University of Bristol

Coursework

Data Center Networking

by

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Abstract

Data Center Networking

This report is the coursework of Data Center Networking. For further references see Lab Note for Data Center Networking or go to the next url: `https://seis.bristol.ac.uk/~sy13201/DCN/Lab%20Note.html`.

Contents

Chapter 1

Simulation Environment Setup

1.1 macOS Platform

Create a folder for this project. mkdir project

Then go into the project folder. cd project

Download the source code of simulation platform.

Platform Repository: `https://github.com/booksim/booksim2.git`

If you have installed git command, then clone the repository to the project path. git clone `https://github.com/booksim/booksim2.git`

Compile the source code:

Go to the path ./project/booksim/src

Execute command: make booksim

The Makefile can be found in the path ./project/booksim/src

After compiling, there will be a booksim executable file in the path.

Then test some examples:

./booksim example/torus88

If you get the results in the terminal, that indicates you build up the simulation environment successfully.

The complete shell commands can be found in listing 1.1.

Listing 1.1: Shell Code

```
mkdir project
cd project
git clone https://github.com/booksim/booksim2.git
cd booksim/src
make booksim
./booksim example/torus88
```

1.2 Ubuntu20.04 Platform

For Ubuntu System, we need to install the dependencies listed below for the simulation platform first.

sudo apt install make g++ flex bison

Create a folder for this project. mkdir project

Then go into the project folder. cd project

Download the source code of simulation platform.

Platform Repository: `https://github.com/booksim/booksim2.git`

If you have installed git command, then clone the repository to the project path.

git clone `https://github.com/booksim/booksim2.git`

Compile the source code:

Go to the path ./project/booksim/src

Execute command: make booksim

The Makefile can be found in the path ./project/booksim/src

After compiling, there will be a booksim executable file in the path.

Then test some examples:

./booksim example/torus88

If you get the results in the terminal, that indicates you build up the simulation environment successfully.

The complete shell commands can be found in listing 1.2.

Listing 1.2: Shell Code

```
sudo apt update
sudo apt install make g++ flex bison
mkdir project
cd project
git clone https://github.com/booksim/booksim2.git
cd booksim/src
make booksim
./booksim example/torus88
```

Chapter 2

Simulation Parameters Introduction

- **k** Network radix, the number of routers per dimension
- **n** Network dimension
- **mesh** A k-ary n-mesh (mesh) topology. The `k` parameter determines the network's radix and the `n` parameter determines the network's dimension.
- **torus** A k-ary n-cube (torus) topology. The `k` parameter determines the network's radix and the `n` parameter determines the network's dimension.
- **num_vcs** The number of virtual channels per physical channel.
- **vc_buf_size** The depth of each virtual channel in flits.
- **wait_for_tail_credit** If non-zero, do not reallocate a virtual channel until the tail flit has left that virtual channel. This conservative approach prevents a dependency from being formed between two packets sharing the same virtual channel in succession.
- **uniform** Each source sends an equal amount of traffic to each destination (`traffic = uniform`).
- **tornado** $d_x = s_x + \lceil k/2 \rceil - 1 \mod k$.

- **latency_thres** If the sampled latency of the current simulation exceeds `latency_thres`, the simulation is immediately ended.

- **sim_type** A simulation can either focus on `throughput` or `latency`. The key difference between these two types is that a `latency` simulation will wait for all measurement packets to drain before ending the simulation to ensure an accurate latency measurement. In `throughput` simulations, this final drain step is eliminated to allow simulation of networks operating beyond their saturation point.

- **injection_rate** The rate at which packets are injected into the simulator is set using the `injection_rate` option. The simulator's cycle time is a flit cycle, the time it takes a single flit to be injected at a source, and the injection rate is specified in packets per flit cycle. For example, setting `injection_rate = 0.25` means that each source injects a new packet in one out of every four simulator cycles. The unit of `injection_rate` can optionally be changed to flits per cycle by setting `injection_rate_uses_flits` to 1.

Chapter 3

Assignment 1

Explore latency in the design of interconnection networks

In this assignment, the impacts of routing, flow control and network size from a latency perspective will be explored in a chosen network topology. In this assignment, 8-ary 2-cube mesh and torus network will be used for simulation. At low traffic, zero-load latency gives an accurate estimate of the simulated latencies. The model uses the time it takes a flit to traverse a channel as the definition of cycles. The router model has a delay of 3 cycles and the serialisation latency is 20 cycles because the packet length is 20 flits.

Here we will compare the performance of four routing algorithms, dimension-order routing (DOR), the randomized, minimal algorithm (ROMM), Valiant's randomized algorithm (VAL), and a minimal-adaptive routing algorithm. The ROMM algorithm is a minimal version of Valiant's algorithm. You may need to read the code to find the corresponding routing algorithms. Your assignment is to run the simulator to collect enough data points (10 data points for each plot) to be able to create plots of latency (cycles) vs. offered load (aka injection rate*packet length) for different routing algorithms. You may need to change the latency_thres to perform the simulations.

3.1 Use “uniform” traffic pattern.

Evaluate all the routing algorithms to get plots of average latency vs. offered load for both the mesh and torus networks. Compare the performance of the two topologies and explain the possible reasons.

3.1.1 Mesh(ary8,dim2)

The first simulation is based on ’mesh’ topology and ’uniform’ traffic pattern to test 4 kinds of different routing algorithms(DOR, VAL, ROMM, MIN-ADAPT).

Simulation parameters setup

The **basic routing parameters** below are fixed during the whole simulation process:
Packet size : 20 flits
Router delay : 3 cycles
Traffic pattern : uniform
Simulation type : latency
Latency threshold : 20000
The default parameters for **flow control** in ’booksim_conf.cpp’ are:
Virtual channel number : 8
Buffer size per channel : 8
Wait for tail credit : 0

* The default **latency threshold** set in ’booksim_conf.cpp’ is 500 cycles. Obviously, lots of average packet latency simulation results are greater than 500. To make the simulation more reliable, we must get enough simulation results to reflect the features of a routing algorithm. Therefore, we set the value of the latency threshold in the simulation process at 20000 to make the simulation stable and get enough data.

Simulation results

The simulation results(average packet/flit/network delay) are listed in the table 3.1. We test 10 different packet injection rates equally spaced for each routing algorithm, ranging from 0.005 to 0.022.

Dimension Order Routing Algorithm

The first ten rows in the table 3.1 is the simulation results of the dimension order routing algorithm(DOR). The average packet delay is increased non-linearly; the increment of average packet delay between injection rates of 0.0201 and 0.022 is dramatic. The lowest average packet delay is 73, and the corresponding injection rate is 0.005. The highest average packet delay is 924, and the corresponding injection rate is 0.022. DOR is a rudimentary routing algorithm in such an interconnection network topology.

Valiant Randomized Algorithm

The next ten rows following the dimension order algorithm are simulated with the Valiant Randomized routing algorithm(VAL). Similar to the simulation results of DOR, the increment of the average packet delay is non-linear. The value of the average packet delay exceeds 500 with an injection rate of 0.0107. Obviously, under 'mesh' topology and 'uniform' traffic pattern, the performance of the DOR algorithm is much better than the VAL. Compared with DOR, VAL will firstly select an intermediate node randomly. Packets will go through this node and then be transmitted to the destination. The detour in the VAL causes the performance of VAL to be worse than DOR.

The Randomized Minimal Algorithm

The randomized minimal algorithm(ROMM) is a minimal version of Valiant's algorithm. So the performance of the ROMM is better than VAL. However, its performance still is not better than DOR. The lowest value of average packet delay is 74, and the highest average packet value is 2009. For the injection rates lower than 0.0182, the corresponding average packet delays are all below 500.

Minimal Adaptive Routing Algorithm

This routing algorithm is different from the three routing algorithms above. All the three algorithms(DOR, VAL, ROMM) above are deterministic, meaning routes choosing for packets without considering any information about the network's present state. Deterministic algorithms are a subset of oblivious algorithms. All the packets from the same source and destination pairs will always choose the same path. In adaptive algorithms, the state of the network is incorporated in routing decisions to adapt to network states such as network congestion. the decision of the routes depends on the states(node, link, length of queues, historical channel load information) of the network.

The last ten rows in the table 3.1 are the simulation results of the minimal adaptive routing algorithm(MIN-ADAPT). The performance of the MIN-ADAPT routing algorithm is better than ROMM and VAL, whilst worse than DOR. Although the MIN-ADAPT routing algorithm considers the states of the network, it cannot guarantee always choosing the shortest path from source to destination.

