

NOTE: The window label, e.g., `Node:h1`, helps identify the host associated with the terminal.

Now start the `iperf3` servers at the destination hosts by typing on both terminals of `h3` and `h4`:

```
iperf3 -s
```

The command should print that port 5201 is used to receive the traffic.

To begin with, we consider a single flow scenario. Start UDP traffic from `h1` to `h3` with 100 kbit/s load by typing on the terminal of `h1`:

```
iperf3 -c 10.0.0.3 -u -t 100 -b 100k
```

NOTE: that you can stop the source when the results stabilize by pressing `CTRL+C`.

Explain below what is the meaning of all of the above options (`-s`, `-c`, `-u`, `-t`, `-b`). Type `man iperf3` to get this info.

Run the experiments for the various input loads reported below in the table. Recall that when the results stabilize and the losses are observed (if any), you can stop the experiment. Before running each experiment, compute the expected throughput (take a note on the way the computation is done). When the run ends, observe the measured throughput (denoted as "Bitrate") and losses measured in `h3` (not in `h1`) and fill the below reported table,

Exp.	Host	Input load [kbit/s]	Throughput [kbit/s]	Loss probability	Expec. Thr. [kbit/s]
1	h1	100			
2	h1	500			
3	h1	900			
4	h1	1200			
5	h1	1500			

Are the results as expected? If not, why?

Now run a scenario with 2 UDP flows (from `h1` to `h3`, and from `h2` to `h4`) for all the combinations of input loads shown in the table below. Before running each experiment, compute the expected throughput and report it below.

Exp.	Host	Input load [kbit/s]	Throughput [kbit/s]	Loss probability	Exp. Thr. [kbit/s]
6	h1 h2	100 200			
7	h1 h2	400 800			
8	h1 h2	400 1200			
9	h1 h2	600 1200			

Are the results as expected? If not, why?

In summary, what are the most evident effects of the FIFO policy?

1.2.1.2 Round-Robin (RR)

Load the second scenario with two flows and a RR scheduler, using the command:

```
sudo python -m lab2.linear_topology.rr
```

Open a terminal for each of the four hosts.

Before running each experiment, compute the expected throughput and report it below. Start the two UDP traffic flows, as shown in the previous scenario, and fill the following table. From now on, we will not consider the loss probability.

Exp.	Host	Input load [kbit/s]	Throughput [kbit/s]	Expected Throughput [kbit/s]
10	h1 h2	100 200		
11	h1 h2	400 800		
12	h1 h2	400 1200		
13	h1 h2	600 1200		

Are the results as expected? If not, why?

In summary, what are the most evident effects of the RR policy?

1.2.1.3 Weighted Round-Robin (WRR)

Load this scenario with the following command:

```
sudo python -m lab2.linear_topology.wrr
```

Then, open a terminal for each of the four hosts.

Before running each experiment, compute the expected throughput and report it below. Start the two UDP traffic flows as described in the previous scenario, and complete the table below.

Recall that the weights for the two flows generated by `h1` and `h2` are set at 4:1, respectively.

Exp.	Host	Input load [kbit/s]	Throughput [kbit/s]	Expected Throughput [kbit/s]
14	h1 h2	100 200		
15	h1 h2	400 800		
16	h1 h2	600 800		
17	h1 h2	800 800		
18	h1 h2	1000 800		

Are the results as expected? If not, why?

In summary, what are the most evident effects of the WRR policy?

1.2.1.4 Strict Priority (SP)

Load this scenario with the following command:

```
sudo python -m lab2.linear_topology.strict_priority
```

Open a terminal for each of the four hosts. Before running each experiment, compute the expected throughput and report it below. Start the two UDP traffic flows, as shown in the previous scenario, and fill the following table.

Remember that the traffic generated by `h1` is assigned the highest priority.

Exp.	Host	Input load [kbit/s]	Throughput [kbit/s]	Expected Throughput [kbit/s]
19	h1 h2	100 200		
20	h1 h2	400 800		
21	h1 h2	600 800		
22	h1 h2	800 800		
23	h1 h2	1200 800		

Are the results as expected? If not, why?

