Master Mini Project

Performance Evaluation of Minimum Delivery Delay Multipath TCP Scheduler Implemented in Linux Kernel

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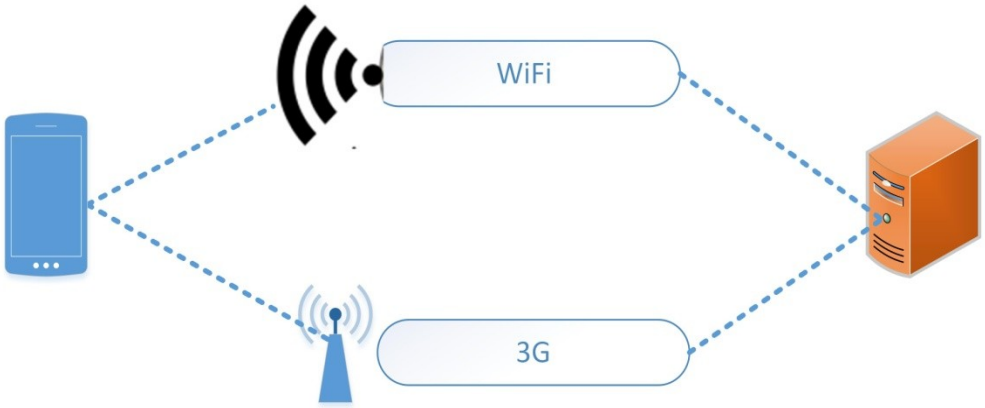
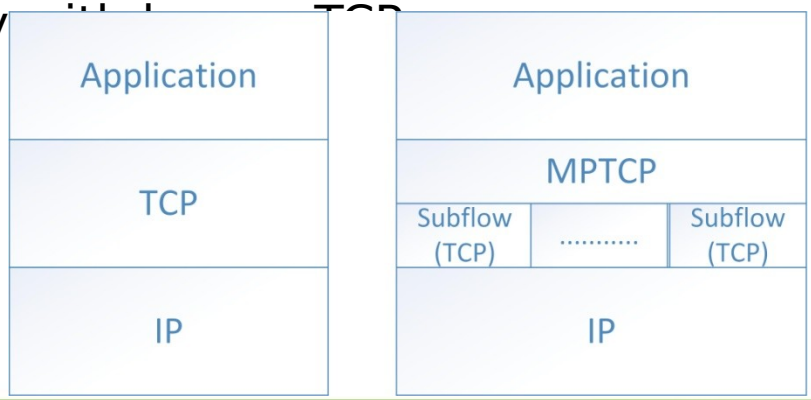
Outline

- Multipath TCP (MPTCP)
- MPTCP Scheduler
  - Existing MPTCP Schedulers on Linux
    - Round Robin Scheduler
    - Shortest Round Trip Time Scheduler
- Implementation of Delivery Delay Scheduler
- Performance Evaluation
- Conclusion & Outlook

Multipath TCP (MPTCP)

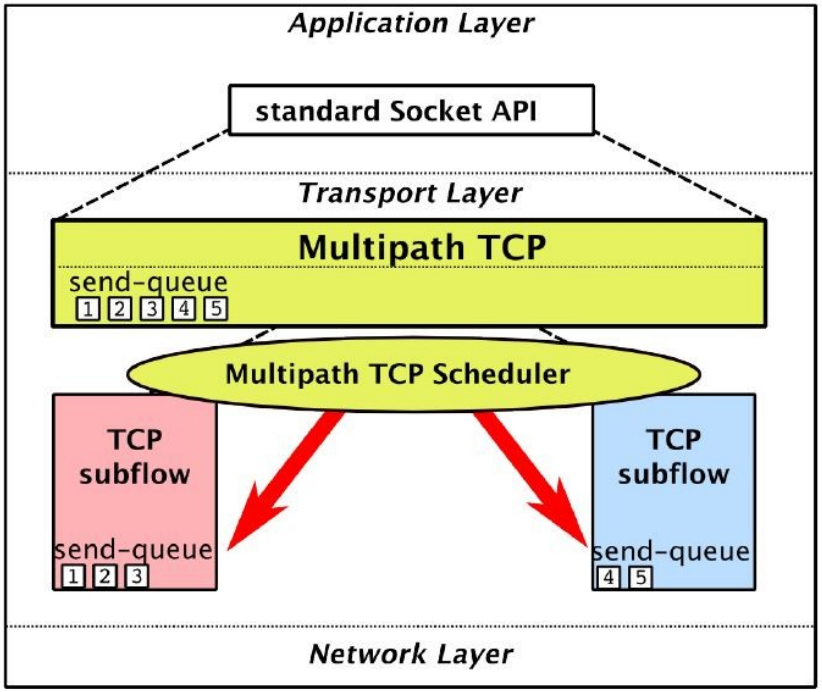
- With the emergence of multihoming capable devices, data transfer through multiple paths for a session become a viable option
- IETF has developed the tra to facilitate multipath data
- MPTCP offers– [1]
  - Increased throughput
  - Robustness against link fai
  - Balance congestion
  - Compatibility





MPTCP Scheduler

- Heterogeneous nature of delay and bandwidth asymmetry of the path can create out-of-order data arrival at the receiver [2]
  - Head-of-Line Blocking
  - Receiver-Window Limitations
- Results higher reordering delay and might give lower throughput



[2]

Round Robin (RR) Scheduler

- Schedule data packets in round robin or cyclic fashion
- Maximum number of consecutive scheduled segments for an instance is configurable
  - Fill up the congestion window of a subflow or
  - Strictly Round Robin
- Disadvantages –
  - May not be able to utilize the whole path capacity when paths have significant delay or capacity differences as the scheduler always tries to distribute equally among all available subflows [5]

Shortest Round Trip Time (sRTT) Scheduler

- Schedule data packets on a subflow with the lowest RTT amongst all available subflows
- Considers delay (RTT) of the paths, which also reflects network condition to some extent
- Disadvantages –
  - High delay assymetry in backward path might affect the scheduling which might influence out-of-order delivery

Delivery Delay (DD) based Scheduler

- Schedule data packet on a subflow with the lowest Delivery Delay (DD) amongst all available subflows
- DD scheduler was first proposed in [8] with the title `` Performance Comparison of Scheduling Algorithms for Multipath Transfer''
  - Was implemented in a Simulator and shown that the End-to-End (ENE) delay is reduced

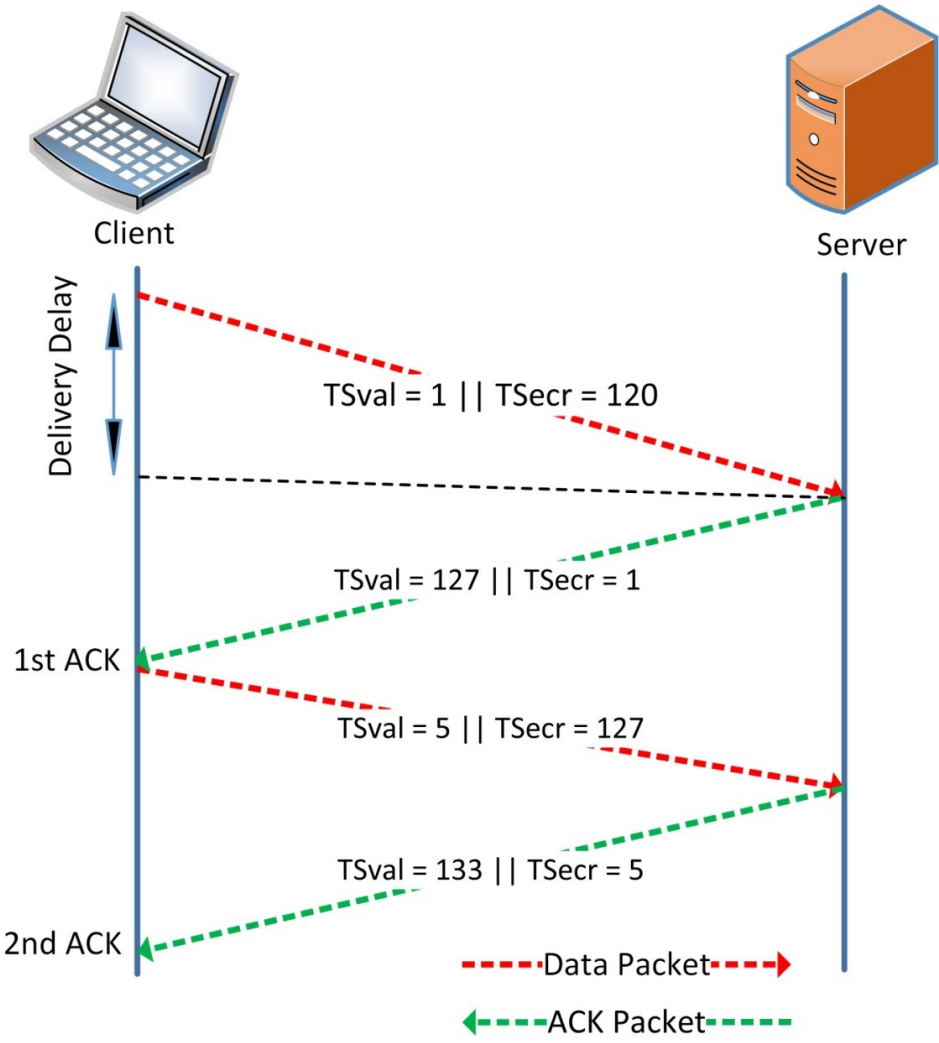
- Focus point –
  - Understand the implemented schedulers (sRTT and RR) in Linux Kernel along with their behaviour
  - Implement the Delivery Delay (DD) based scheduler in Linux Kernel
  - Performance analysis of DD scheduler along with the other two implemented schedulers for different network scenarios

Estimation of Delivery Delay

TCP Timestamps [9]			
Kind = 8	Length	TSval	TSecr
1 Byte	1 Byte	4 Bytes	4 Bytes

- TSval is the current value of the timestamp's clock
- TSecr is the TSval value contained in the received data/ack packet