Simulation Results and Analysis

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
mesh(ary8,dim2)	dor	0.005	73.0662	71.6361	49.2098
mesh(ary8,dim2)	dor	0.0069	76.8418	74.6871	49.963
mesh(ary8,dim2)	dor	0.0088	83.8149	80.5435	53.0305
mesh(ary8,dim2)	dor	0.0107	91.8645	87.0211	55.9655

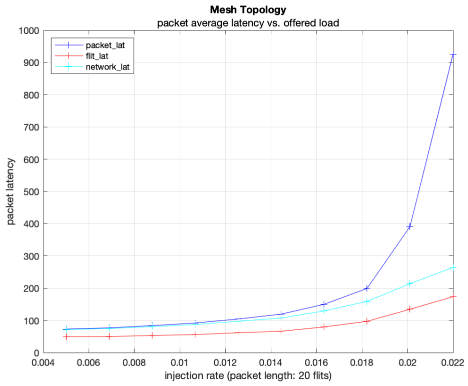
Continue...

topology	routing _algorithm	injection _rate	average _packet _delay	average _network _latency	average _flit _delay
mesh(ary8,dim2)	dor	0.0126	104.239	97.2317	61.6683
mesh(ary8,dim2)	dor	0.0144	119.377	107.245	66.2991
mesh(ary8,dim2)	dor	0.0162	149.792	129.338	79.5861
mesh(ary8,dim2)	dor	0.0182	198.997	158.855	97.1164
mesh(ary8,dim2)	dor	0.0201	391.166	213.962	134.511
mesh(ary8,dim2)	dor	0.022	924.686	264.37	173.478
mesh(ary8,dim2)	val	0.005	126.603	123.984	92.6255
mesh(ary8,dim2)	val	0.0069	163.498	159.68	112.072
mesh(ary8,dim2)	val	0.0088	275	261.325	176.152
mesh(ary8,dim2)	val	0.0107	763.36	588.338	452.777
mesh(ary8,dim2)	val	0.0126	2195.81	763.164	608.67
mesh(ary8,dim2)	val	0.0144	3140.07	743.479	595.49
mesh(ary8,dim2)	val	0.0162	5028.93	748.846	615.219
mesh(ary8,dim2)	val	0.0182	5420.19	782.895	639.082
mesh(ary8,dim2)	val	0.0201	6616.17	785.49	620.81
mesh(ary8,dim2)	val	0.022	7429.83	785.592	624.163
mesh(ary8,dim2)	romm	0.005	74.2736	72.9289	49.3448
mesh(ary8,dim2)	romm	0.0069	80.2078	77.9392	51.4906
mesh(ary8,dim2)	romm	0.0088	88.9635	85.2276	54.8927
mesh(ary8,dim2)	romm	0.0107	100.114	93.8712	59.8575
mesh(ary8,dim2)	romm	0.0126	112.004	103.435	64.4221
mesh(ary8,dim2)	romm	0.0144	152.793	134.21	83.4388
mesh(ary8,dim2)	romm	0.0162	263.473	179.936	110.442

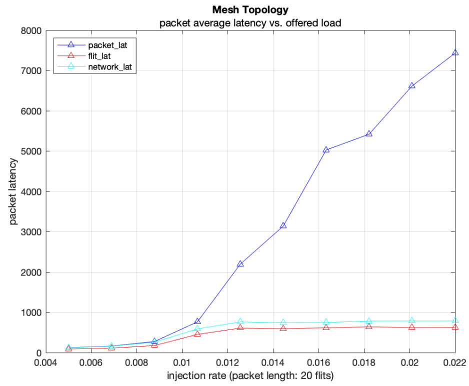
Continue. . .

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
mesh(ary8,dim2)	romm	0.0182	783.632	245.982	162.311
mesh(ary8,dim2)	romm	0.0201	1342.57	258.939	172.721
mesh(ary8,dim2)	romm	0.022	2099.52	273.717	183.03
mesh(ary8,dim2)	min_adapt	0.005	73.0579	71.7891	51.0248
mesh(ary8,dim2)	min_adapt	0.0069	79.4548	77.1725	54.4017
mesh(ary8,dim2)	min_adapt	0.0088	83.6194	80.1709	56.1564
mesh(ary8,dim2)	min_adapt	0.0107	103.026	95.4367	67.8351
mesh(ary8,dim2)	min_adapt	0.0126	120.213	108.884	78.5965
mesh(ary8,dim2)	min_adapt	0.0144	146.395	126.887	92.7529
mesh(ary8,dim2)	min_adapt	0.0162	228.894	159.679	117.972
mesh(ary8,dim2)	min_adapt	0.0182	614.154	213.857	150.876
mesh(ary8,dim2)	min_adapt	0.0201	1130.59	235.374	169.241
mesh(ary8,dim2)	min_adapt	0.022	1711.64	253.519	177.158

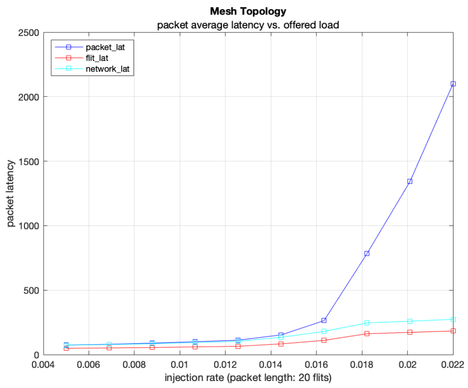
The blue lines in all the figures 3.1, 3.2 depicts the change of the average packet delay against offered load. According to the first sub-figure in the figure 3.2, we can know that the performance of the DOR routing algorithm in such a mesh(8-ary, 2-dim) topology with a uniform traffic pattern is better than all the other three routing algorithms(VAL, ROMM, MIN-ADAPT).



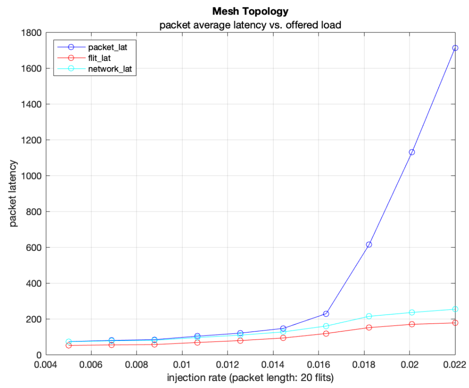
(a) dimension order



(b) valiant



(c) romm



(d) minimal adaptive

Figure 3.1: Simulation results of Mesh topology with uniform traffic

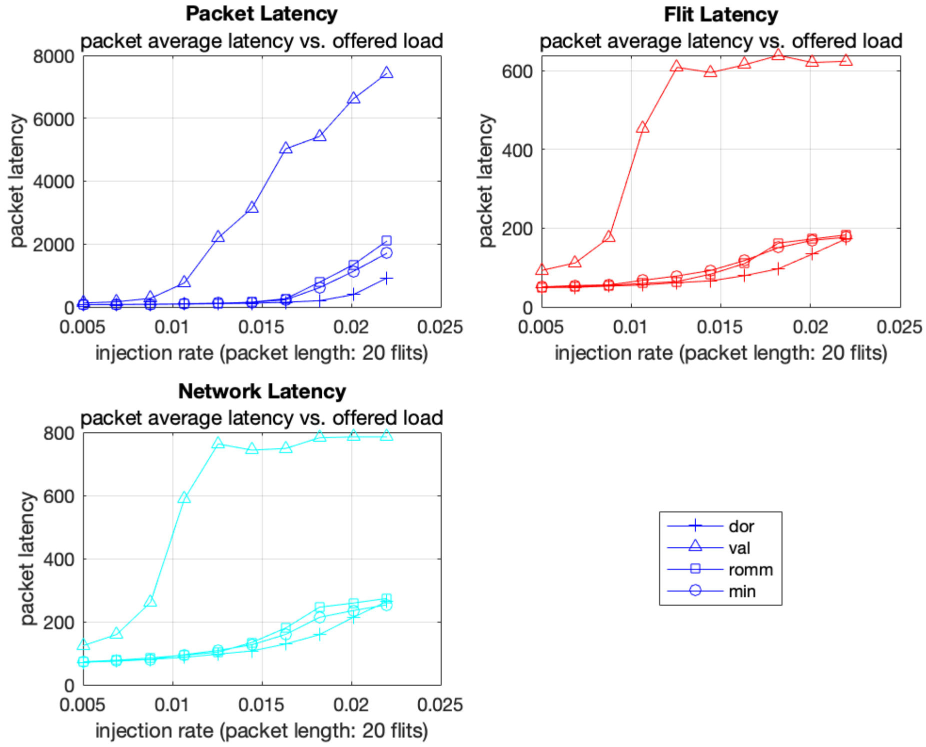


Figure 3.2: Latency comparison of 4 traffic patterns

3.1.2 Torus(ary8,dim2)

The second simulation is based on 'torus' topology and 'uniform' traffic pattern to test 3 kinds of different routing algorithms.

Simulation parameters setup

The **basic routing parameters** below are fixed during the whole simulation process:

Packet size : 20 flits

Router delay : 3 cycles

Traffic pattern : uniform

Simulation type : latency

Latency threshold : 20000

The default parameters for **flow control** in 'booksim_conf.cpp' are:

Virtual channel number : 8

Buffer size per channel : 8

Wait for tail credit : 0

* The default **latency threshold** set in 'booksim_conf.cpp' is 500 cycles. It is obvious that lots of average packet latency simulation results greater than 500. To make the simulation more reliable, we must get enough simulation results to reflect the features of a routing algorithm. Therefore, we set the value of latency threshold in the simulation process with 20000 to make the simulation stable and get enough data.

Simulation results

The simulation results(average packet/flit/network delay) are listed in the table 3.2. For each routing algorithm, we test 10 different packet injection rates equally spaced ranging from 0.005 to 0.022.

Dimension Order Routing Algorithm

The simulation results with torus topology under the same traffic pattern and packet injection rates are listed in the table 3.2. It is obvious that the average packet delay for different packet injection rates with DOR routing algorithm all better than the performance in mesh topology. The key reason is that, compared to the mesh topology, the torus topology links the edge nodes in the mesh topology. Previously, the diameter of the topology is $2 * (sqrt(N) - 1)$. In torus topology, the diameter is $sqrt(N)$.

Valiant Randomized Algorithm

The performance of VAL in torus is also better than in mesh topology with the same reason described above. There is an abnormal simulation result in table 3.2 marked in yellow. The original injection rate should be 0.0201 since the injection rates are equally spaced ranging from 0.005 to 0.022. However, with injection rate of 0.0201, it will always cause deadlock and cannot perform the whole simulation process. The same outcome to the injection rate of 0.0202. So the injection rate 0.0203 marked in yellow is an alternative here.

Minimal Adaptive Routing Algorithm

The simulation results with minimal adaptive routing algorithm in torus topology are also better than in mesh topology with the same reason described in 3.1.2.