In summary, what are the most evident effects of the SP policy?

1.2.1.5 Max-min fairness

In the scenario of Fig. 1.1, compute the max-min fair allocation for the two flows.

Flow	Max-min fair rate allocation [kbit/s]
`h1-h3`	
`h2-h4`	

Now list the experiment number in which the throughput at the receiver is the same as the one computed according to the max-min fair allocation:

Which scheduling policy (FIFO, RR, WRR, SP) provides, at the receivers, the same rate as the one of the max-min fair allocation when the bottleneck link is overloaded?

Is there any difference among schedulers in underload? Why?

1.2.2 Multiple flows scenarios

The objective of this section is to compare the performance of different scheduling algorithms, namely FIFO, Round-Robin (RR), Weighted Round-Robin (WRR), and Strict Priority (SP), with multiple flows across two topologies: a single bottleneck and a meshed topology.

For this part of the lab, you will run the script `run.py`, providing a configuration file that defines the topology, scheduler, and flows to simulate.

Look at the example configuration file `linear5_underload_fifo.yml` that you can find in the `lab2/configs/` folder and familiarize with the main options available, i.e.:

- `experiment_name`: can be anything you like. This is the name of the output directory

where the results will be stored;

- `topology`: the topology to use:
  - `linear_topology`
  - `linear_topology_5`
  - `mesh_topology_5`
- `scheduler`: the scheduler to use:
  - `fifo`
  - `rr`
  - `wrr`
  - `strict_priority`
- `flows`: the various flows we want to generate. For each flow, the most important options are:
  - `rate`: the rate we want to generate;
  - `start_time`: the starting time at which the flow should start generating traffic.

You will have to create a configuration file for each experiment. It is recommended to make multiple copies of the above-mentioned example file.

NOTE: remember to change the experiment name, otherwise output files will be overwritten.

You can keep the default values of all other parameters for the moment.

To run the experiment through the `run.py` program, use the following command:

```
sudo python -m lab2.run lab2/configs/<config_file_name>
```

where `<config_file_name>` is a placeholder, which you need to replace with the file name of the experiment you want to run. E.g.,

```
sudo python -m lab2.run lab2/configs/linear5_underload_fifo.yml
```

All experiments last for the duration set in the config file (suggested value 60 seconds (at least)).

The program generates a folder with the experiment name on the `Desktop`, which contains the following:

- a `.csv` file containing the input and output rates of all interfaces;
- a `.txt` file for each server, containing the `iperf3` output;
- a `.png` plot showing both the offered load and the throughput of each flow.

For the remainder of this lab, you will mostly look at the throughput graph.

1.2.2.1 Single bottleneck

In the first scenario, the topology is made of two switches, with 5 hosts connected to each of them, as shown in Fig. 1.2. All links between hosts and switches operate at 2 Mbps with a delay of 40 ms. The link between the two switches (denoted as the “bottleneck”), runs at 1 Mbps with a delay of 10 ms.

To use this topology, specify `linear_topology_5` as the `topology` of the configuration file.