- Delivery Delay – **1st ACK** = TSval – TSecr = 127 – 1 = 126
- Delivery Delay – **2st ACK** = TSval – TSecr = 133 – 5 = 128



Scheduling Algorithm – For each packet

```
min_delivery_delay = MAX_INT

for each subflow i do
    if (current packet is a retransmission) and (has been transmitted on
  the subflow i) then          continue
    end if
    if (subflow i is definitely unavailable) or (subflow i is temporary
  unavailable) then            continue
    end if
    if (delivery_delay _i < min_delivery_delay) then
        min_delivery_delay = delivery_delay_i
        selected_subflow = i
  end if
end for
```

Performance Evaluation

Test Topology - 2 Node

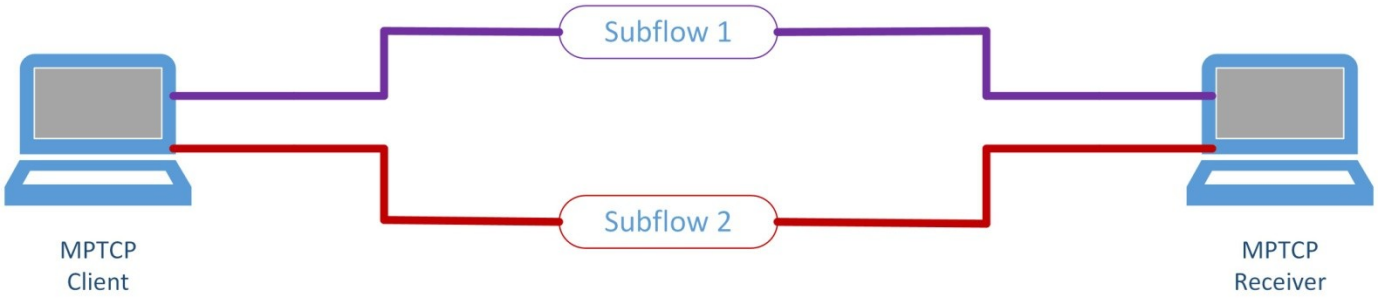


Figure : Two Node Testbed

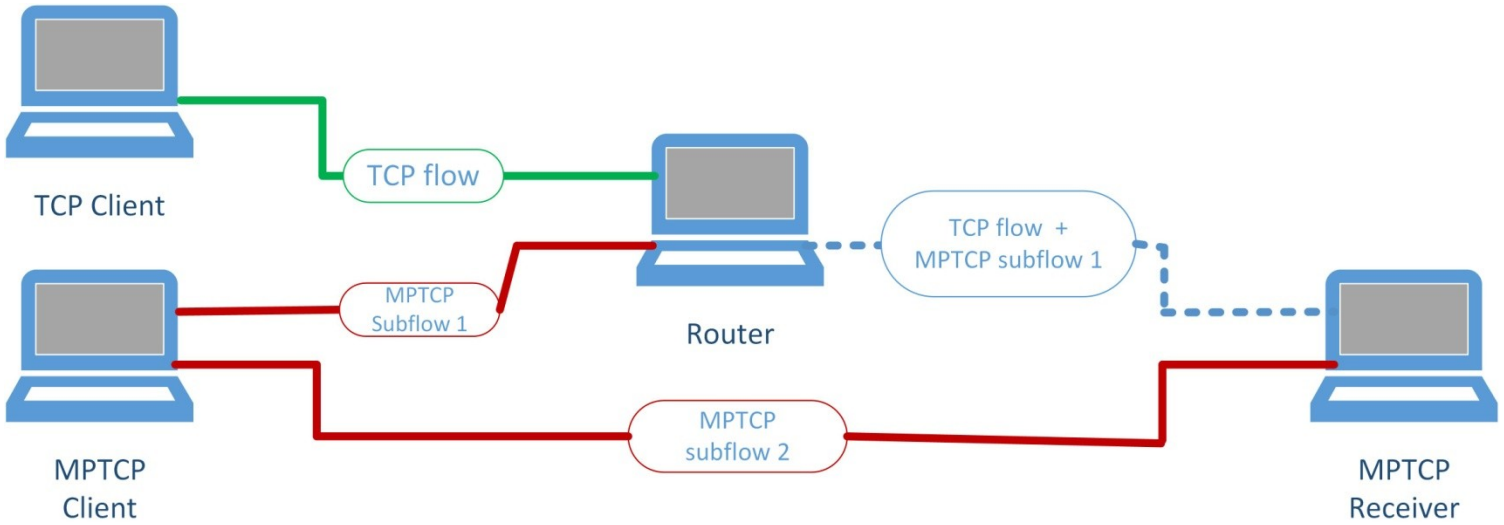


Figure : Extended Testbed

Test Topology – Two Node Testbed with Router

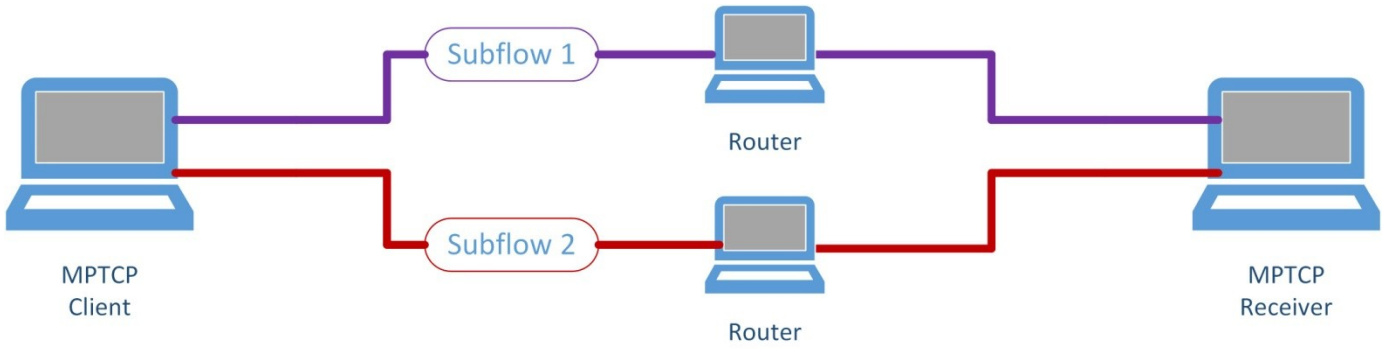
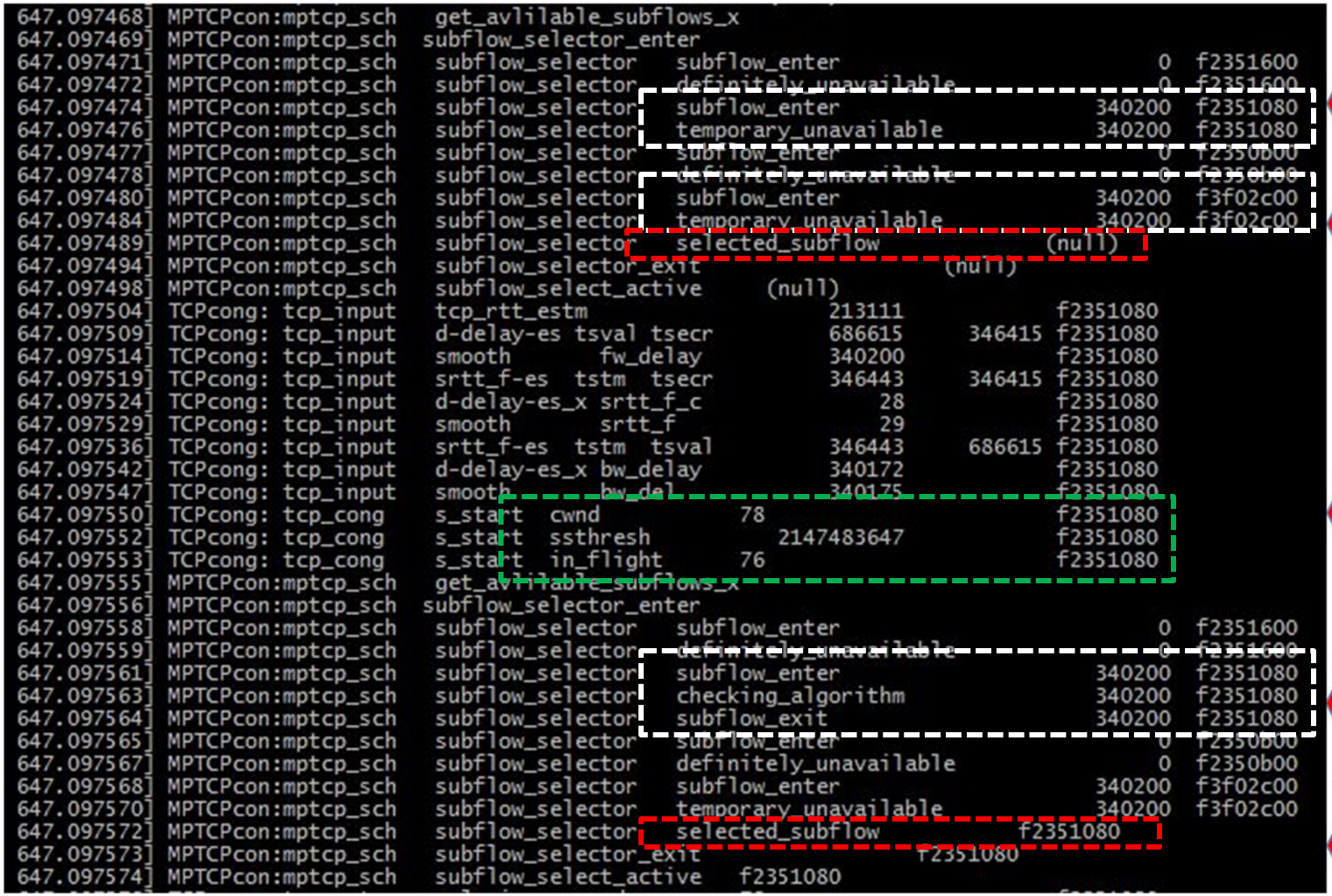