The performance of the MIN-ADAPT routing algorithm in torus topology is better than VAL, whilst worse than DOR. Although MIN-ADAPT routing algorithm considers the states of the network, it cannot guarantee always chosing the shortest path from source to destination.

Simulation Results and Analysis

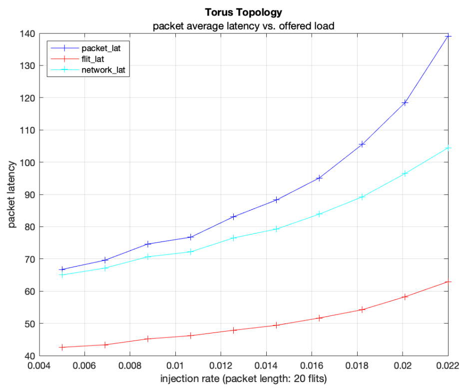
topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
torus(ary8,dim2)	dor	0.005	66.7399	65.0149	42.5716
torus(ary8,dim2)	dor	0.0069	69.5791	67.1535	43.3476
torus(ary8,dim2)	dor	0.0088	74.6169	70.6552	45.1903
torus(ary8,dim2)	dor	0.0107	76.7209	72.1913	46.1854
torus(ary8,dim2)	dor	0.0126	83.0781	76.5032	47.8748
torus(ary8,dim2)	dor	0.0144	88.2678	79.2485	49.4006
torus(ary8,dim2)	dor	0.0162	95.1119	83.882	51.6748
torus(ary8,dim2)	dor	0.0182	105.513	89.2365	54.2422
torus(ary8,dim2)	dor	0.0201	118.494	96.4839	58.2716
torus(ary8,dim2)	dor	0.022	139.122	104.441	62.9165
torus(ary8,dim2)	val	0.005	107.974	106.021	78.5071
torus(ary8,dim2)	val	0.0069	120.072	116.528	84.0434

Continue. . .

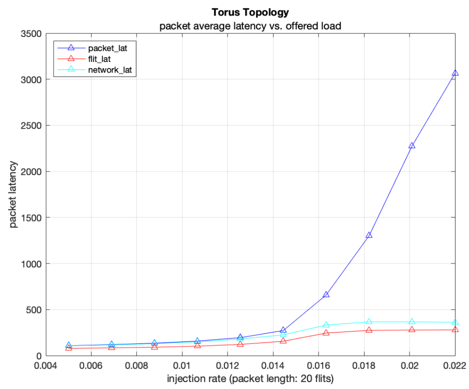
topology	routing _algorithm	injection _rate	average _packet _delay	average _network _latency	average _flit _delay
torus(ary8,dim2)	val	0.0088	135.254	130.466	91.0194
torus(ary8,dim2)	val	0.0107	157.945	149.038	102.686
torus(ary8,dim2)	val	0.0126	195.304	179.965	121.86
torus(ary8,dim2)	val	0.0144	272.25	226.084	155.958
torus(ary8,dim2)	val	0.0162	658.898	332.127	245.099
torus(ary8,dim2)	val	0.0182	1301.86	366.269	274.249
torus(ary8,dim2)	val	0.0203	2276.21	365.761	277.312
torus(ary8,dim2)	val	0.022	3064.75	362.109	279.278
torus(ary8,dim2)	min_adapt	0.005	67.0736	65.2945	43.9873
torus(ary8,dim2)	min_adapt	0.0069	69.3613	67.0838	45.1162
torus(ary8,dim2)	min_adapt	0.0088	75.7793	71.8472	48.9873
torus(ary8,dim2)	min_adapt	0.0107	82.82	76.9492	52.1749
torus(ary8,dim2)	min_adapt	0.0126	91.8262	82.0425	56.353
torus(ary8,dim2)	min_adapt	0.0144	108.177	90.2746	63.1311
torus(ary8,dim2)	min_adapt	0.0162	144.896	100.749	71.3917
torus(ary8,dim2)	min_adapt	0.0182	291.051	120.425	87.2741
torus(ary8,dim2)	min_adapt	0.0201	803.945	135.229	99.242
torus(ary8,dim2)	min_adapt	0.022	1535.8	141.041	103.491

The blue lines in all the figures 3.3, 3.4 depicts the change of the average packet delay against offered load. According to the first sub-figure in the figure 3.4, we can know that the performance of the DOR routing algorithm in such a torus(8-ary, 2-dim) topology with uniform traffic patterns is better than all the other three routing algorithms(VAL, MIN-ADAPT).

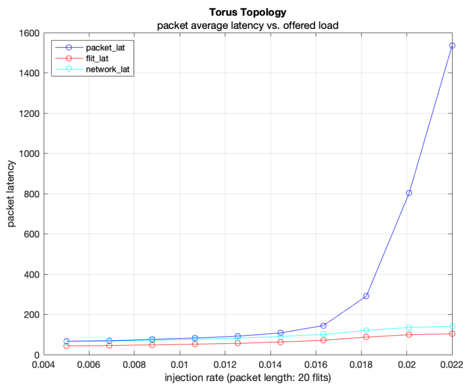
The data in Tab. 3.2 marked in yellow is initially should be 0.0201; however, the simulation results with an injection rate of 0.0201(same results with 0.0202) will always lead to a deadlock. Thus, the injection rates intervals between 0.0182 and 0.022 are not distributed evenly.



(a) dimension order



(b) valiant



(c) minimal adaptive

Figure 3.3: Simulation results of Torus topology with uniform traffic

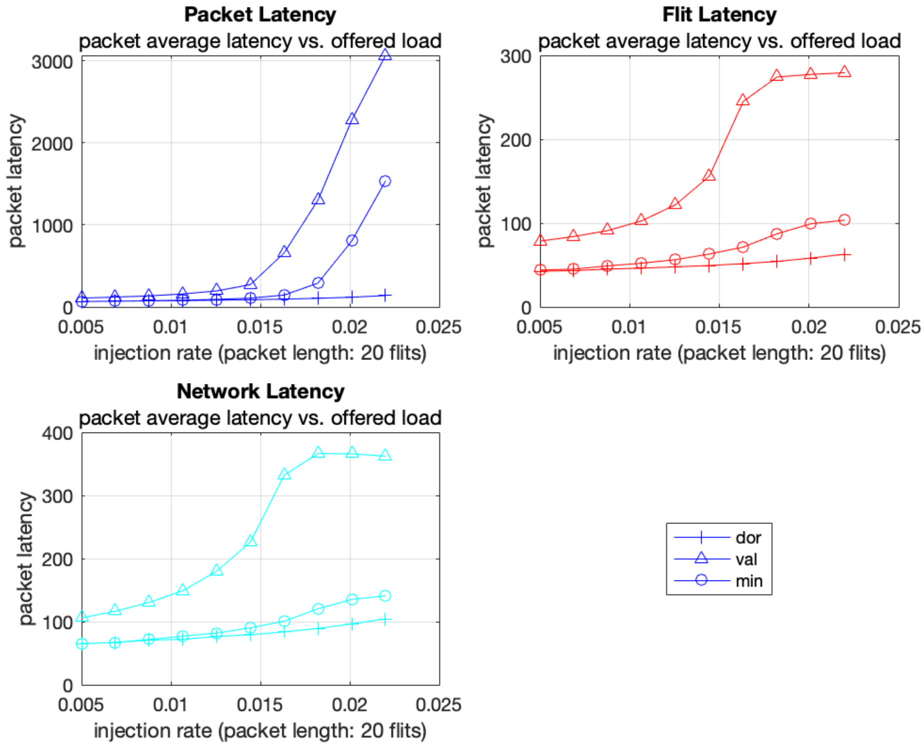
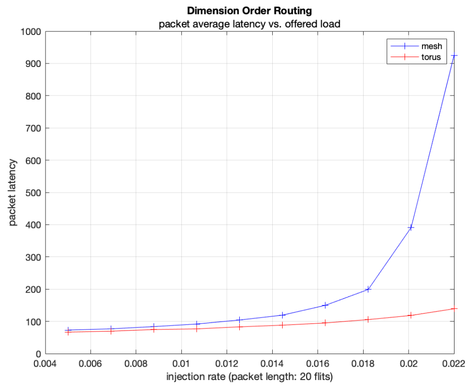
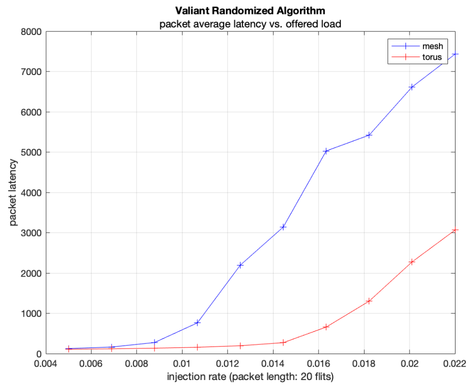


Figure 3.4: Latency comparison of 4 traffic patterns

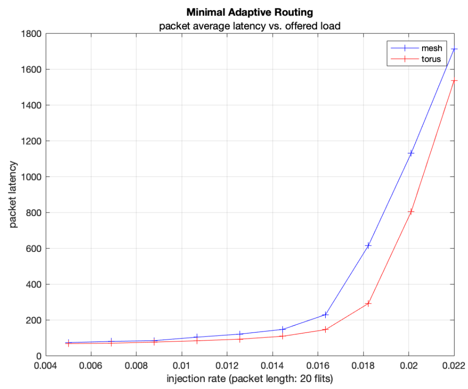
3.1.3 Performance Comparison and Analysis



(a) dimension order



(b) valiant



(c) minimal adaptive

Figure 3.5: Comparison under 'Uniform' traffic pattern

The figure 3.5 compared the mesh and torus with different algorithms(DOR, VAL, MIN-ADAPT) separately. The average packet delay in all the sub-figures of Torus topology(red curve) always below the average packet delay of Mesh topology(blue curve). The difference of the average packet delay of these two topologies is quite small, but with the injection rate increasing, the difference also increases. From the analysis above, we can draw the conclusion that: under the uniform traffic pattern, no matter we use which routing algorithm in the network, the performance of Torus topology always better than Mesh topology. DOR routing algorithm is the suitable for both mesh and torus topologies under uniform traffic pattern.