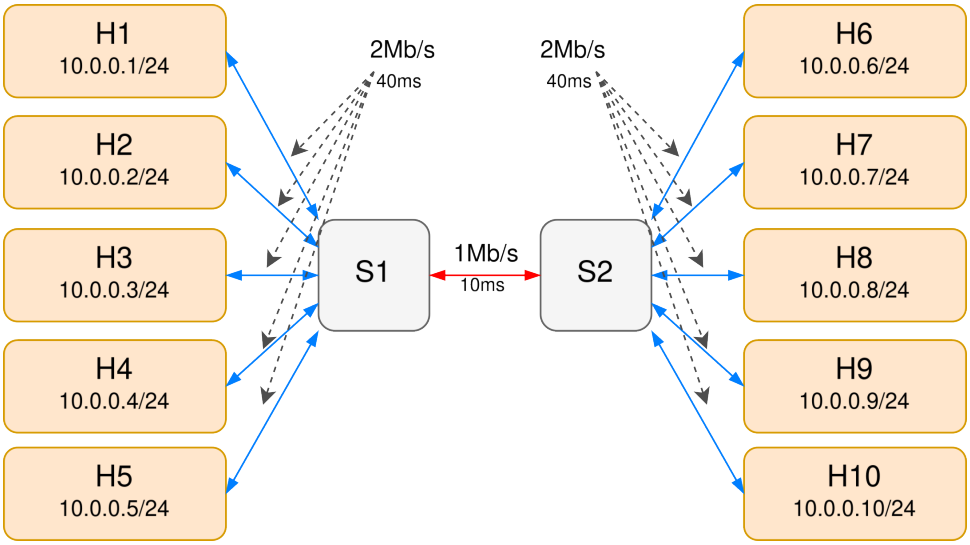


Figure 1.2: Linear topology with 5 flows

You must compare the effect of different schedulers with different offered loads.

Underload

First run the experiments under low-traffic conditions. Set the rates of the five flows to `100, 100, 100, 200, 350 kbit/s`, respectively, and complete the table below with the average throughput values obtained from the plot.

FIFO - Underload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Repeat the experiment for the remaining three schedulers: Round-Robin, Weighted Round-Robin, and Strict Priority, and report the results. The weights for the WRR scheduler are set to 1, 1, 1, 2, and 5, respectively. For the Strict Priority scheduler, the priorities are set to 1, 2, 2, 2, and 3, where a lower number indicates a higher priority.

Round-Robin - Underload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Weighted Round-Robin - Underload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Strict Priority - Underload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Briefly discuss per-flow throughput and fairness properties comparing the various test cases, with the help of the plots.

Overload

In overloaded conditions, the available capacity is not sufficient to serve all flows with their input rates. Modify the configuration file and change the rates of the five flows from `100, 100, 100, 200, 350 kbit/s` to `200, 200, 200, 300, 600 kbit/s`, respectively.

Fill the table below by extracting the information from the plots.

FIFO - Overload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Repeat the experiments for the other three schedulers: Round-Robin, Weighted Round-Robin and Strict Priority, and report the results.

Round-Robin - Overload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Weighted Round-Robin - Overload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Strict Priority - Overload		
Flow ID	Input load	Throughput
1		
2		
3		
4		
5		

Briefly discuss per-flow throughput and fairness properties by comparing the various test cases, with the help of graphs.

Max-min fairness

In the scenario of Fig. 1.2, compute the max-min fair allocation for the five flows.

Flow	Max-min fair rate allocation [kbit/s]
`h1-h6`	
`h2-h7`	
`h3-h8`	
`h4-h9`	
`h5-h10`	

Now list the experiment number in which the throughput at the receiver is the same as the one computed according to the max-min fair allocation.

Which scheduling policy (FIFO, RR, WRR, SP) provides the same rate as those of the max-min fair allocation. Why?

1.2.2.2 Mesh topology

For this section, you will use the topology shown in Fig. 1.3 with the depicted flows and routes. All links between hosts and switches operate at **20 Mbps** with a delay of 40 ms. The links between all the switches run at **10 Mbps** with a delay of 10 ms.

To use this topology, specify `mesh_topology_5` as the `topology` in the configuration file.