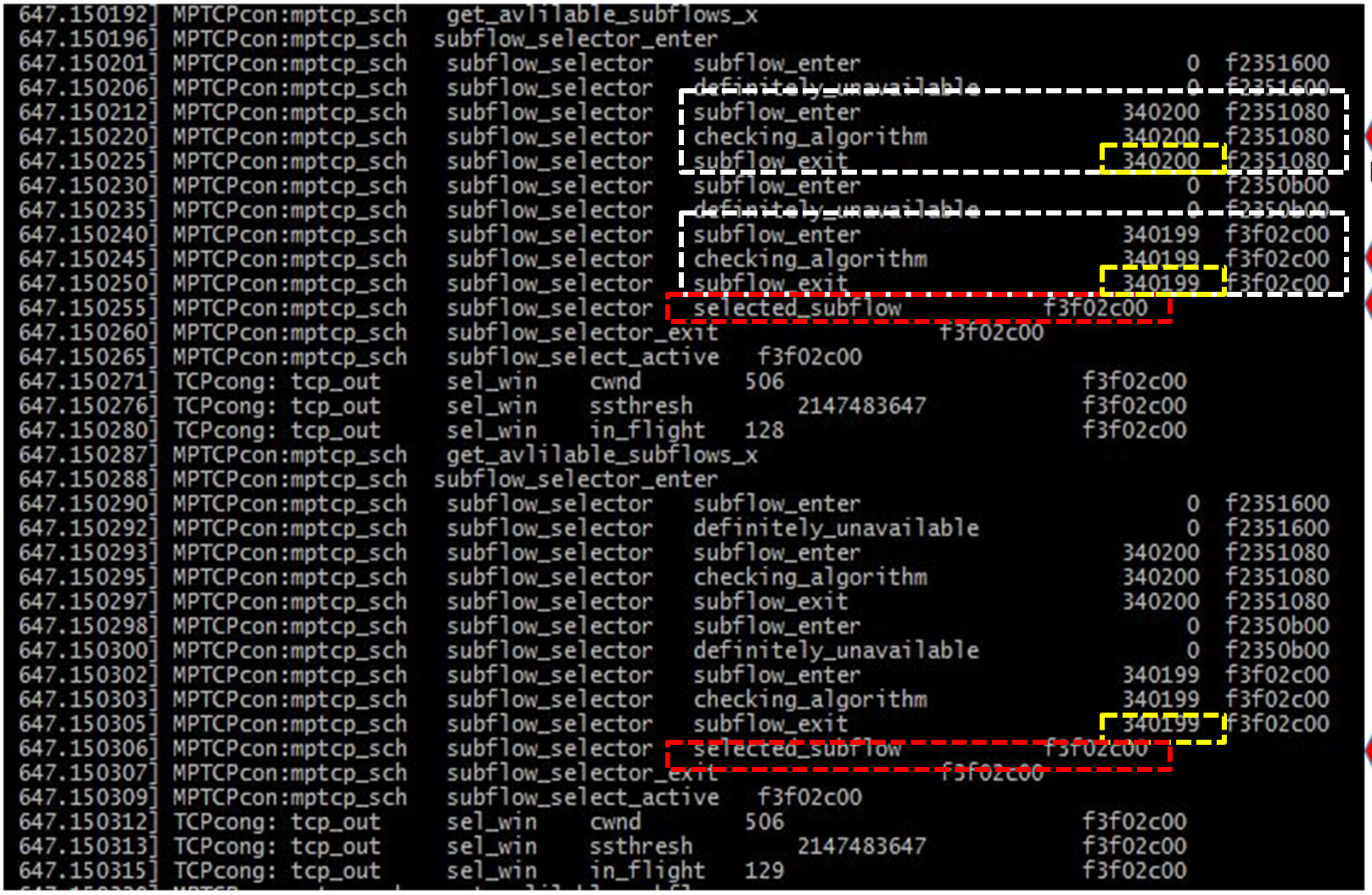
Figure : Two Node Testbed with Router

- Configuration :
  - Congestion Control = Reno
  - tc qdisc "add" dev "ethX" root netem delay “Yms“ – at router

Validation of Delivery Delay Scheduler - I



Validation of Delivery Delay Scheduler - II



Both subflows are available

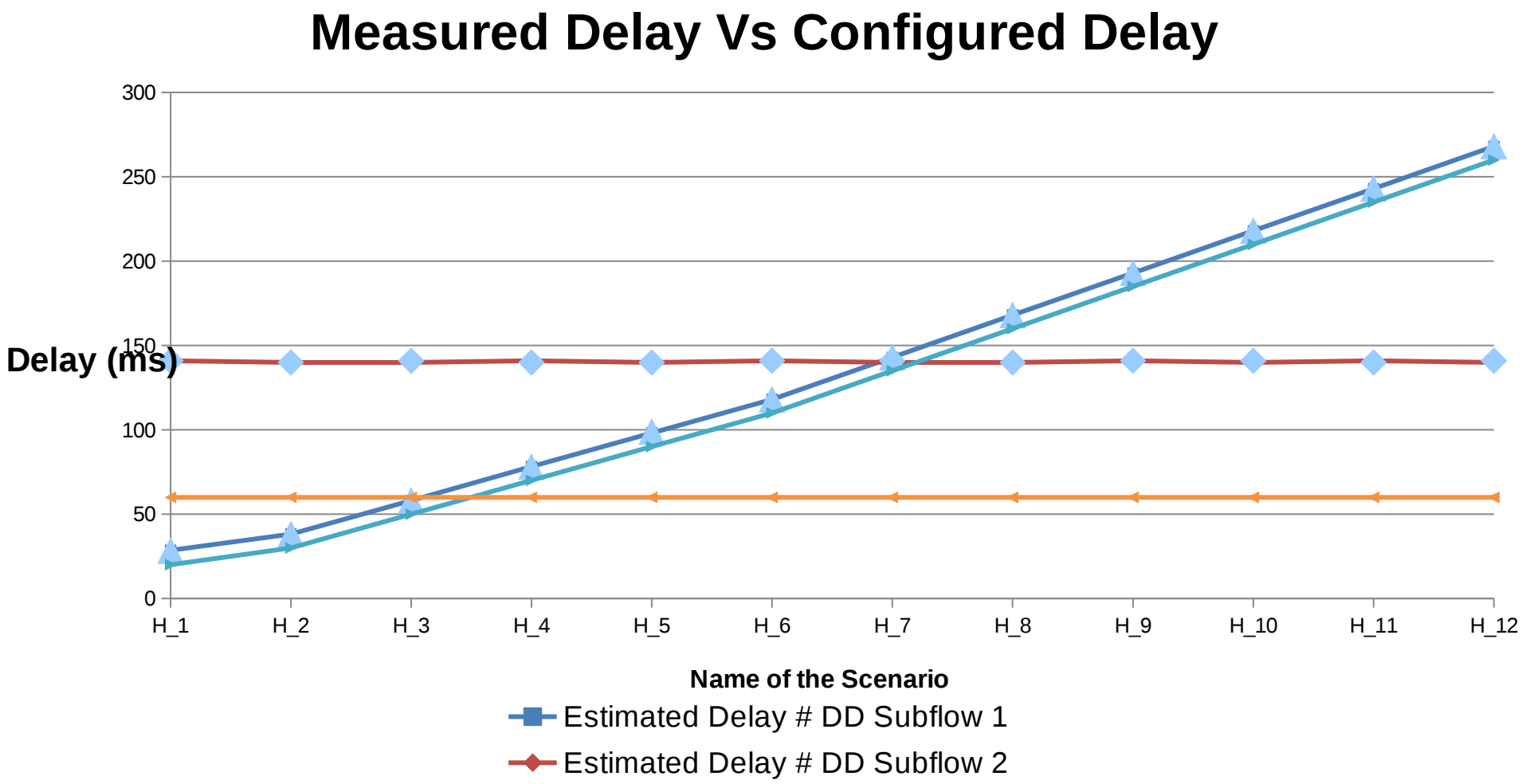
Subflow 1's delivery delay is lower than that of subflow 2, therefore subflow 1 is selected