3.2 Use “Tornado” traffic pattern

Evaluate all the routing algorithms to get plots of average latency vs. offered load. Compare the performance of the two topologies and explain the possible reasons.

3.2.1 Mesh(ary8,dim2)

The first simulation is based on ’mesh’ topology and ’tornado’ traffic pattern to test 4 kinds of different routing algorithms(DOR, VAL, ROMM, MIN-ADAPT).

Simulation parameters setup

The **basic routing parameters** below are fixed during the whole simulation process:
Packet size : 20 flits
Router delay : 3 cycles
Traffic pattern : tornado
Simulation type : latency
Latency threshold : 20000
The default parameters for **flow control** in ’booksim_conf.cpp’ are:
Virtual channel number : 8
Buffer size per channel : 8
Wait for tail credit : 0

* The default **latency threshold** set in ’booksim_conf.cpp’ is 500 cycles. It is obvious that lots of average packet latency simulation results greater than 500. To make the simulation more reliable, we must get enough simulation results to reflect the features of a routing algorithm. Therefore, we set the value of latency threshold in the simulation process with 20000 to make the simulation stable and get enough data.

Simulation results

The simulation results(average packet/flit/network delay) are listed in the table 3.3. For each routing algorithm, we test 10 different packet injection rates equally spaced ranging from 0.005 to 0.022.

Dimension Order Routing Algorithm

The first ten rows in the table 3.3 is the simulation results of dimension order routing algorithm(DOR). The average packet delay is increased non-linearly. The lowest average packet delay is 92, and the corresponding injection rate is 0.005. The highest average packet delay is 4574, and the corresponding injection rate is 0.022. DOR is a basic routing algorithm in such an interconnection network topology.

Valiant Randomized Algorithm

The next ten rows following dimension order algorithm is simulated with Valiant Randomized routing algorithm(VAL). Similar to the simulation results of DOR, the increment of the average packet delay is non-linear. The value of the average packet delay exceeds 500 with the injection rate of 0.0107. It is obvious that under 'mesh' topology and 'tornado' traffic pattern, the performance of DOR algorithm is much better than the VAL. Compared with DOR, VAL will firstly select an intermediate node randomly. Packets will go through this node and then be transmitted to the destination. The detour in the VAL causes the performance of VAL worse than DOR.

The Randomized Minimal Algorithm

The randomized minimal algorithm(ROMM) is a minimal version of Valiant's algorithm. So the performance of the ROMM is better than VAL. However, its performance still is not better than DOR. The lowest value of average packet delay is 96, and the highest value of average packet value is 8106. For the injection rates lower than 0,0126, the corresponding average packet delays all below 500.

Minimal Adaptive Routing Algorithm

This routing algorithm is a different class compared to the three routing algorithm above. All the three algorithms(DOR, VAL, ROMM) above are deterministic, which means that routes choosing for packets without considering any information about the network present state. Deterministic algorithms are a subset of oblivious algorithms. All the packets from the same source and destination pairs will always choose the same path. In adaptive algorithms, the state of the network is incorporated in making routing decision to adapt to network state such as network congestion. the decision of the routes depending on the states(node, link, length of queues, historical channel load information) of the network.

The last ten rows in the table 3.3 is the simulation results of the minimal adaptive routing algorithm(MIN-ADAPT). The performance of the MIN-ADAPT routing algorithm is better than ROMM and VAL, whilst worse than DOR. Although MIN-ADAPT routing algorithm considers the states of the network, it cannot guarantee always chosing the shortest path from source to destination.

Simulation Results and Analysis

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
mesh(ary8,dim2)	dor	0.005	92.5512	90.9669	65.8955
mesh(ary8,dim2)	dor	0.0069	98.7774	96.2007	68.3627
mesh(ary8,dim2)	dor	0.0088	117.208	113.057	77.0379
mesh(ary8,dim2)	dor	0.0107	139.696	131.427	87.5752
mesh(ary8,dim2)	dor	0.0126	219.069	195.073	129.456

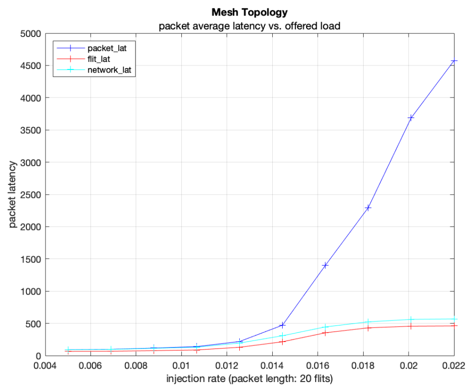
Continue. . .

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
mesh(ary8,dim2)	dor	0.0144	471.793	308.206	214.884
mesh(ary8,dim2)	dor	0.0162	1399.5	445.489	353.935
mesh(ary8,dim2)	dor	0.0182	2294.67	523.546	431.162
mesh(ary8,dim2)	dor	0.0201	3685.97	562.134	456.579
mesh(ary8,dim2)	dor	0.022	4574.78	569.106	461.14
mesh(ary8,dim2)	val	0.005	126.226	124.342	93.5684
mesh(ary8,dim2)	val	0.0069	156.676	153.348	108.156
mesh(ary8,dim2)	val	0.0088	285.179	270.562	180.599
mesh(ary8,dim2)	val	0.0107	747.549	575.838	442.555
mesh(ary8,dim2)	val	0.0126	2053.08	725.558	640.968
mesh(ary8,dim2)	val	0.0144	3814.45	830.045	686.359
mesh(ary8,dim2)	val	0.0162	6192.3	856.751	701.208
mesh(ary8,dim2)	val	0.0182	8041.86	892.967	692.578
mesh(ary8,dim2)	val	0.0201	7796	870.164	729.27
mesh(ary8,dim2)	val	0.022	8569.72	856.703	714.446
mesh(ary8,dim2)	romm	0.005	96.4438	94.857	67.6557
mesh(ary8,dim2)	romm	0.0069	112.702	109.95	74.673
mesh(ary8,dim2)	romm	0.0088	168.245	159.831	103.616
mesh(ary8,dim2)	romm	0.0107	440.438	272.12	215.058
mesh(ary8,dim2)	romm	0.0126	1325.87	443.626	349.825
mesh(ary8,dim2)	romm	0.0144	3148.01	522.839	407.701
mesh(ary8,dim2)	romm	0.0162	4539.88	551.965	447.395
mesh(ary8,dim2)	romm	0.0182	5478.99	546.734	446.799

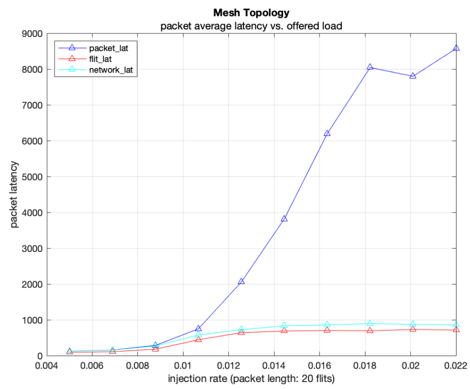
Continue. . .

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
mesh(ary8,dim2)	romm	0.0201	7106.34	552.425	459.937
mesh(ary8,dim2)	romm	0.022	8106.32	579.571	460.133
mesh(ary8,dim2)	min_adapt	0.005	92.4276	91.0017	69.6105
mesh(ary8,dim2)	min_adapt	0.0069	101.992	99.497	74.1709
mesh(ary8,dim2)	min_adapt	0.0088	124.28	118.963	88.0493
mesh(ary8,dim2)	min_adapt	0.0107	157.429	148.367	107.914
mesh(ary8,dim2)	min_adapt	0.0126	278.497	234.037	175.002
mesh(ary8,dim2)	min_adapt	0.0144	775.582	349.928	301.309
mesh(ary8,dim2)	min_adapt	0.0162	1888.02	477.1	375.548
mesh(ary8,dim2)	min_adapt	0.0182	3220.62	536.745	430.401
mesh(ary8,dim2)	min_adapt	0.0201	4601.75	606.393	457.444
mesh(ary8,dim2)	min_adapt	0.022	6315.09	602.46	428.54

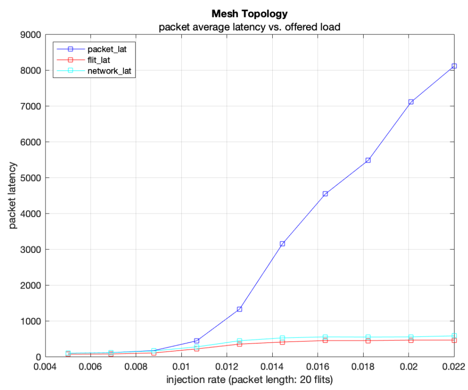
The blue lines in all the figures 3.6, 3.7 depicts the change of the average packet delay against offered load. According to the first sub-figure in the figure 3.7, we can know that the performance of the DOR routing algorithm in such a mesh(8-ary, 2-dim) topology with uniform traffic pattern better than all the other three routing algorithms(VAL, ROMM, MIN-ADAPT).