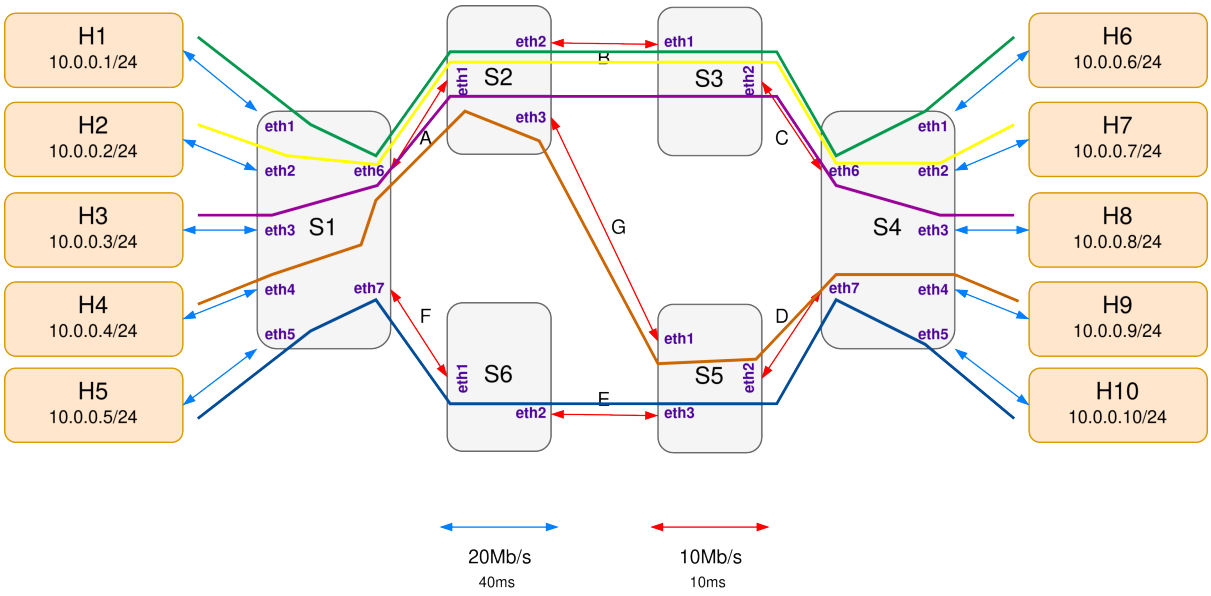


Figure 1.3: Mesh topology with 5 flows

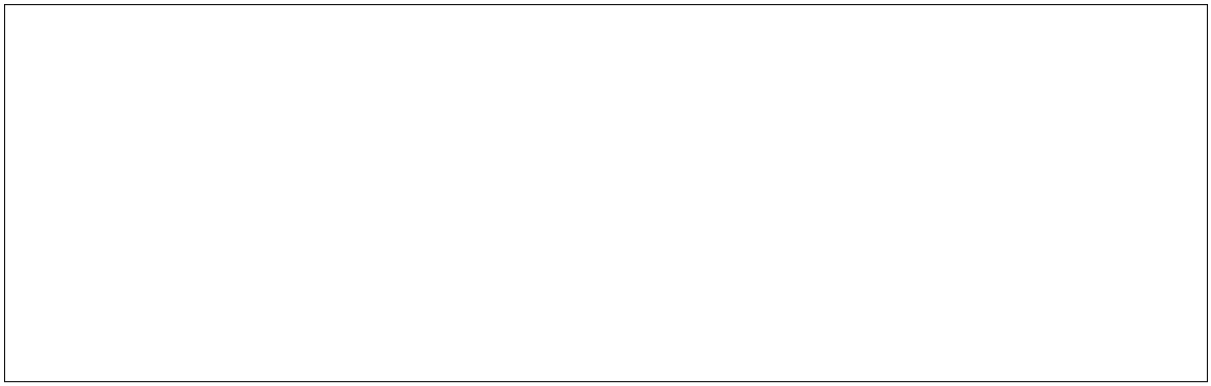
Underload

Set the input rates of all flows to `1 Mbit/s` (you will specify that as `1M` in the file).

Report below and compare the results

Underload				
Flow ID	Throughput		Expected Losses [%]	
	FIFO	Round-Robin	FIFO	Round-Robin
1				
2				
3				
4				
5				

Would you expect to see any difference among schedulers? Explain the results.



Overload

We now increase the rate of each flow to **10 Mbit/s**. Is some link in the topology overloaded?

