

# Simulation analysis of Flow-Aware Multi-Topology Adaptive Routing

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The purpose of this report is to evaluate the FAMTAR mechanism by showing the benefits it provides over the classical networks with standard routing protocols. This is relevant for the patent application in which we will show how the proposed invention expands the state-of-the-art solutions.

## SIMULATION ENVIRONMENT AND RESULTS

Simulator: NS-2

Simulation topology:

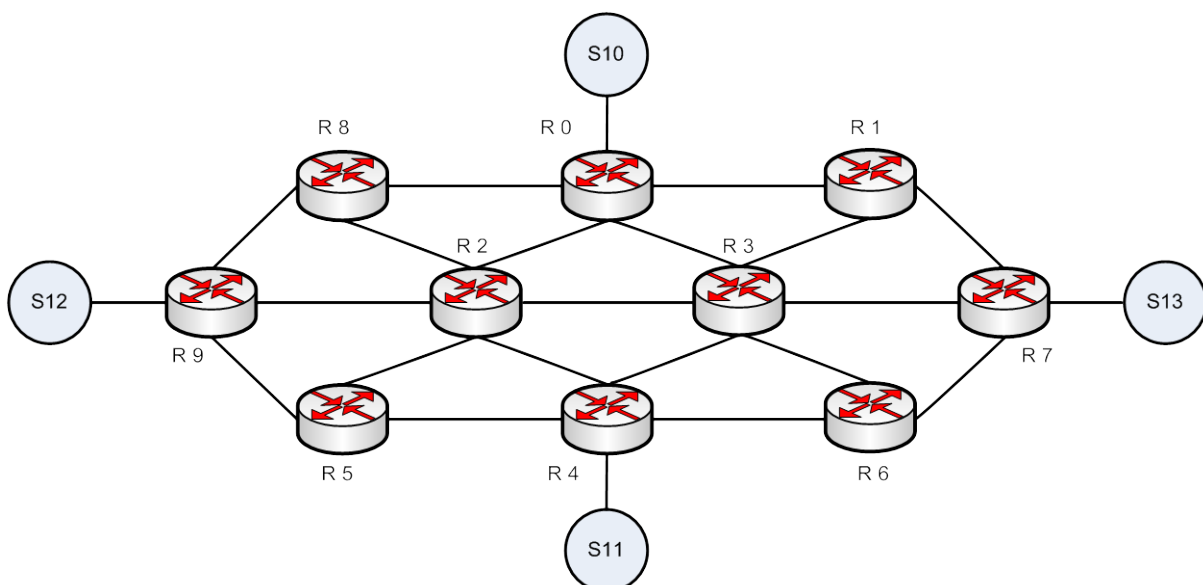


Figure 1: Simulation topology

The simulation topology is presented in Figure 1. There are 4 source/destination nodes (S10-S13) which transmit data to randomly chosen nodes. There are 10 core nodes.

We have performed several simulation experiments grouped into two scenarios. In both of them, we compare the efficiency of FAMTAR and regular network with standard routing protocols. We used FIFO queues sized to 1000 packets and the OSPF routing protocol. The simulations were repeated 5 times for each configuration. The repetition was performed in order to obtain statistically credible results.

The simulation parameters of scenario 1 are presented below.

### **Scenario 1**

- Number of flows: 15 000
- Mean flow size: 2 000 000 B
- Max. flow size: 200 000 000 B
- Flows start during the whole simulation with the intensity: 60 flows/sec.
  
- Simulation time: 250 sec.
- Warm-up time: 30 sec. (packets sent after 230th second are disregarded)
  
- In FAMTAR, the thresholds were set to 60% and 80% of the link capacity respectively.

The aim of this scenario was to analyze how much more data can be sent in a network in a given time. Source nodes produce much more traffic that can be sent.

The results of this set of experiments are presented in Table 1. This scenario shows that FAMTAR can dramatically increase the amount of data that are sent in a network. In this setup, we were able to obtain almost twice the gain in received data and received packets.

The simulation parameters of scenario 2 are presented below.

### **Scenario 2**

- Number of flows: 5 000
- Mean flow size: 4 000 000 B
- Max. flow size: 200 000 000 B
- All the flows start within the first 20 seconds of the simulation.
  
- Simulation time: 2000 sec.
- No warm-up time.
  
- In FAMTAR, the thresholds were set to 60% and 80% of the link capacity respectively.

The aim of this scenario was to analyze how quickly can a network transmit a certain amount of data. In this setup, one source produces a large amount of data and tries to send it as quickly as possible. We measure the amount of time it takes to complete all the transmissions.

The results of this set of experiments are presented in Table 2. The results show that the mean transmission time is reduced twice. This means that the same amount of data was sent through the network in half the time. Again, the results depend heavily on the network

topology. In networks in which there are many alternative paths, the gain will be even greater.

### **Conclusions**

The simulation results confirm that the analyzed mechanism allows for efficient transmission in a network. It has two strong advantages: we are able to transmit more traffic than in the standard network, and with lower delays. Moreover, looking from another perspective, we were able to transmit the same amount of traffic but quicker. In our analysis we used links with relatively low capacity due to the simulator constraints. However, the proposed solution is scalable and may be implemented in large networks with high speed links.

### **Acknowledgment**

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Table 1. Simulation results. Scenario 1.