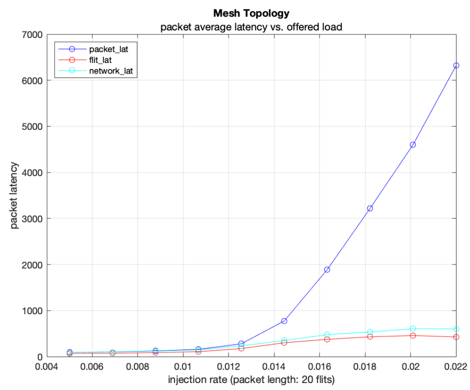
(a) dimension order



(b) valiant



(c) romm



(d) minimal adaptive

Figure 3.6: Simulation results of Mesh topology with uniform traffic

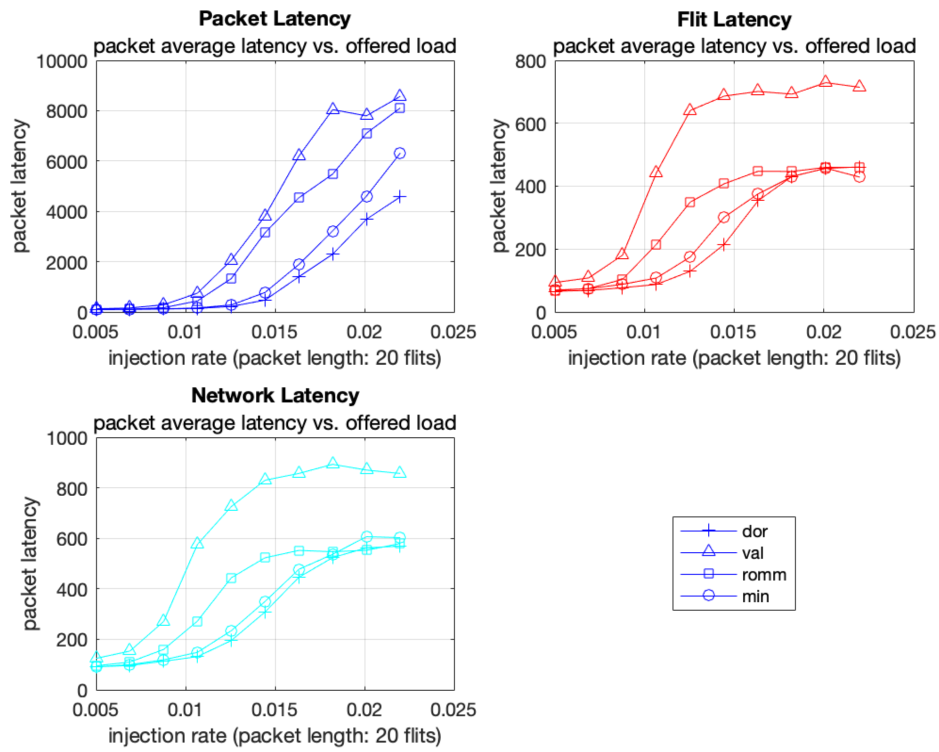


Figure 3.7: Latency comparison of 4 traffic patterns

3.2.2 Torus(ary8,dim2)

The simulation based on 'mesh' topology and 'uniform' traffic pattern for testing 3 kinds of different routing algorithms(DOR, VAL, MIN-ADAPT).

Simulation parameters setup

The **basic routing parameters** below are fixed during the whole simulation process:

Packet size : 20 flits

Router delay : 3 cycles

Traffic pattern : tornado

Simulation type : latency

Latency threshold : 20000

The default parameters for **flow control** in 'booksim_conf.cpp' are:

Virtual channel number : 8

Buffer size per channel : 8

Wait for tail credit : 0

* The default **latency threshold** set in 'booksim_conf.cpp' is 500 cycles. It is obvious that lots of average packet latency simulation results greater than 500. To make the simulation more reliable, we must get enough simulation results to reflect the features of a routing algorithm. Therefore, we set the value of latency threshold in the simulation process with 20000 to make the simulation stable and get enough data.

Simulation results

The simulation results(average packet/flit/network delay) are listed in the table 4.2. For each routing algorithm, we test 10 different packet injection rates equally spaced ranging from 0.005 to 0.022.

Dimension Order Routing Algorithm

The first ten rows in the table 4.2 is the simulation results of dimension order routing algorithm(DOR). The average packet delay is increased non-linearly. The lowest average packet delay is 92, and the corresponding injection rate is 0.005. The highest average packet delay is 5043, and the corresponding injection rate is 0.022. DOR is a basic routing algorithm in such an interconnection network topology.

Valiant Randomized Algorithm

The next ten rows following dimension order algorithm is simulated with Valiant Randomized routing algorithm(VAL). Similar to the simulation results of DOR, the increment of the average packet delay is non-linear. The value of the average packet delay exceeds 500 with the injection rate of 0.0162. It is obvious that under 'torus' topology and 'tornado' traffic pattern, the performance of VAL algorithm is better than the DOR. Overall, the VAL routing algorithm is suitable for tornado traffic pattern in torus topology.

Minimal Adaptive Routing Algorithm

This routing algorithm is a different class compared to the three routing algorithm above. All the three algorithms(DOR, VAL, ROMM) above are deterministic, which means that routes choosing for packets without considering any information about the network present state. Deterministic algorithms are a subset of oblivious algorithms. All the packets from the same source and destination pairs will always choose the same path. In adaptive algorithms, the state of the network is incorporated in making routing decision to adapt to network state such as network congestion. the decision of the routes depending on the states(node, link, length of queues, historical channel load information) of the network.

The last ten rows in the table 4.2 is the simulation results of the minimal adaptive routing algorithm(MIN-ADAPT). The performance of the MIN-ADAPT routing algorithm is worse than VAL and DOR. Although MIN-ADAPT routing algorithm considers the states of the network, it cannot guarantee always chosing the shortest path from source to destination. It is absolutely unsuitable under the tornado traffic pattern and torus topology. Compared with DOR and VAL, the MIN-ADAPT routing algorithm cannot support the packet injection rate greater than 0.0088(even the latency threshold is set to 20000).

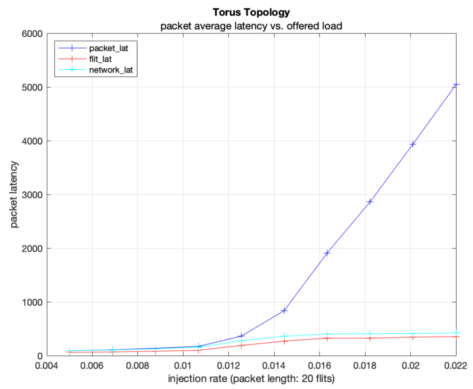
Simulation Results and Analysis

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
torus(ary8,dim2)	dor	0.005	92.1058	90.276	61.9455
torus(ary8,dim2)	dor	0.0069	108.389	104.833	68.7191
torus(ary8,dim2)	dor	0.0088	137.161	128.17	81.5888
torus(ary8,dim2)	dor	0.0107	172.671	157.295	99.4385
torus(ary8,dim2)	dor	0.0126	362.042	277.472	189.382
torus(ary8,dim2)	dor	0.0144	838.898	361.144	270.791
torus(ary8,dim2)	dor	0.0162	1912.07	403.002	324.703
torus(ary8,dim2)	dor	0.0182	2862.45	408.578	324.832
torus(ary8,dim2)	dor	0.0201	3938.27	411.311	344.349
torus(ary8,dim2)	dor	0.022	5043.89	422.361	352.914
torus(ary8,dim2)	val	0.005	106.959	104.855	78.292
torus(ary8,dim2)	val	0.0069	115.671	112.929	81.4504
torus(ary8,dim2)	val	0.0088	132	127.453	88.8903
torus(ary8,dim2)	val	0.0107	152.575	143.34	98.1318
torus(ary8,dim2)	val	0.0126	197.001	177.248	120.275
torus(ary8,dim2)	val	0.0144	289.791	236.069	159.346
torus(ary8,dim2)	val	0.0162	519.209	305.833	220.084
torus(ary8,dim2)	val	0.0182	1223.42	347.443	259.418
torus(ary8,dim2)	val	0.0201	1981.35	361.04	268.811
torus(ary8,dim2)	val	0.022	2905.55	371.079	275.155
torus(ary8,dim2)	min_adapt	0.005	100.019	97.5045	74.2563
torus(ary8,dim2)	min_adapt	0.0069	315.48	163.529	128.807
torus(ary8,dim2)	min_adapt	0.0088	5571.58	408.495	229.849

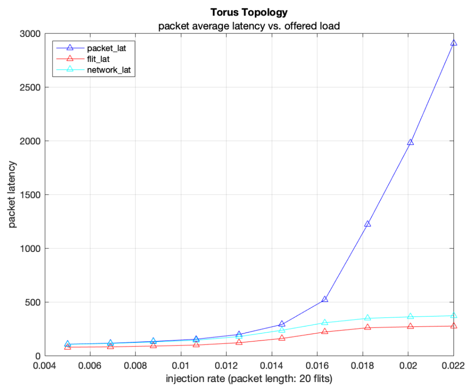
Continue...

topology	**routing _algorithm**	**injection _rate**	**average _packet _delay**	**average _network _latency**	**average _flit _delay**
torus(ary8,dim2)	min_adapt	0.0107			
torus(ary8,dim2)	min_adapt	0.0126			
torus(ary8,dim2)	min_adapt	0.0144			
torus(ary8,dim2)	min_adapt	0.0162			
torus(ary8,dim2)	min_adapt	0.0182			
torus(ary8,dim2)	min_adapt	0.0201			
torus(ary8,dim2)	min_adapt	0.022			

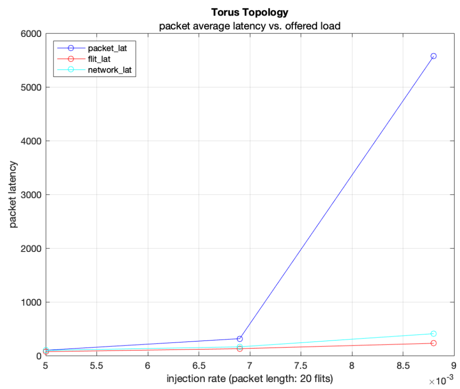
The blue lines in all the figures 3.8, 3.9 depicts the change of the average packet delay against offered load. According to the first sub-figure in the figure 3.9, we can know that the performance of the VAL routing algorithm in such a torus(8-ary, 2-dim) topology with uniform traffic pattern better than all the other three routing algorithms(DOR, MIN-ADAPT).