Before running the experiment, compute the expected rates that a **max-min fairness** algorithm would assign to the five flows and write the values in the table below. Then, run the experiments and fill in the table.

Overload - Throughput			
Flow ID	MAX MIN fair rate	FIFO rate	Round-Robin rate
1			
2			
3			
4			
5			

Compare and explain the results.

1.2.2.3 Rate limiting

For this step, use the same configuration of Sec. 1.2.2.2 but limiting the link rates for flow 1 and flow 2 to **1 Mbit/s**. Before running the experiment, compute the expected rates that a **max-min fairness** algorithm would assign to the new five flows and write the values in the table below.

Rate limiting - Throughput			
Flow ID	MAX MIN fair rate	FIFO rate	Round-Robin rate
1			
2			
3			
4			
5			

Run the experiments and report in the above table the throughput achieved by the FIFO and Round-Robin schedulers.

Do the results of the tests with the two different schedulers differ? Discuss and explain the results.

1.2.3 Two-flows scenario - Transient (Optional)

For this section, you will re-use the same topology used in Sec.1.2.1 (reported below for your convenience)

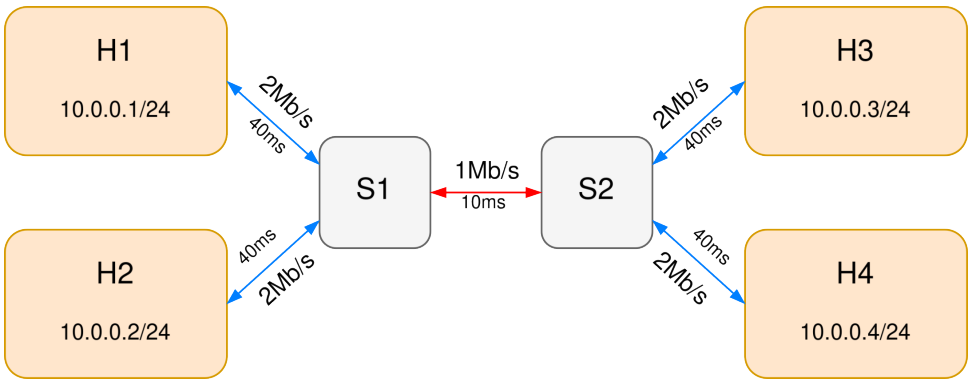


Figure 1.4: Linear topology with two flows

The script `run.py` provides a configuration file that defines the topology, the scheduler, flows and forwarding tables to simulate the scenario under study.

The objective of this experiment is to analyze how different scheduling algorithms behave in a transient scenario, where one flow starts later than the other. This allows us to observe the impact of various schedulers on network performance during dynamic traffic changes.

Look at the example configuration file `linear_underload_fifo_transient.yml` you can find in the `lab2/configs/`. To use this topology, specify `linear_topology` as the `topology` of the configuration file.

In each experiment you have to change, for each flow, both the `rate` and the `start_time`.

To run the experiment through the `run.py` program, use the following command:

```
sudo python -m lab2.run lab2/configs/<config_file_name>
```

where `<config_file_name>` is a placeholder, which you need to replace with the file name of the experiment you want to run. E.g.,

```
sudo python -m lab2.run lab2/configs/linear_underload_fifo_transient.yml
```

All experiments last for the duration set in the config file (suggested simulation length is 30 seconds).

The program generates a folder with the experiment name on the `Desktop`, which contains the following:

- a `.csv` file containing the input and output rates of all interfaces;
- a `.txt` file for each server, containing the `iperf3` output;
- a `.png` plot showing both the offered load and the throughput of each flow.

For this exercise, you will mostly look at the throughput graph.