	IP	FAMTAR	IP	FAMTAR	IP	FAMTAR	IP	FAMTAR	IP	FAMTAR
<b>Seed</b>	1	1	2	2	3	3	4	4	5	5
<b>Generated data [GB]</b>	26.576	26.576	26.489	26.489	26.715	26.715	26.252	26.252	26.912	26.912
General										
<b>Packets sent</b>	25550077	42846095	25606340	41947723	24688046	42988610	25956343	43084435	25399041	43734142
<b>Packets received</b>	23343446	40549120	23379625	39554341	22647178	40716127	23637753	40761639	23199774	41205304
<b>Packets lost</b>	2206656	2300588	2231035	2393820	2045047	2272663	2318590	2323143	2199862	2529403
<b>Received to sent ratio</b>	0.91	0.95	0.91	0.94	0.92	0.95	0.91	0.95	0.91	0.94
<b>Data sent [GB]</b>	13.279	22.002	13.315	21.534	12.833	22.059	13.504	22.108	13.217	22.506
<b>Data received [GB]</b>	12.318	21.200	12.341	20.718	11.900	21.295	12.495	21.305	12.225	21.641
<b>Data lost [GB]</b>	0.961	0.802	0.974	0.816	0.933	0.764	1.009	0.803	0.992	0.865
<b>Received to sent ratio</b>	0.93	0.96	0.93	0.96	0.93	0.97	0.93	0.96	0.92	0.96
Packet statistics										
<b>Mean delay [ms]</b>	26.5	24.9	31.4	24.4	31.9	22.6	26.1	23.7	28.0	24.4
<b>Mean hop count</b>	7.07	7.65	7.06	7.68	7.06	7.70	7.06	7.67	7.06	7.73
<b>Min. delay [ms]</b>	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
<b>Min. hop count</b>	7	7	7	7	7	7	7	7	7	7
<b>Max delay [ms]</b>	30053.9	30072.1	30085.8	30095.3	30085.3	30084.6	88.8	30084.5	30083.5	30099.7
<b>Max hop count</b>	8	28	8	24	8	17	8	31	8	29
Flow statistics										
<b>Min. mean delay [ms]</b>	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
<b>Max. mean delay [ms]</b>	155.0	30005.4	30026.3	2339.5	30023.9	30013.1	60.0	7549.8	1095.0	6032.9
<b>Min. mean hop count</b>	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
<b>Max. mean hop count</b>	8.00	10.00	8.00	10.17	8.00	10.32	8.00	10.53	8.00	10.52
<b>Mean delay [ms]</b>	26	38	50	29	39	26	27	29	28	29
<b>Mean hop count [-]</b>	7.09	7.67	7.09	7.71	7.10	7.72	7.09	7.68	7.10	7.76
<b>Mean transmission time [s]</b>	61.75	76.65	64.14	72.39	61.29	77.17	64.71	76.12	66.68	83.97
Other										
<b>Link const changes</b>	0	856	0	912	0	912	0	860	0	942

Table 2. Simulation results. Scenario 2.

	IP	FAMTAR	IP	FAMTAR	IP	FAMTAR	IP	FAMTAR	IP	FAMTAR
<b>Seed</b>	1	1	2	2	3	3	4	4	5	5
<b>Generated data [GB]</b>	17491.53	17491.53	17813.10	17813.10	18150.21	18150.21	17878.44	17878.44	18884.52	18884.52
General										
<b>Packets sent</b>	39065896	37898950	39822414	38599137	40460271	39265676	39961628	38715680	42059058	40839109
<b>Packets received</b>	36007018	37155768	36636010	37750431	37422405	38524770	36812060	37949206	38901138	39996329
<b>Packets lost</b>	3058878	743182	3186404	848706	3037866	740906	3149568	766474	3157920	842780
<b>Received to sent ratio</b>	0.92	0.98	0.92	0.98	0.92	0.98	0.92	0.98	0.92	0.98
<b>Data sent [GB]</b>	20769	19747	21176	20120	21503	20450	21255	20171	22335	21272
<b>Data received [GB]</b>	19346	19494	19714	19828	20046	20194	19777	19903	20858	20974
<b>Data lost [GB]</b>	1422	253	1462	292	1457	256	1477	267	1476	297
<b>Received to sent ratio</b>	0.93	0.99	0.93	0.99	0.93	0.99	0.93	0.99	0.93	0.99
Packet statistics										
<b>Mean delay [ms]</b>	25.3	16.6	25.3	16.7	25.3	15.5	25.2	17.0	24.5	15.7
<b>Mean hop count</b>	7.13	7.69	7.12	7.65	7.12	7.60	7.12	7.69	7.12	7.60
<b>Min. delay [ms]</b>	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
<b>Min. hop count</b>	7	7	7	7	7	7	7	7	7	7
<b>Max delay [ms]</b>	89.2	102.0	88.8	107.4	89.2	102.7	89.2	108.2	89.2	108.4
<b>Max hop count</b>	8	13	8	31	8	15	8	24	8	24
Flow statistics										
<b>Min. mean delay [ms]</b>	6.1	6.5	6.2	6.2	6.1	6.2	6.5	6.3	6.5	6.4
<b>Max. mean delay [ms]</b>	46.4	39.9	46.0	40.3	47.0	39.2	46.5	42.4	46.7	40.2
<b>Min. mean hop count</b>	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
<b>Max. mean hop count</b>	8.00	9.98	8.00	10.05	8.00	9.92	8.00	10.11	8.00	9.96
<b>Mean delay [ms]</b>	30	19	30	20	30	18	30	20	30	19
<b>Mean hop count [-]</b>	7.13	7.69	7.13	7.68	7.13	7.62	7.13	7.71	7.13	7.63
<b>Mean transmission time [s]</b>	162.05	75.01	157.47	75.99	166.77	75.18	164.38	76.32	163.55	77.17
Other										
<b>Link const changes</b>	490	402	541	433	578	330	511	330	583	452