For the next packet, subflow 1 is also selected

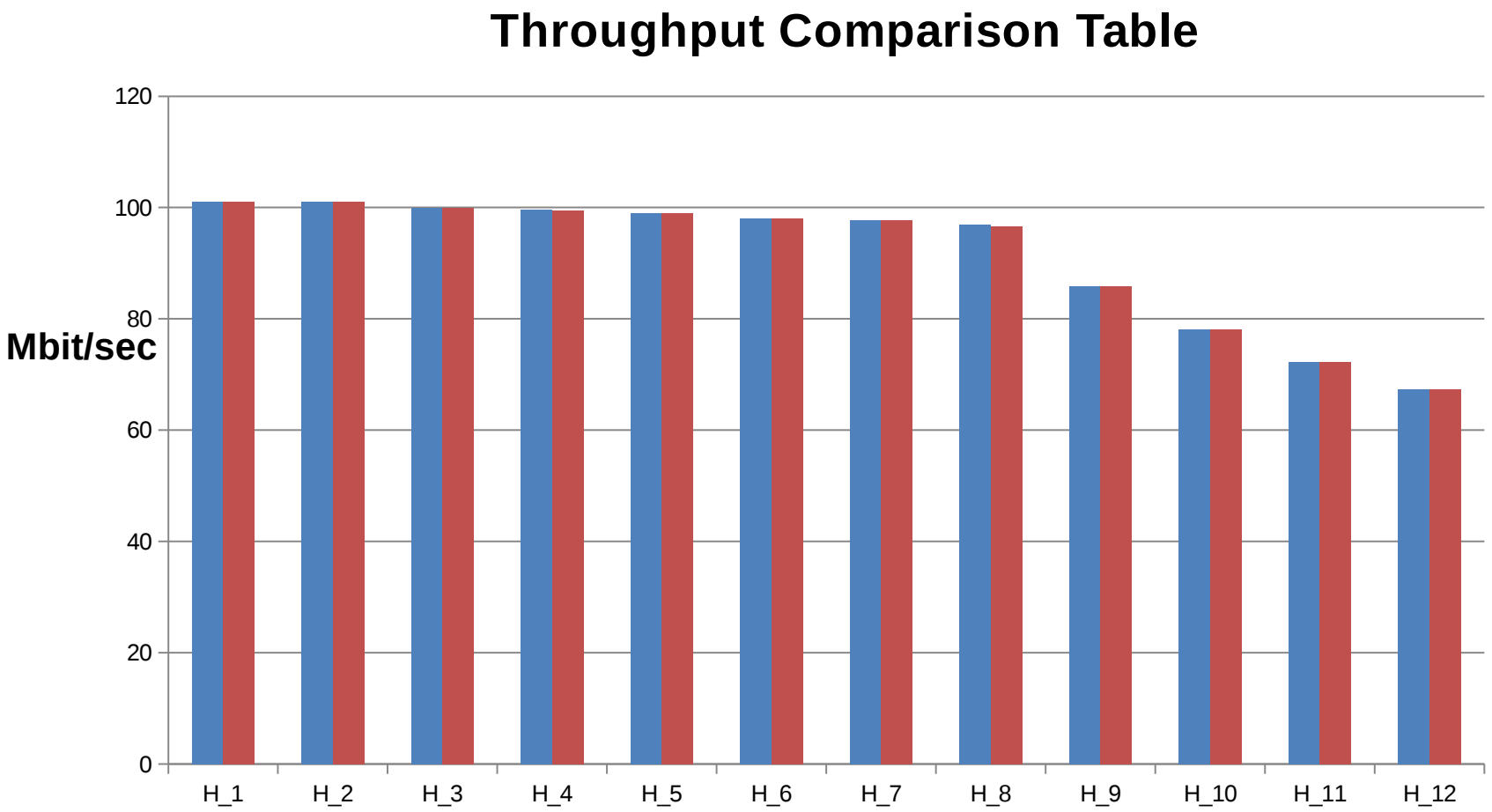
Performance Evaluation - Two Node Testbed with Router

Name of the Scenario	Subflow 1		Subflow 2	
	RTT (ms)	FPD+BPD (ms)	RTT (ms)	FPD+BPD (ms)
H_1	20	10 + 10	60	50 + 10
H_2	30	10 + 20	60	50 + 10
H_3	50	10 + 40	60	50 + 10
H_4	70	10 + 60	60	50 + 10
H_5	90	10 + 80	60	50 + 10
H_6	110	10 + 100	60	50 + 10
H_7	135	10 + 125	60	50 + 10
H_8	160	10 + 150	60	50 + 10
H_9	185	10 + 175	60	50 + 10
H_10	210	10 + 200	60	50 + 10
H_11	235	10 + 225	60	50 + 10
H_12	260	10 + 250	60	50 + 10

Link Capacity – 100/10 (Mbit/sec)



Link Capacity 100/10 (Mbit/sec)



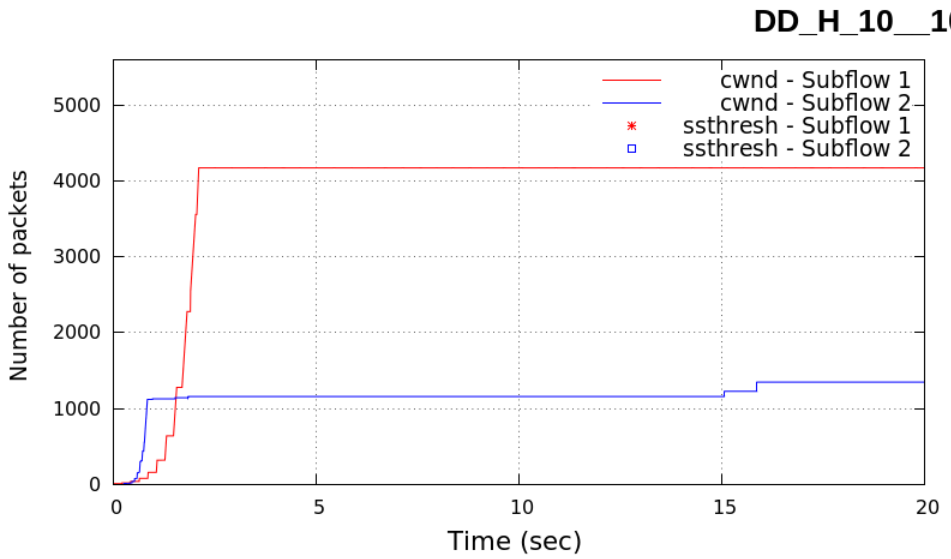
Graphical Analysis

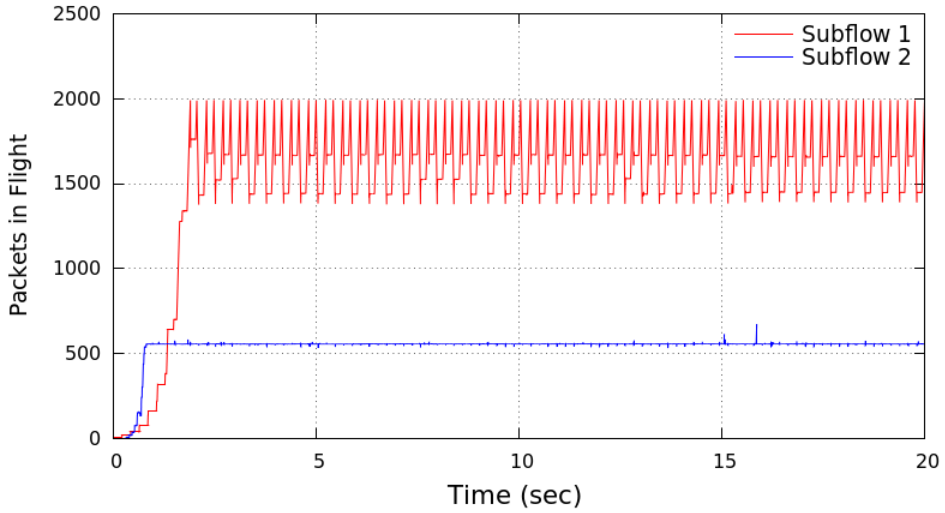
Link Capacity 100/100 (Mbit/sec)

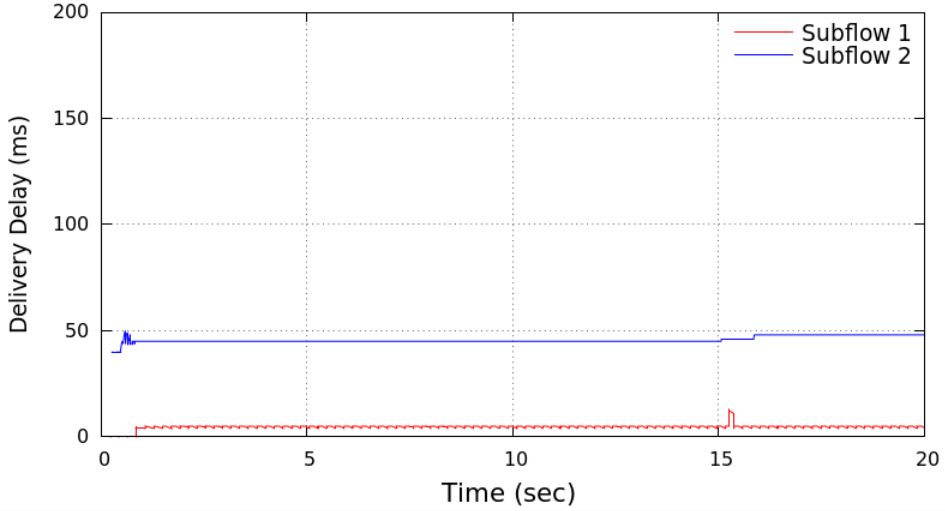
Scenario H_10

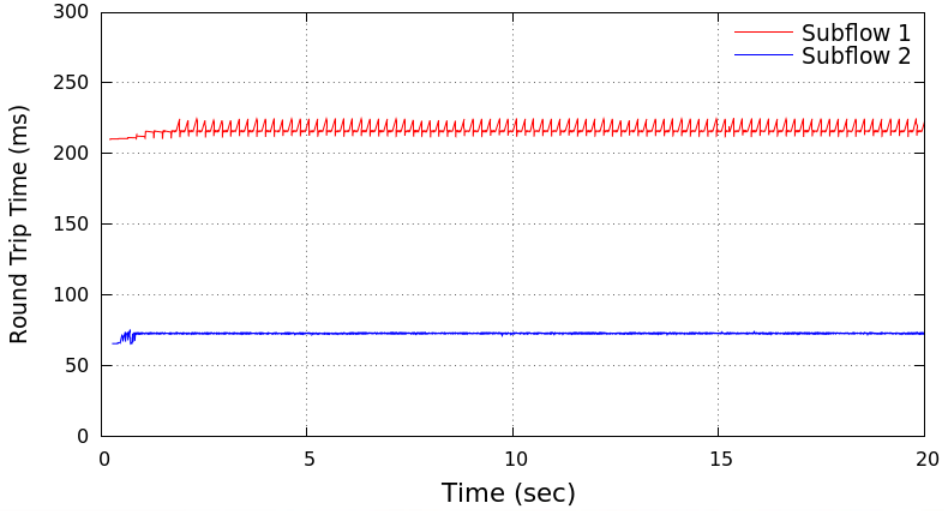
Subflow 1 RTT – 210 ms (10 ms + 200 ms)
Subflow 2 RTT – 60 ms (50 ms + 10 ms)