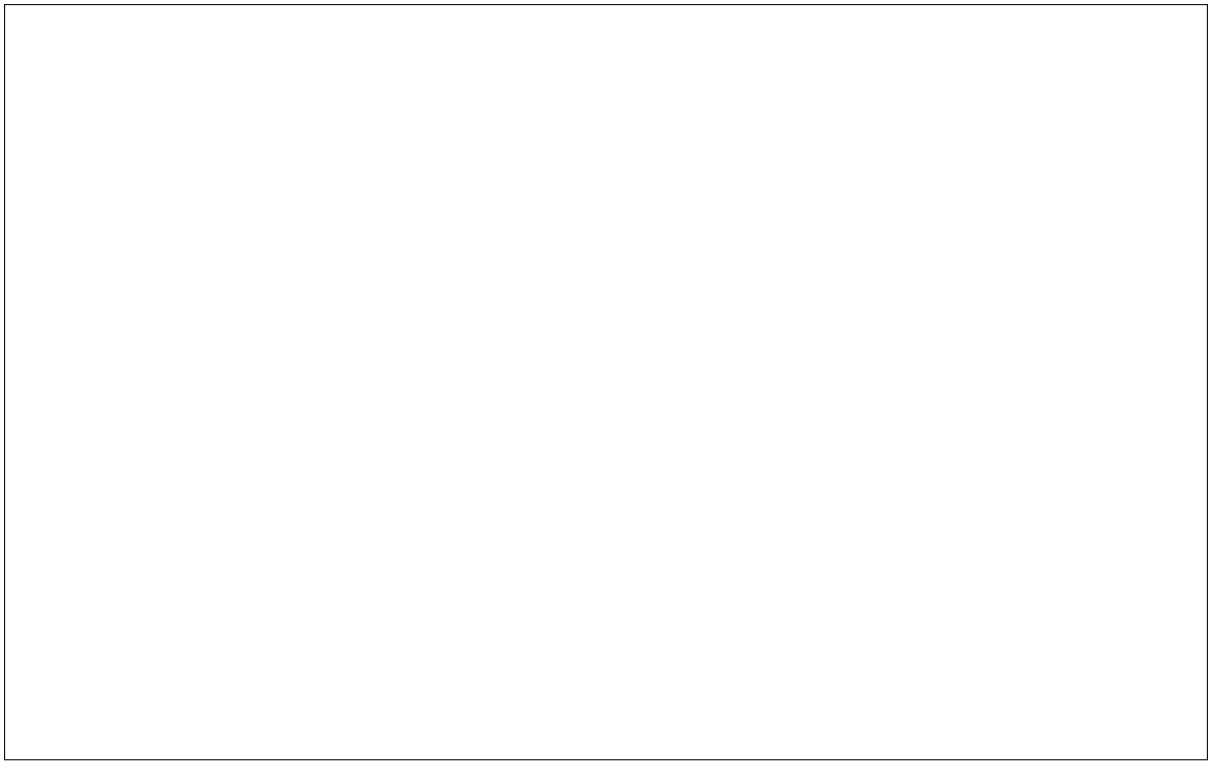
1.2.3.1 FIFO

In this first scenario, we will use the FIFO scheduler.

We report below the various configurations (i.e., input loads) you should run. Before running the experiments, write the expected throughput for the various flows. Then, complete the table by reporting the offered load and the average throughput achieved towards the end of the simulation, once the simulation reaches a stable condition:

Exp #	Host	Input load [kbit/s]	Start time [s]	Expected throughput [kbit/s]	Offered load [kbit/s]	Throughput [kbit/s]
1	h1 h2	200 400	0 10			
2	h1 h2	400 800	0 10			
3	h1 h2	800 400	10 0			
4	h1 h2	800 800	0 10			

Discuss and explain below the results and flow behaviour.