(a) dimension order



(b) valiant



(c) minimal adaptive

Figure 3.8: Simulation results of Torus topology with uniform traffic

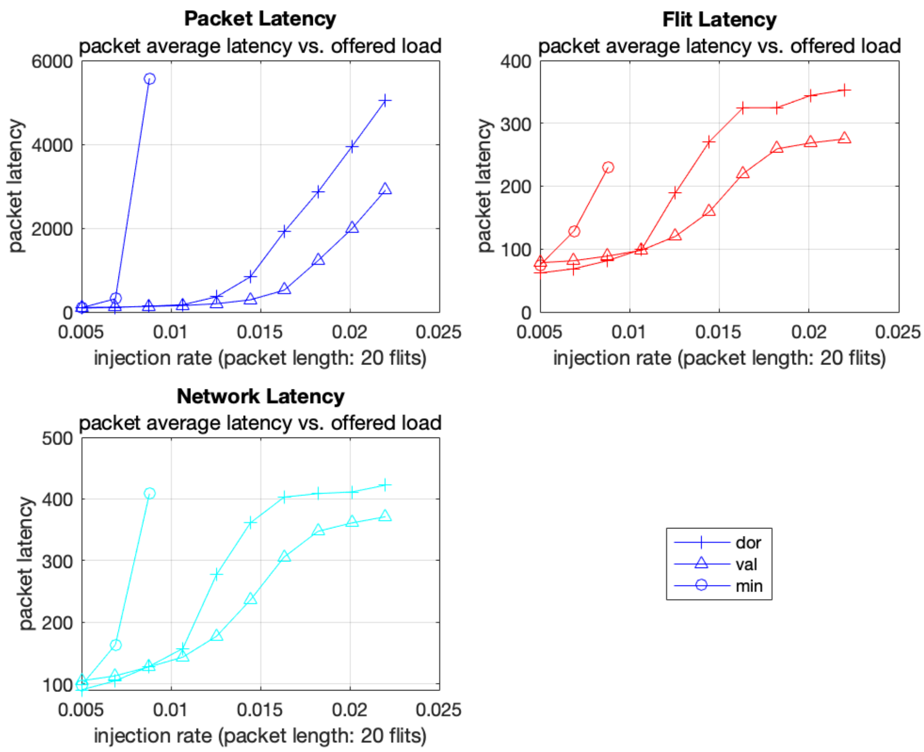
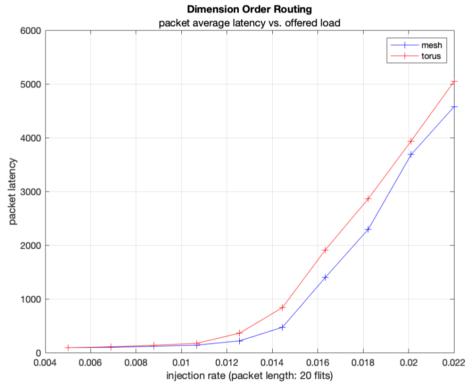


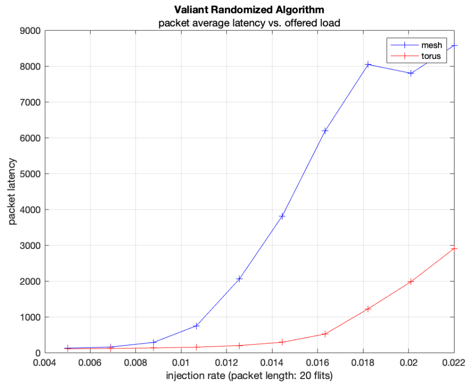
Figure 3.9: Latency comparison of 4 traffic patterns

3.2.3 Performance Comparison and Analysis

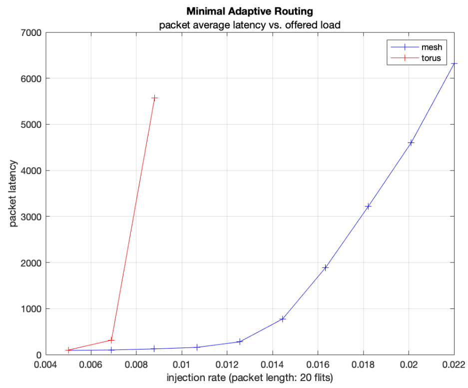
The figure 3.10 compared the mesh and torus with different algorithms(DOR, VAL, MIN-ADAPT) separately. The DOR and MIN-ADAPT routing algorithms can support tornado traffic patterns in a mesh topology, and the corresponding performance of mesh topology is better than torus topology. However, the VAL routing algorithm performs better in torus topology under tornado traffic patterns. Overall, the VAL is suitable for Torus topology under tornado traffic patter. DOR is the suitable routing algorithm for mesh topology under tornado traffic patterns.



(a) dimension order



(b) valiant



(c) minimal adaptive

Figure 3.10: Comparison under 'Tornado' traffic pattern

3.3 Flow Control Comparison

This additional experiment is executed under 'Mesh(ary8, dim2)' topology and 'uniform' traffic pattern.

3.3.1 8 Virtual Channels, 8 buffer size per channel

For the experiment results of this configuration, please refer to section 3.1.1.

3.3.2 4 Virtual Channels, 20 buffer size per channel

topology	routing _algorithm	injection _rate	packet _size	flow _control	average _packet _delay
mesh(ary8,dim2)	dor	0.005	20	4_20	70.976
mesh(ary8,dim2)	dor	0.0069	20	4_20	76.8099
mesh(ary8,dim2)	dor	0.0088	20	4_20	80.3712
mesh(ary8,dim2)	dor	0.0107	20	4_20	87.1603
mesh(ary8,dim2)	dor	0.0126	20	4_20	97.3517
mesh(ary8,dim2)	dor	0.0144	20	4_20	109.592
mesh(ary8,dim2)	dor	0.0162	20	4_20	127.506
mesh(ary8,dim2)	dor	0.0182	20	4_20	165.402
mesh(ary8,dim2)	dor	0.0201	20	4_20	304.805
mesh(ary8,dim2)	dor	0.022	20	4_20	1006.15
mesh(ary8,dim2)	val	0.005	20	4_20	127.754
mesh(ary8,dim2)	val	0.0069	20	4_20	155.127
mesh(ary8,dim2)	val	0.0088	20	4_20	249.517
mesh(ary8,dim2)	val	0.0107	20	4_20	1642.6
mesh(ary8,dim2)	val	0.0126	20	4_20	4275.11
mesh(ary8,dim2)	val	0.0144	20	4_20	
mesh(ary8,dim2)	val	0.0162	20	4_20	
mesh(ary8,dim2)	val	0.0182	20	4_20	
mesh(ary8,dim2)	val	0.0201	20	4_20	
mesh(ary8,dim2)	val	0.022	20	4_20	
mesh(ary8,dim2)	romm	0.005	20	4_20	72.4624
mesh(ary8,dim2)	romm	0.0069	20	4_20	79.232
mesh(ary8,dim2)	romm	0.0088	20	4_20	83.2038

Continue...

topology	**routing _algorithm**	**injection _rate**	**packet _size**	**flow _control**	**average _packet _delay**
mesh(ary8,dim2)	romm	0.0107	20	4_20	95.5831
mesh(ary8,dim2)	romm	0.0126	20	4_20	112.182
mesh(ary8,dim2)	romm	0.0144	20	4_20	154.486
mesh(ary8,dim2)	romm	0.0162	20	4_20	994.973
mesh(ary8,dim2)	romm	0.0182	20	4_20	3016.01
mesh(ary8,dim2)	romm	0.0201	20	4_20	6296.15
mesh(ary8,dim2)	romm	0.022	20	4_20	
mesh(ary8,dim2)	min_adapt	0.005	20	4_20	71.158
mesh(ary8,dim2)	min_adapt	0.0069	20	4_20	78.0626
mesh(ary8,dim2)	min_adapt	0.0088	20	4_20	83.0506
mesh(ary8,dim2)	min_adapt	0.0107	20	4_20	93.1438
mesh(ary8,dim2)	min_adapt	0.0126	20	4_20	111.268
mesh(ary8,dim2)	min_adapt	0.0144	20	4_20	132.44
mesh(ary8,dim2)	min_adapt	0.0162	20	4_20	194.157
mesh(ary8,dim2)	min_adapt	0.0182	20	4_20	281.173
mesh(ary8,dim2)	min_adapt	0.0201	20	4_20	641.147
mesh(ary8,dim2)	min_adapt	0.022	20	4_20	1467.9