Delivery Delay Scheduler

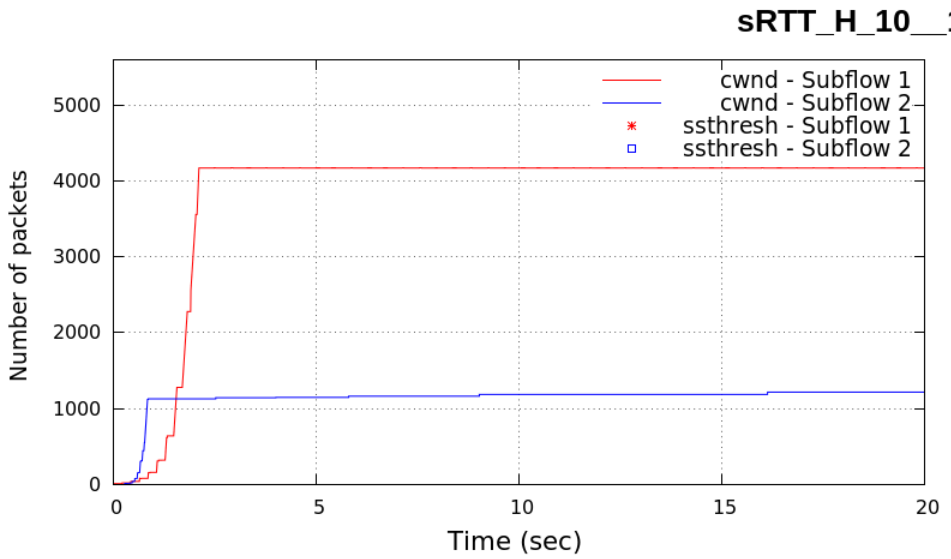


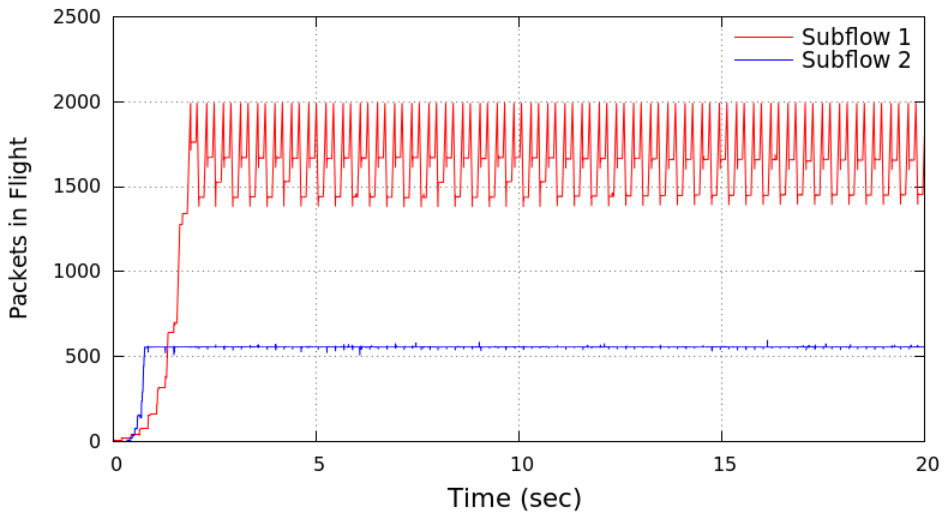


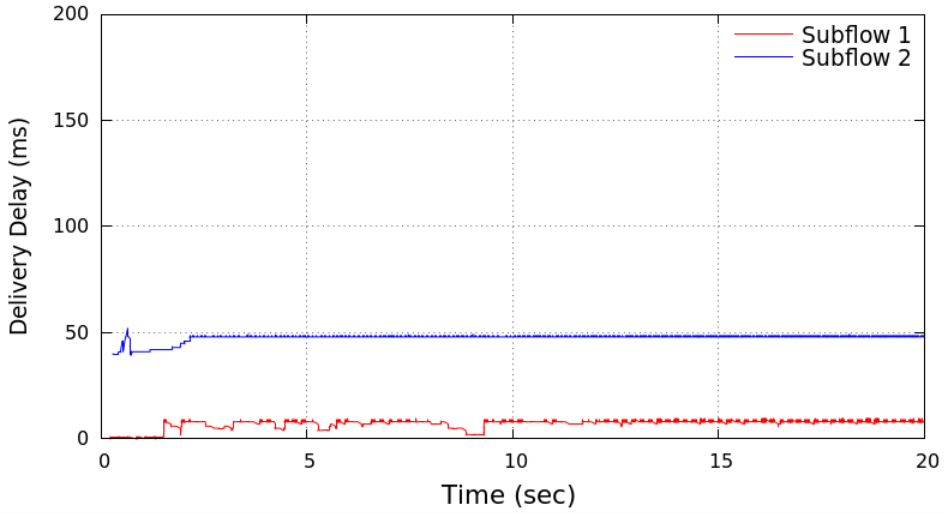


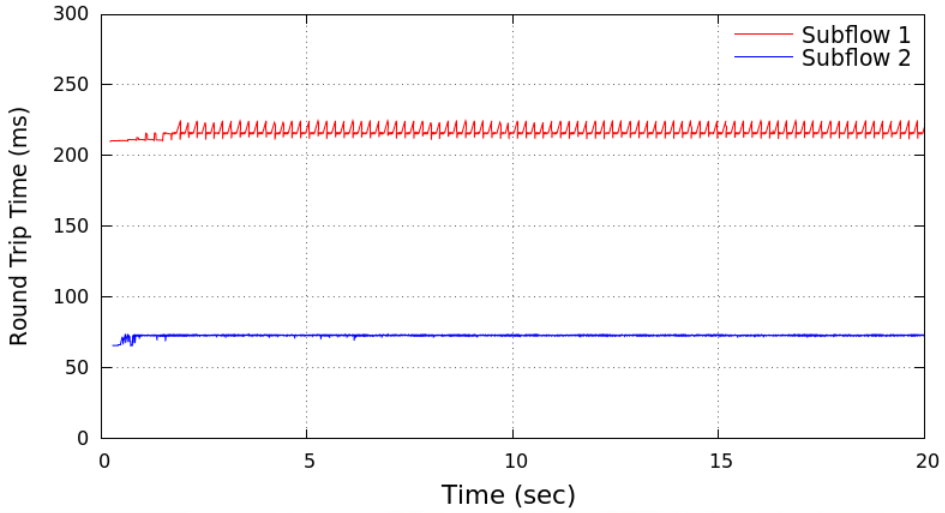


Shortest Round Trip Time Scheduler









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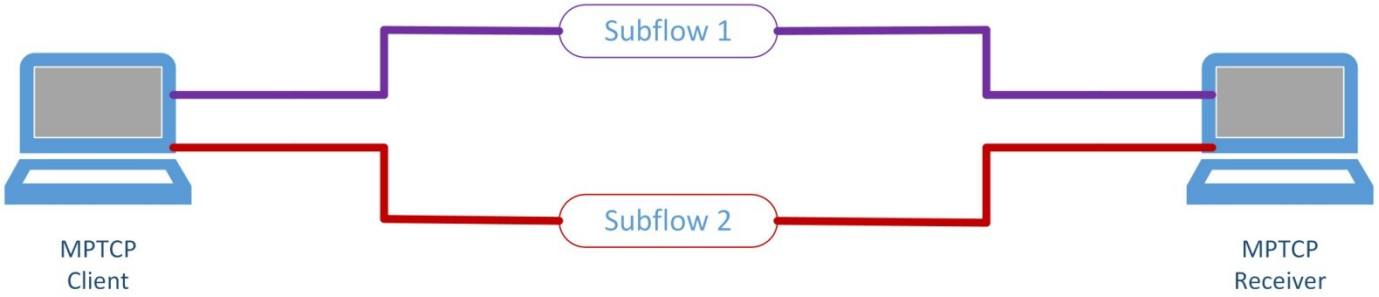
Graphical Analysis- Two Node Testbed