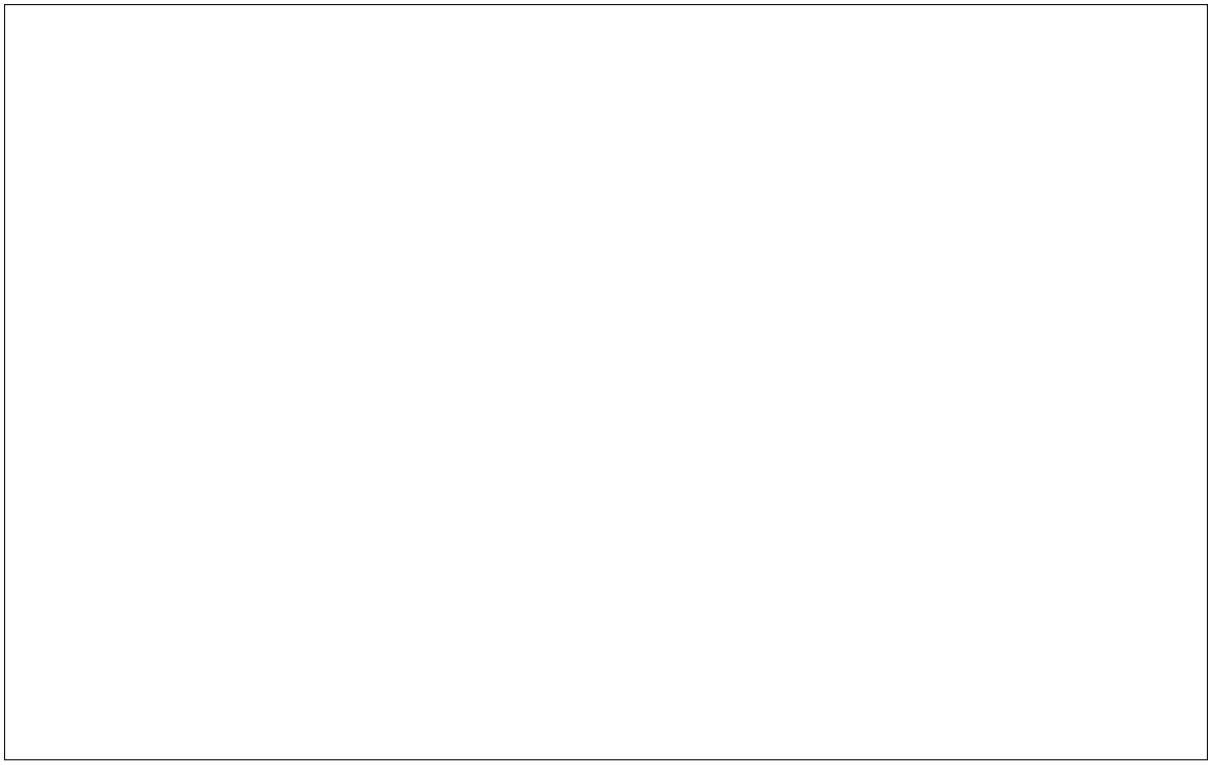
1.2.3.2 Round-Robin

In this second scenario, we will use the Round-Robin scheduler.

We report below the various configurations (i.e., input loads) you should run. Before running the experiments, write the expected throughput for the various flows. Then, complete the table by reporting the offered load and the average throughput achieved towards the end of the simulation, once the simulation reaches a stable condition:

Exp #	Host	Input load [kbit/s]	Start time [s]	Expected throughput [kbit/s]	Offered load [kbit/s]	Throughput [kbit/s]
1	h1 h2	200 400	0 10			
2	h1 h2	400 800	0 10			
3	h1 h2	800 400	10 0			
4	h1 h2	800 800	0 10			

Discuss and explain below the results and flow behaviour.