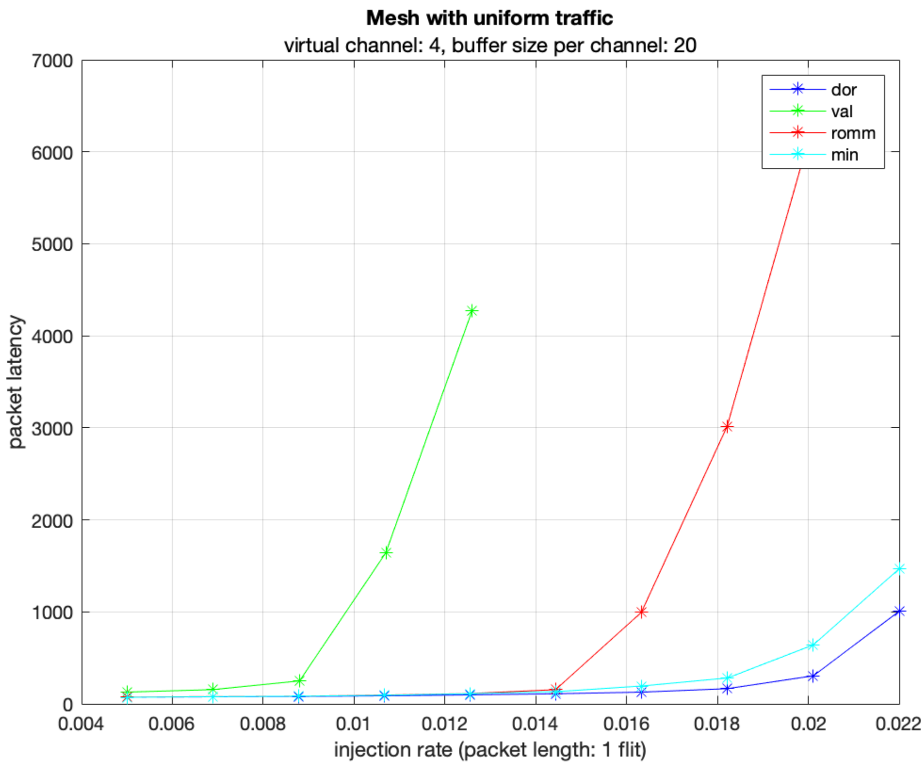


Figure 3.11: Mesh topology with uniform traffic patter

In Fig. 3.12, each curve represents a kind of routing algorithm under the same topology and traffic pattern; the performance of this configuration indicates that DOR is still the best routing algorithm for mesh topology, which is the same as we concluded in section 3.1.1.

3.3.3 8 Virtual Channels, 20 buffer size per channel

topology	**routing _algorithm**	**injection _rate**	**packet _size**	**flow _control**	**average _packet _delay**
mesh(ary8,dim2)	dor	0.005	20	8_20	71.1348
mesh(ary8,dim2)	dor	0.0069	20	8_20	76.9622
mesh(ary8,dim2)	dor	0.0088	20	8_20	80.4911

Continue. . .

topology	**routing _algorithm**	**injection _rate**	**packet _size**	**flow _control**	**average _packet _delay**
mesh(ary8,dim2)	dor	0.0107	20	8_20	87.7844
mesh(ary8,dim2)	dor	0.0126	20	8_20	98.2077
mesh(ary8,dim2)	dor	0.0144	20	8_20	112.963
mesh(ary8,dim2)	dor	0.0162	20	8_20	135.599
mesh(ary8,dim2)	dor	0.0182	20	8_20	169.159
mesh(ary8,dim2)	dor	0.0201	20	8_20	247.456
mesh(ary8,dim2)	dor	0.022	20	8_20	542.698
mesh(ary8,dim2)	val	0.005	20	8_20	128.261
mesh(ary8,dim2)	val	0.0069	20	8_20	155.178
mesh(ary8,dim2)	val	0.0088	20	8_20	238.409
mesh(ary8,dim2)	val	0.0107	20	8_20	738.991
mesh(ary8,dim2)	val	0.0126	20	8_20	3624.72
mesh(ary8,dim2)	val	0.0144	20	8_20	4687.82
mesh(ary8,dim2)	val	0.0162	20	8_20	
mesh(ary8,dim2)	val	0.0182	20	8_20	
mesh(ary8,dim2)	val	0.0201	20	8_20	
mesh(ary8,dim2)	val	0.022	20	8_20	
mesh(ary8,dim2)	romm	0.005	20	8_20	72.8313
mesh(ary8,dim2)	romm	0.0069	20	8_20	80.3477
mesh(ary8,dim2)	romm	0.0088	20	8_20	84.3721
mesh(ary8,dim2)	romm	0.0107	20	8_20	95.5874
mesh(ary8,dim2)	romm	0.0126	20	8_20	112.338
mesh(ary8,dim2)	romm	0.0144	20	8_20	135.455

Continue. . .

topology	**routing _algorithm**	**injection _rate**	**packet _size**	**flow _control**	**average _packet _delay**
mesh(ary8,dim2)	romm	0.0162	20	8_20	203.494
mesh(ary8,dim2)	romm	0.0182	20	8_20	874.43
mesh(ary8,dim2)	romm	0.0201	20	8_20	
mesh(ary8,dim2)	romm	0.022	20	8_20	
mesh(ary8,dim2)	min_adapt	0.005	20	8_20	71.5045
mesh(ary8,dim2)	min_adapt	0.0069	20	8_20	78.1588
mesh(ary8,dim2)	min_adapt	0.0088	20	8_20	82.9398
mesh(ary8,dim2)	min_adapt	0.0107	20	8_20	92.3613
mesh(ary8,dim2)	min_adapt	0.0126	20	8_20	106.342
mesh(ary8,dim2)	min_adapt	0.0144	20	8_20	138.05
mesh(ary8,dim2)	min_adapt	0.0162	20	8_20	188.865
mesh(ary8,dim2)	min_adapt	0.0182	20	8_20	270.352
mesh(ary8,dim2)	min_adapt	0.0201	20	8_20	391.475
mesh(ary8,dim2)	min_adapt	0.022	20	8_20	766.477

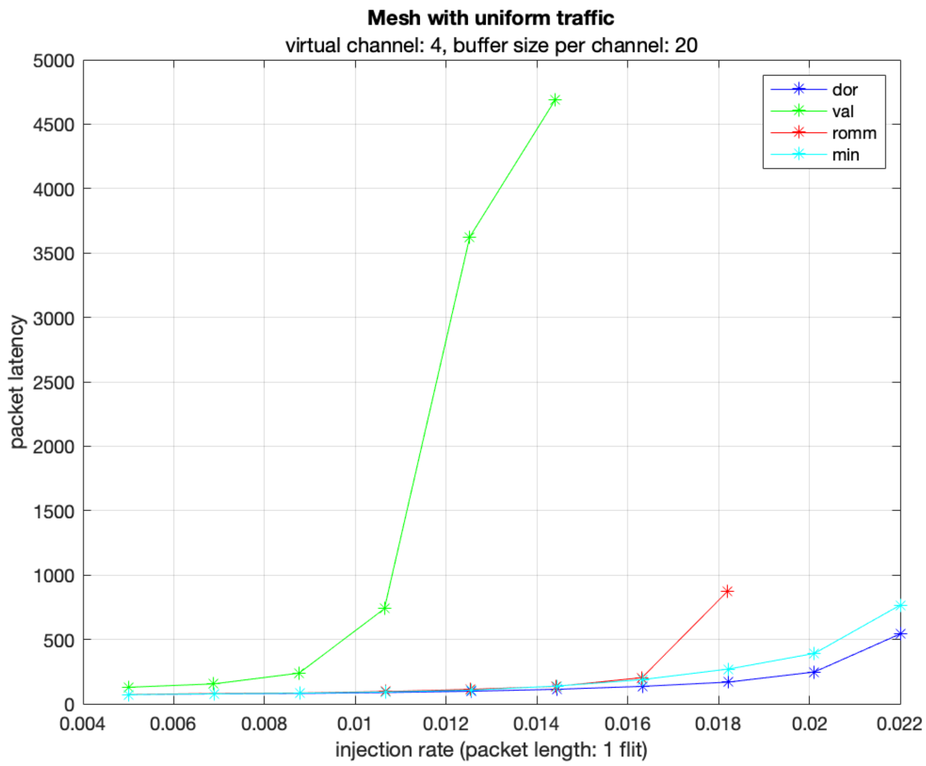


Figure 3.12: Mesh topology with uniform traffic patter

In Fig. 3.12, each curve represent a kind of routing algorithm under the same topology and traffic pattern, the performance of this configuration indicates that DOR is still the best routing algorithm for mesh topology which is the same as we concluded in section 3.1.1.

Comprehensive Comparison

According to Fig. 3.11 and Fig. 3.12, we can find that for the same topology(mesh) and the same traffic pattern(uniform), the performance with more virtual channels will have lower latency. However, the latency does not always decrease with the increment of the virtual channel number.