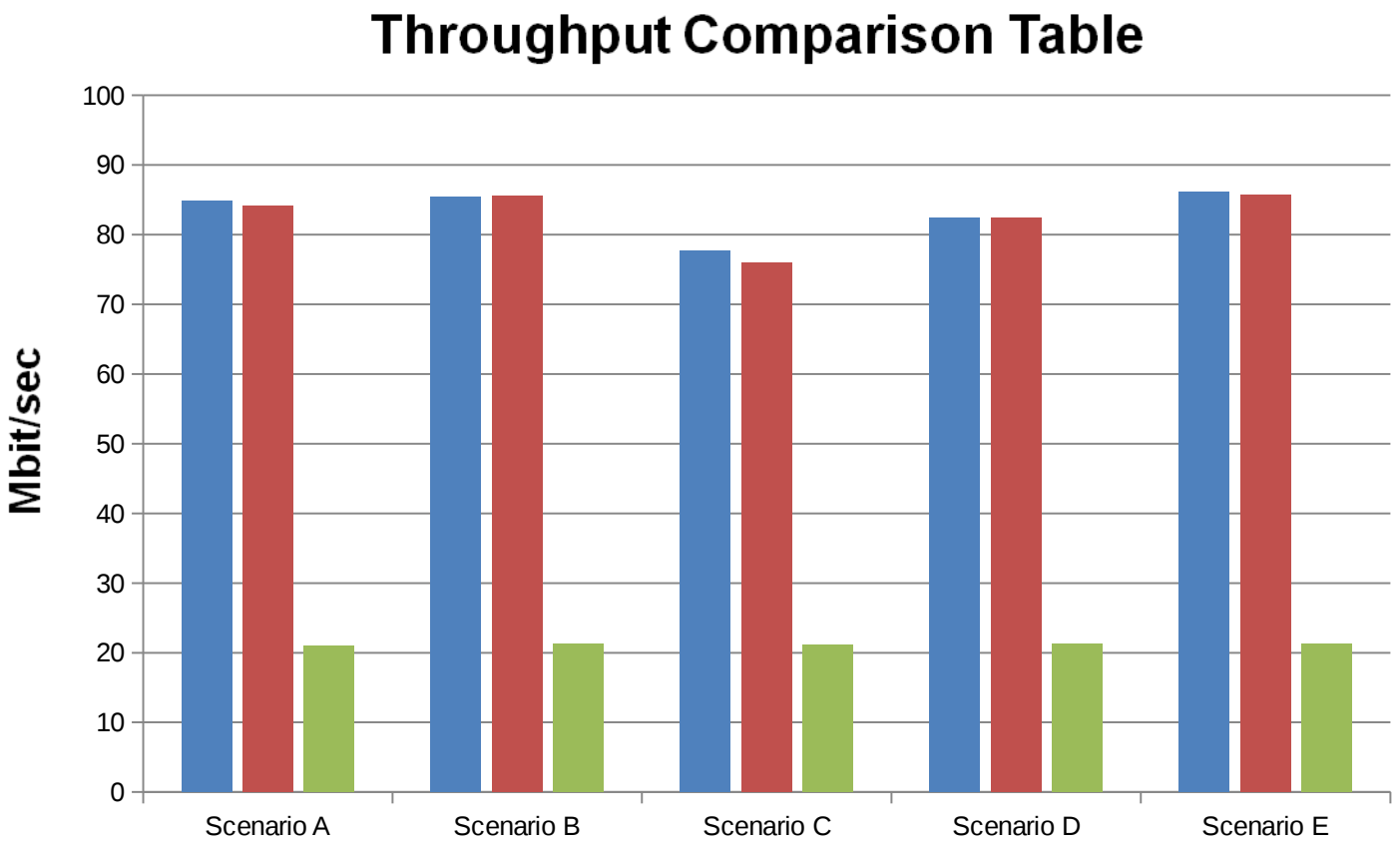
Configuration

- Congestion Control = Reno
- tc qdisc "add" dev "ethX" root netem delay “Yms“ – at Client and Server

Scenarios

Capacity (Mbit/sec)	Name of Scenario	Subflow 1			Subflow 2		
		FPD (ms)	BPD (ms)	RTT (ms)	FPD (ms)	BPD (ms)	RTT (ms)
100/100 & 100/10 & 10/10	A	10	20	30	20	10	30
	B	10	10	20	20	10	30
	C	10	40	50	20	20	40
	D	10	20	30	20	40	60
	E	10	10	20	20	20	40
	F	10	200	210	20	400	420

Link Capacity 100/10 (Mbit/sec)



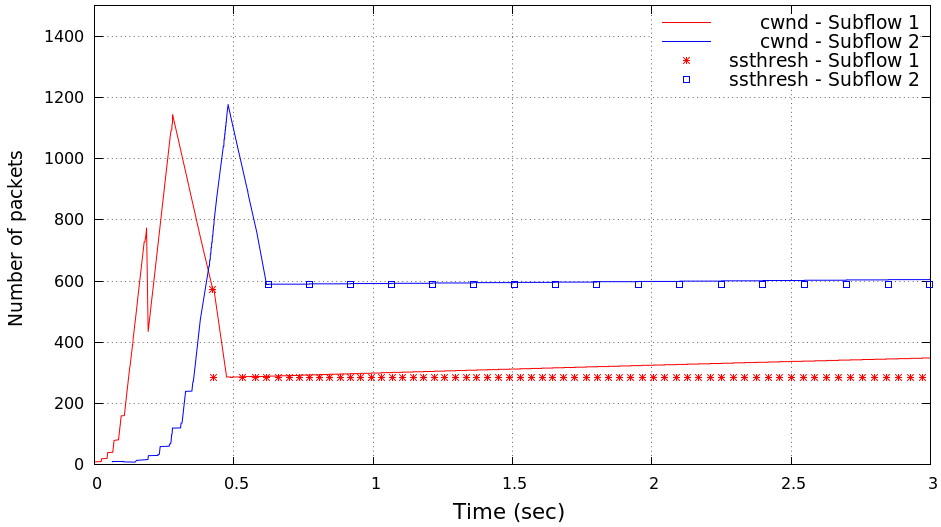
Graphical Analysis

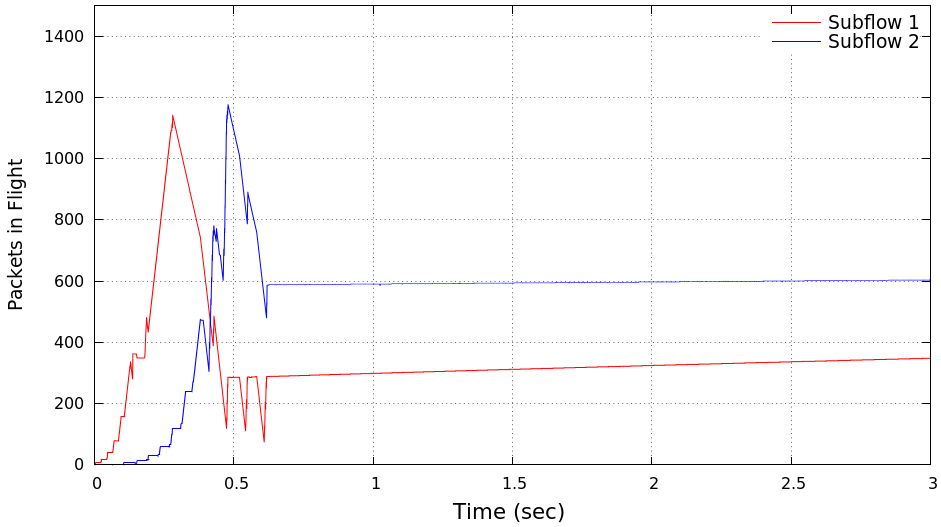
Link Capacity 100/100 (Mbit/sec)

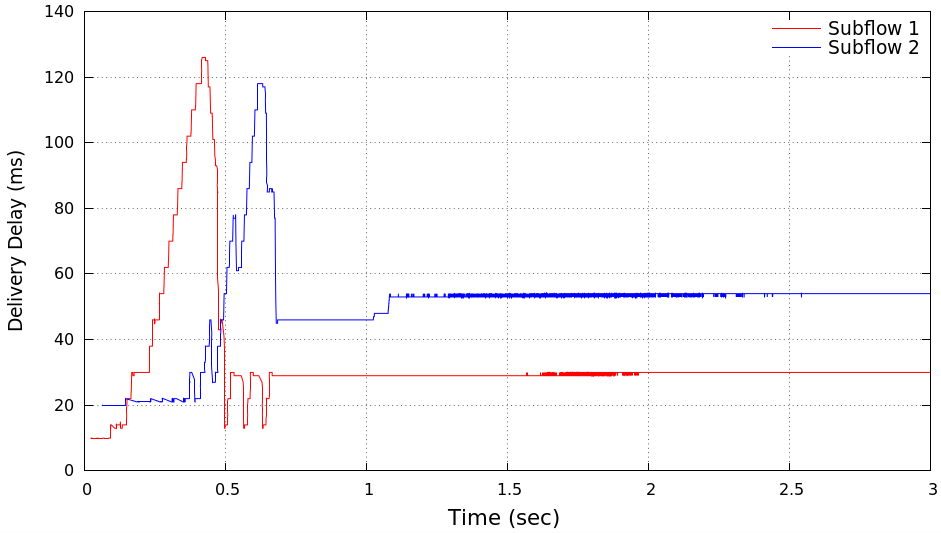
Scenario E

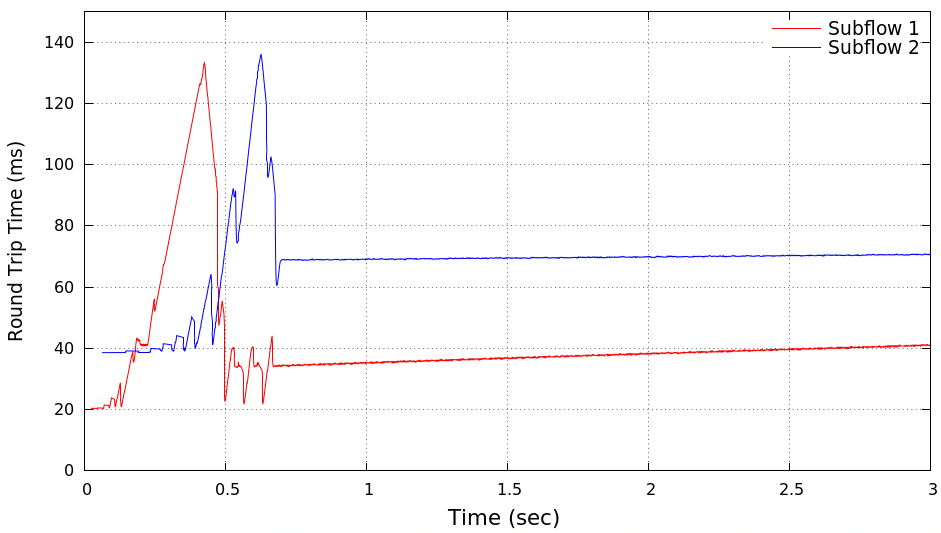
Subflow 1 RTT – 20 ms (10 ms + 20 ms)
Subflow 2 RTT – 40 ms (20 ms + 20 ms)