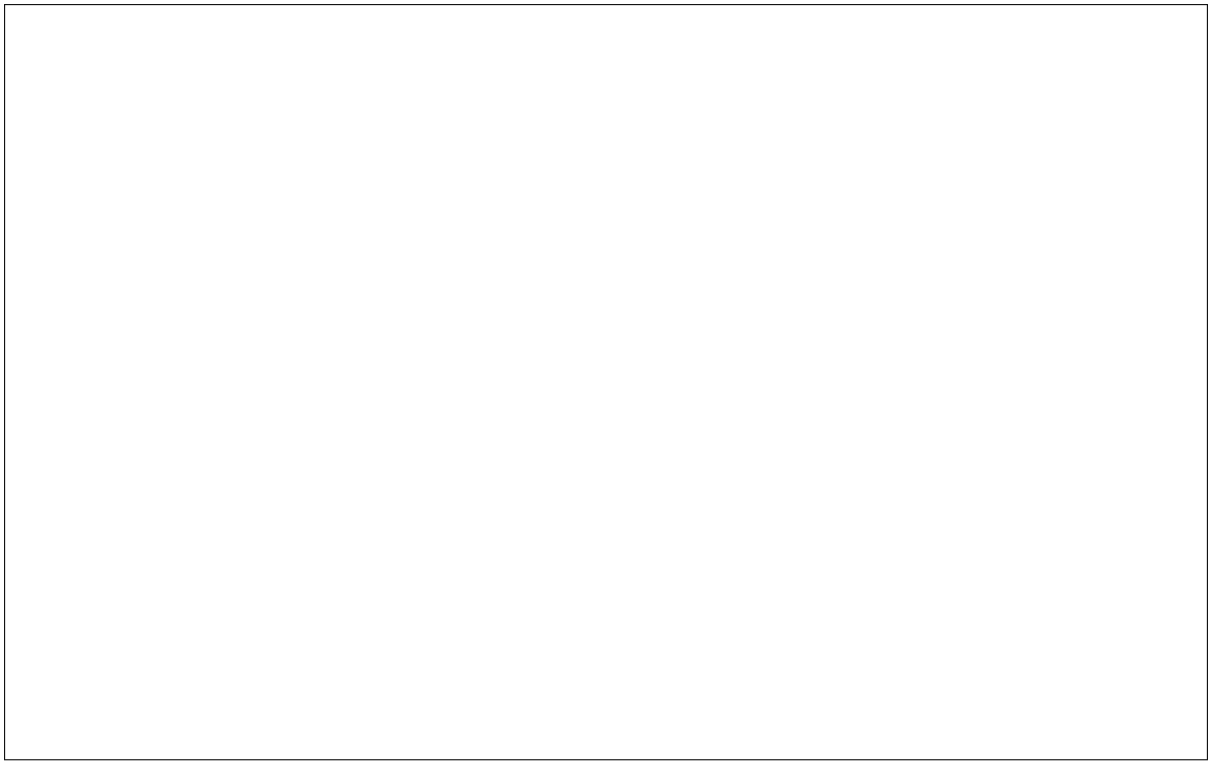
1.2.3.3 Weighted Round-Robin

In this third scenario, we will use the Round-Robin scheduler. Remember that the weights for the two flows generated by `h1` and `h2` are set at 4:1, respectively.

We report below the various configurations (i.e., input loads) you should run. Before running the experiments, write the expected throughput for the various flows. Then, complete the table by reporting the offered load and the average throughput achieved towards the end of the simulation, once the simulation reaches a stable condition:

Exp #	Host	Input load [kbit/s]	Start time [s]	Expected throughput [kbit/s]	Offered load [kbit/s]	Throughput [kbit/s]
1	h1 h2	200 400	0 10			
2	h1 h2	400 800	0 10			
3	h1 h2	800 400	10 0			
4	h1 h2	800 800	0 10			

Discuss and explain below the results and flow behaviour.



1.2.3.4 Strict priority

In this last scenario, we will use the Strict Priority scheduler. Remember that the traffic generated by `h1` is assigned the highest priority.

We report below the various configurations (i.e., input loads) you should run. Before running the experiments, write the expected throughput for the various flows. Then, complete the table by reporting the offered load and the average throughput achieved towards the end of the simulation, once the simulation reaches a stable condition:

Exp #	Host	Input load [kbit/s]	Start time [s]	Expected throughput [kbit/s]	Offered load [kbit/s]	Throughput [kbit/s]
1	h1 h2	200 400	0 10			
2	h1 h2	400 800	0 10			
3	h1 h2	800 400	10 0			
4	h1 h2	800 800	0 10			

Discuss and explain below the results and flow behaviour.