Chapter 4

Assignment 2

Implement your own network topologies and evaluate the performance

The detailed description of this assignment can be found here: Lab Note for Data Center Networking or go to the next url: `https://seis.bristol.ac.uk/~sy13201/DCN/Lab%20Note.html`

4.1 Use booksim to evaluate the performance of a network topology designed in the guidance

4.1.1 Define performance metric for the evaluation

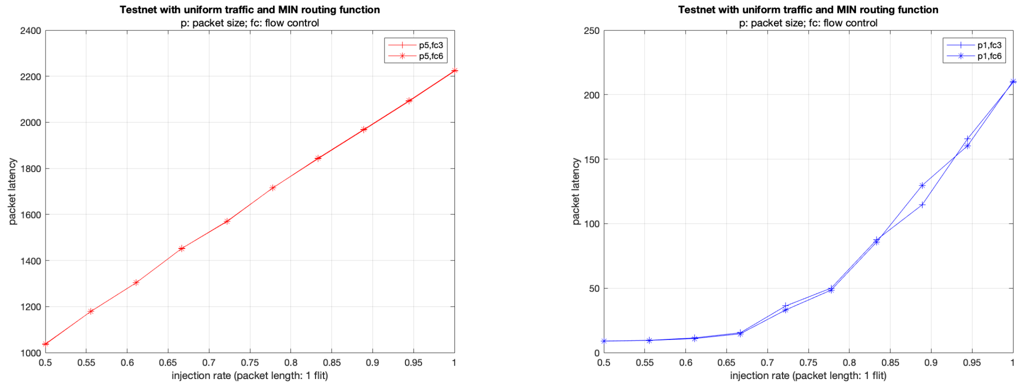
We will test the **latency** with different combinations of the parameters in the configuration file. (e.g., packet size, virtual channel)

4.1.2 Results and discussion for the evaluation

topology	injection _rate	Traffic	packet _size	flow _control	average _packet _delay
testnet(r4,e3)	0.55	uniform	1	default	9.00424
testnet(r4,e3)	0.6	uniform	1	default	9.55989
testnet(r4,e3)	0.65	uniform	1	default	11.4555
testnet(r4,e3)	0.7	uniform	1	default	15.3622
testnet(r4,e3)	0.75	uniform	1	default	36.1957
testnet(r4,e3)	0.8	uniform	1	default	50.0457
testnet(r4,e3)	0.85	uniform	1	default	87.4587
testnet(r4,e3)	0.9	uniform	1	default	114.525
testnet(r4,e3)	0.95	uniform	1	default	165.763
testnet(r4,e3)	1	uniform	1	default	209.438
testnet(r4,e3)	0.55	uniform	5	default	1035.9
testnet(r4,e3)	0.6	uniform	5	default	1178.85
testnet(r4,e3)	0.65	uniform	5	default	1303.66
testnet(r4,e3)	0.7	uniform	5	default	1452.35
testnet(r4,e3)	0.75	uniform	5	default	1569.47
testnet(r4,e3)	0.8	uniform	5	default	1714.97
testnet(r4,e3)	0.85	uniform	5	default	1842.04
testnet(r4,e3)	0.9	uniform	5	default	1966.17
testnet(r4,e3)	0.95	uniform	5	default	2091.34
testnet(r4,e3)	1	uniform	5	default	2221.98
testnet(r4,e3)	0.55	uniform	1	6	8.89958
testnet(r4,e3)	0.6	uniform	1	6	9.46639
testnet(r4,e3)	0.65	uniform	1	6	10.9079

Continue...

topology	injection _rate	Traffic	packet _size	flow _control	average _packet _delay
testnet(r4,e3)	0.7	uniform	1	6	14.5966
testnet(r4,e3)	0.75	uniform	1	6	33.1129
testnet(r4,e3)	0.8	uniform	1	6	48.5042
testnet(r4,e3)	0.85	uniform	1	6	85.7041
testnet(r4,e3)	0.9	uniform	1	6	129.583
testnet(r4,e3)	0.95	uniform	1	6	160.373
testnet(r4,e3)	1	uniform	1	6	210.397
testnet(r4,e3)	0.55	uniform	1	6	1037.71
testnet(r4,e3)	0.6	uniform	1	6	1178.58
testnet(r4,e3)	0.65	uniform	1	6	1303.54
testnet(r4,e3)	0.7	uniform	1	6	1452.23
testnet(r4,e3)	0.75	uniform	1	6	1571.02
testnet(r4,e3)	0.8	uniform	1	6	1714.49
testnet(r4,e3)	0.85	uniform	1	6	1844.23
testnet(r4,e3)	0.9	uniform	1	6	1968.37
testnet(r4,e3)	0.95	uniform	1	6	2093.63
testnet(r4,e3)	1	uniform	1	6	2224.28



(a) p1 (b) p5

Figure 4.1: Simulation results testnet

From Fig. 4.1, we can find that the latency is always increasing with the increments of the injection rates. Under packet size of 1, the performances with virtual channels of 3 and 6 are almost the same. Under packet size of 5, the performances with virtual channels of 3 and 6 are slightly different.

4.2 Build your own network

4.2.1 Build the network

Build a network with the name as DesignNet. It includes 8 routers and 32 nodes. Between routers, the links drawn in the figures are bidirectional links. Here we assume a fully connected network is setup between all routers. Some links between routers are omitted for simplicity. Create the network and evaluate the performance.

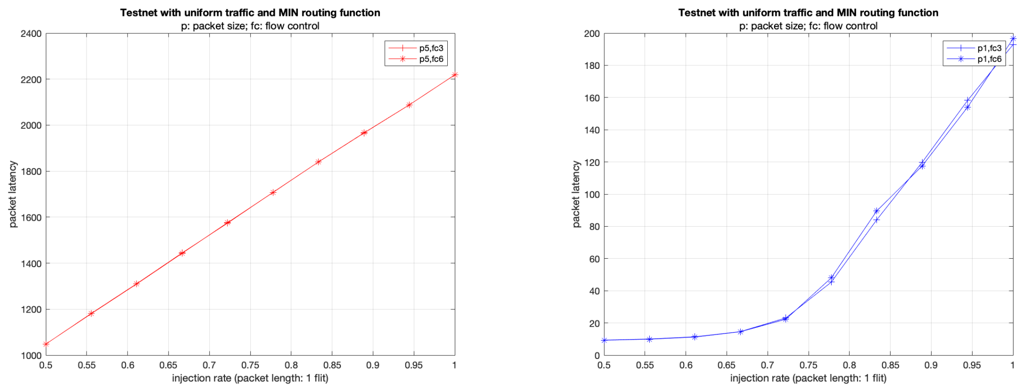
topology	**injection _rate**	**Traffic**	**packet _size**	**flow _control**	**average _packet _delay**
testnet(r4,e3)	0.55	uniform	1	default	9.34287
testnet(r4,e3)	0.6	uniform	1	default	10.0335

Continue...

topology	injection _rate	Traffic	packet _size	flow _control	average _packet _delay
testnet(r4,e3)	0.65	uniform	1	default	11.4095
testnet(r4,e3)	0.7	uniform	1	default	14.6115
testnet(r4,e3)	0.75	uniform	1	default	23.1209
testnet(r4,e3)	0.8	uniform	1	default	45.322
testnet(r4,e3)	0.85	uniform	1	default	84.0369
testnet(r4,e3)	0.9	uniform	1	default	119.761
testnet(r4,e3)	0.95	uniform	1	default	158.2
testnet(r4,e3)	1	uniform	1	default	192.858
testnet(r4,e3)	0.55	uniform	5	default	1048.03
testnet(r4,e3)	0.6	uniform	5	default	1181.38
testnet(r4,e3)	0.65	uniform	5	default	1310.65
testnet(r4,e3)	0.7	uniform	5	default	1444.5
testnet(r4,e3)	0.75	uniform	5	default	1574.2
testnet(r4,e3)	0.8	uniform	5	default	1707.99
testnet(r4,e3)	0.85	uniform	5	default	1839.84
testnet(r4,e3)	0.9	uniform	5	default	1965.54
testnet(r4,e3)	0.95	uniform	5	default	2088.24
testnet(r4,e3)	1	uniform	5	default	2218.58
testnet(r4,e3)	0.55	uniform	1	6	9.27776
testnet(r4,e3)	0.6	uniform	1	6	9.91647
testnet(r4,e3)	0.65	uniform	1	6	11.266
testnet(r4,e3)	0.7	uniform	1	6	14.5709
testnet(r4,e3)	0.75	uniform	1	6	22.3257

Continue...

topology	injection _rate	Traffic	packet _size	flow _control	average _packet _delay
testnet(r4,e3)	0.8	uniform	1	6	48.0027
testnet(r4,e3)	0.85	uniform	1	6	89.5332
testnet(r4,e3)	0.9	uniform	1	6	117.538
testnet(r4,e3)	0.95	uniform	1	6	154.02
testnet(r4,e3)	1	uniform	1	6	196.502
testnet(r4,e3)	0.55	uniform	1	6	1048.27
testnet(r4,e3)	0.6	uniform	1	6	1180.26
testnet(r4,e3)	0.65	uniform	1	6	1309.58
testnet(r4,e3)	0.7	uniform	1	6	1442.91
testnet(r4,e3)	0.75	uniform	1	6	1576.07
testnet(r4,e3)	0.8	uniform	1	6	1707.35
testnet(r4,e3)	0.85	uniform	1	6	1840.15
testnet(r4,e3)	0.9	uniform	1	6	1966.2
testnet(r4,e3)	0.95	uniform	1	6	2088.38
testnet(r4,e3)	1	uniform	1	6	2218.73



(a) p1 (b) p5

Figure 4.2: Simulation results testnet

From Fig. 4.2, we can find that the latency is always increasing with the increments of the injection rates. Under packet size of 1, the performances with virtual channels of 3 and 6 are almost the same. Under packet size of 5, the performances with virtual channels of 3 and 6 are slightly different.

4.2.2 Evaluation

Evaluate the performance based on the metrics defined in 4.1.1.

From all the simulation results above, it is impossible to determine which routing algorithm is the best and under what kind of flow control we can get the best performance. Since the performance of a network system not only depends on the topology itself, the traffic patterns, packet size, injection rates, and flow control will all impact the performance of such a network system.

Appendix A

Simulation Package

The attached booksim.zip file contains all the source code of the simulaiton platform and some Python scripts for efficiency. The place of the newly added files mostly in path booksim/src/project. The Python scripts for modifying and executing simulations are under the path booksim/src, they are named Datacenter_00x.py (x is in range from 1 to 4). The simulation results will be stored in the path booksim/src/project/results. Before running the script, please read the codes and create corresponding folder under the path booksim/src/project/results.

For the data extraction part, under the simulation results folder(e.g., booksim/src/project/results/testnet_dir_p1), there will be a python script named data_collection.py. Running this file, you will get a newly created file under this path, all the data we needed for reports is extracted and stored in this file(e.g., Testnetconfig_res).