Delivery Delay Based Scheduler









Receiver Buffer Occupancy

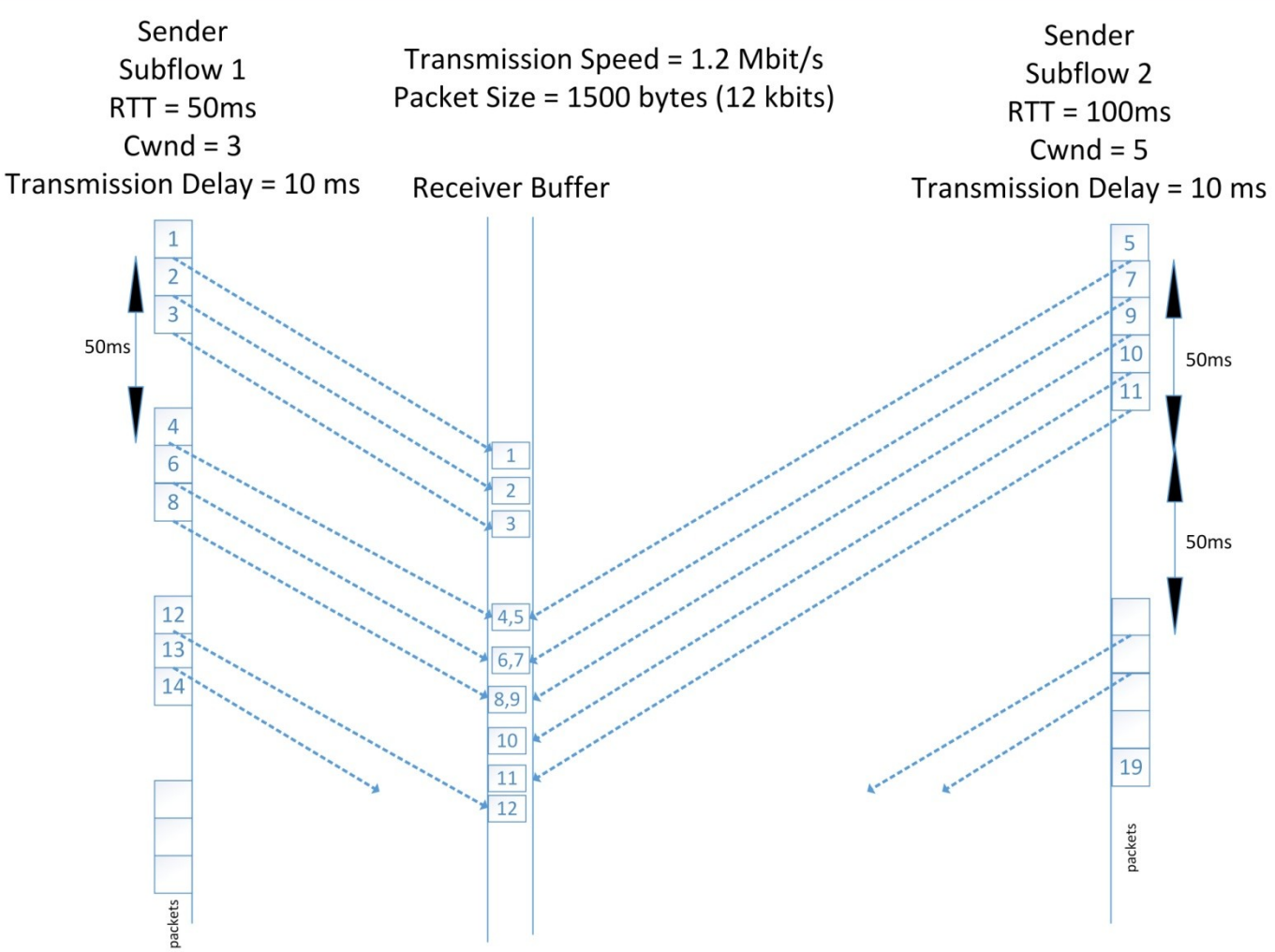
Scenario			
Link Capacity = 1.2 Mbit /sec	Transmission Delay	RTT (ms)	FPD+BPD (ms)
Subflow 1	10 ms	110	10 + 100
Subflow 2	10 ms	60	50 + 10

Receiver Buffer (sRTT Scheduler)															
4	5	6	1	2	3	7	10	8	9	12	14	11	13	15	19
20	16	21	17	18	22	23	24	28	29	30	25	26	27	31	32
33	36	38	39	34	35	37	40	41	44	42	46	48	43	45	47

Receiver Buffer (DD Scheduler)															
1	2	3	4	5	6	7	10	8	11	9	13	12	14	15	19
16	20	17	21	18	22	23	24	28	29	25	30	26	27	31	32
33	36	38	39	34	35	37	40	41	42	44	46	48	43	45	47

Outlook (Intelligent DD Scheduler)

Packet no	Reordering Delay (ms)	End-to Delay (
1	0	50
2	0	50
3	0	50
4	0	50
5	0	100
6	0	50
7	0	100
8	0	50
9	0	100
10	0	100
11	0	100
12	0	50



Conclusion

- The performance of Round Robin scheduler is poor compared to Delivery Delay and sRTT scheduler in case of high link capacity and delay asymmetry

- Throughput performance of Delivery Delay scheduler and sRTT scheduler are similar (ack-clocked)
  - Scheduling is considered only among the subflows which have an open congestion window
  - Congestion window's increase is dependent on the ACK packets and hence also controls the scheduler's performance
  - When the backward delay (delivery delay for the ACK packet) on the subflows remains constant throughout the simulation run, the sRTT scheduler almost acts as the delivery delay scheduler

- Artificial delay configuration at the sender nodes created performance issues in the experimental setup
  - Delay should be configured on the routers

Outlook

- The performance comparison of different schedulers can be evaluated in different network conditions
  - In wireless networks
  - With bidirectional data traffic
- Intelegent Delivery Delay scheduler can be implemented to minimize the out-of-order delivery
  - Advance packet scheduling by estimating the forward paths behavior

References

1. Costin Raiciu, Mark Handley, and Damon Wischik. “Coupled congestion control for multipath transport protocols “. RFC6356, October, 2011.
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7. Sébastien Barré, Christoph Paasch, and Olivier Bonaventure. ``Multipath tcp: from theory to practice’’. In NETWORKING 2011, pages 444–457. Springer, 2011.
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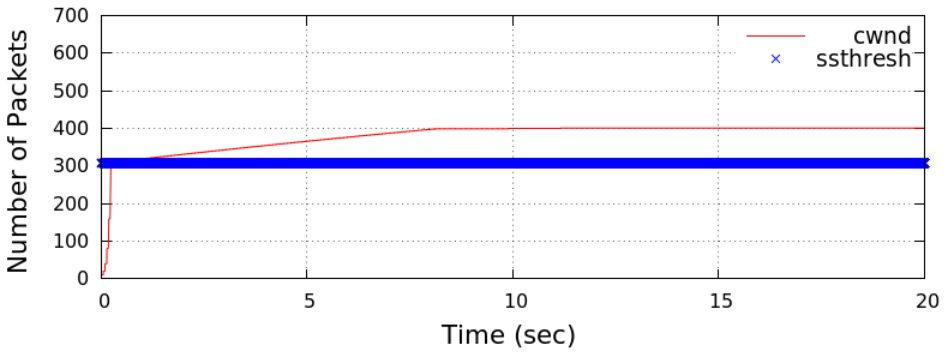
Questions??

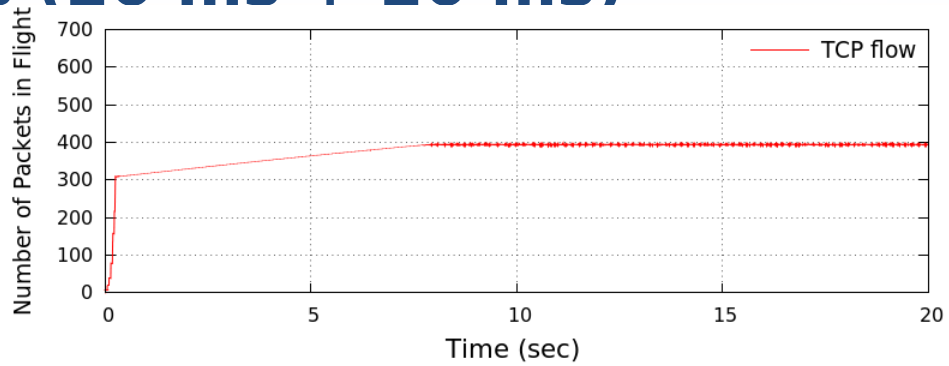
Thank you!!!

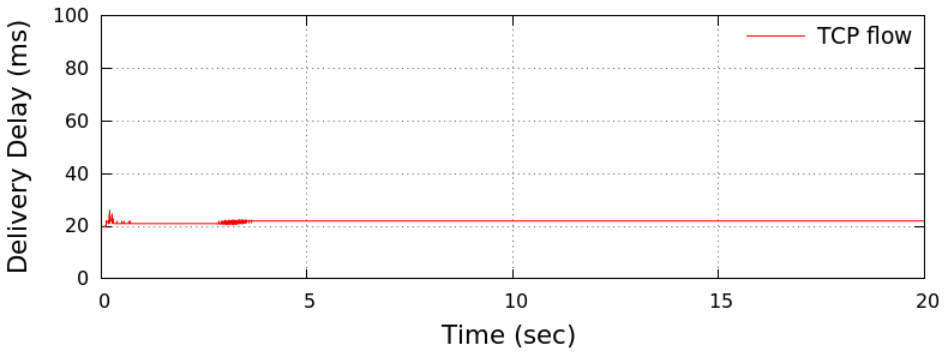
Backup Slides

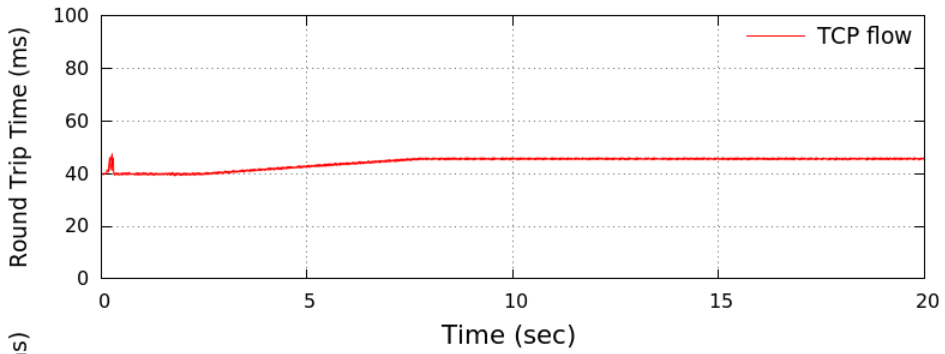
TCP with Router – Link Capacity 100 (Mbit/sec)

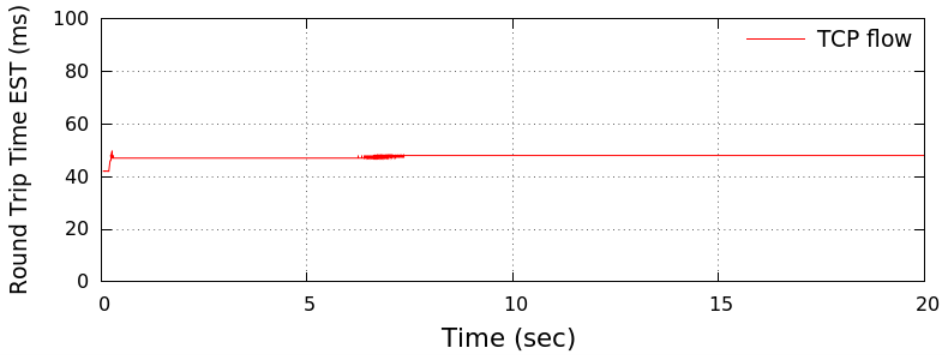
Delay - 40 ms (20 ms + 20 ms)

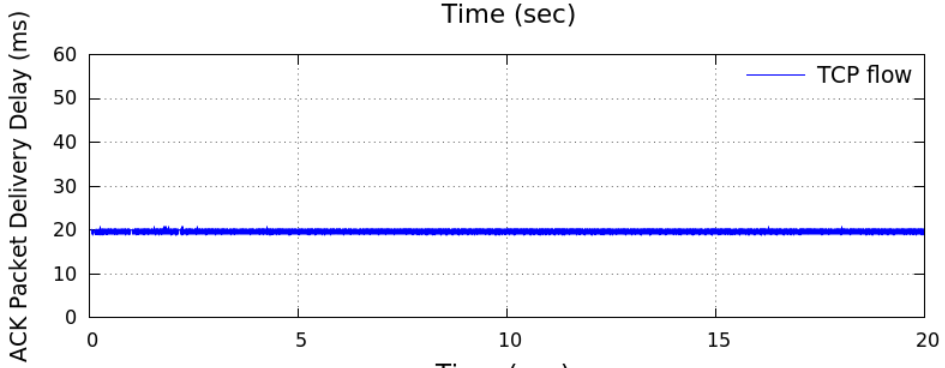






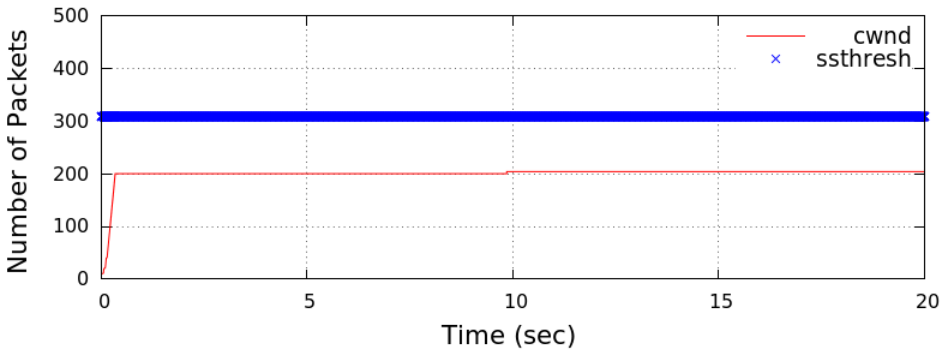


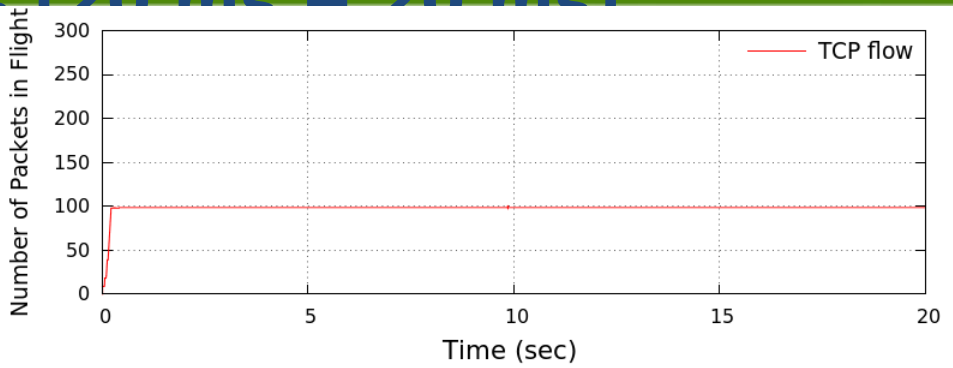


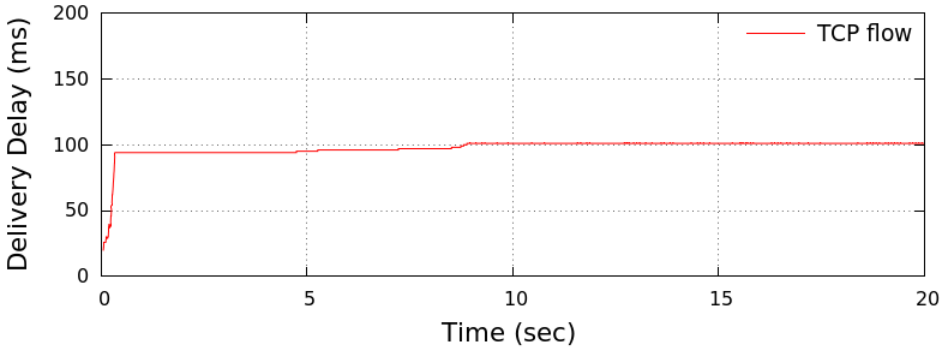


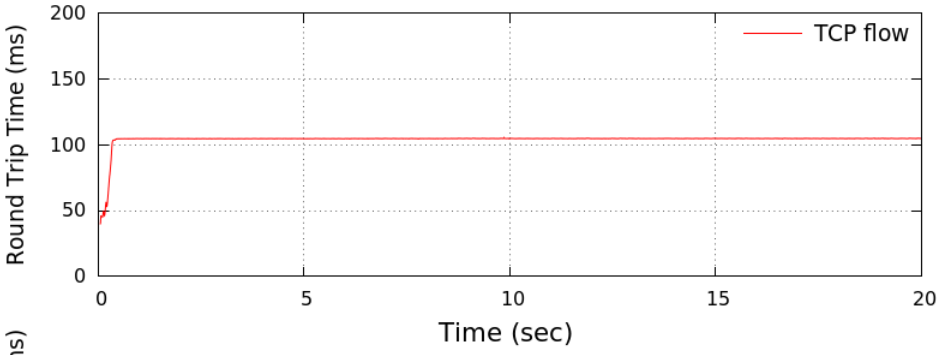
TCP with Router – Link Capacity 10 (Mbit/sec)

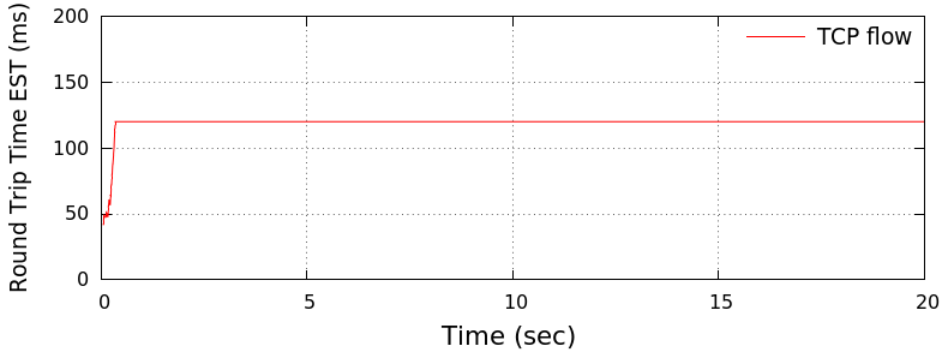
Delay - 40 ms (20 ms + 20 ms)

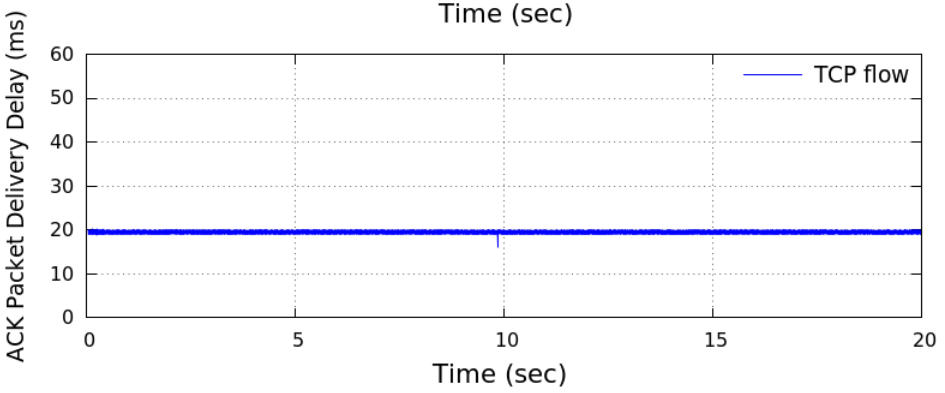






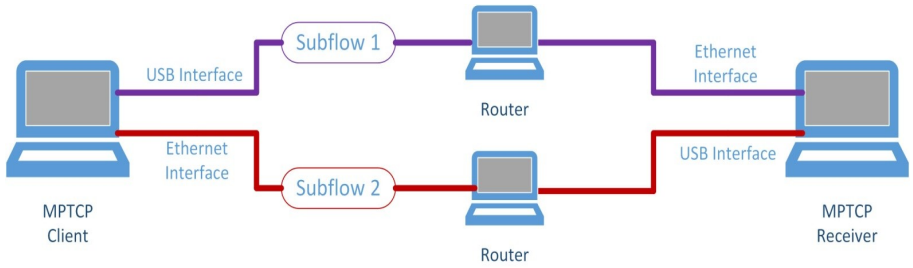






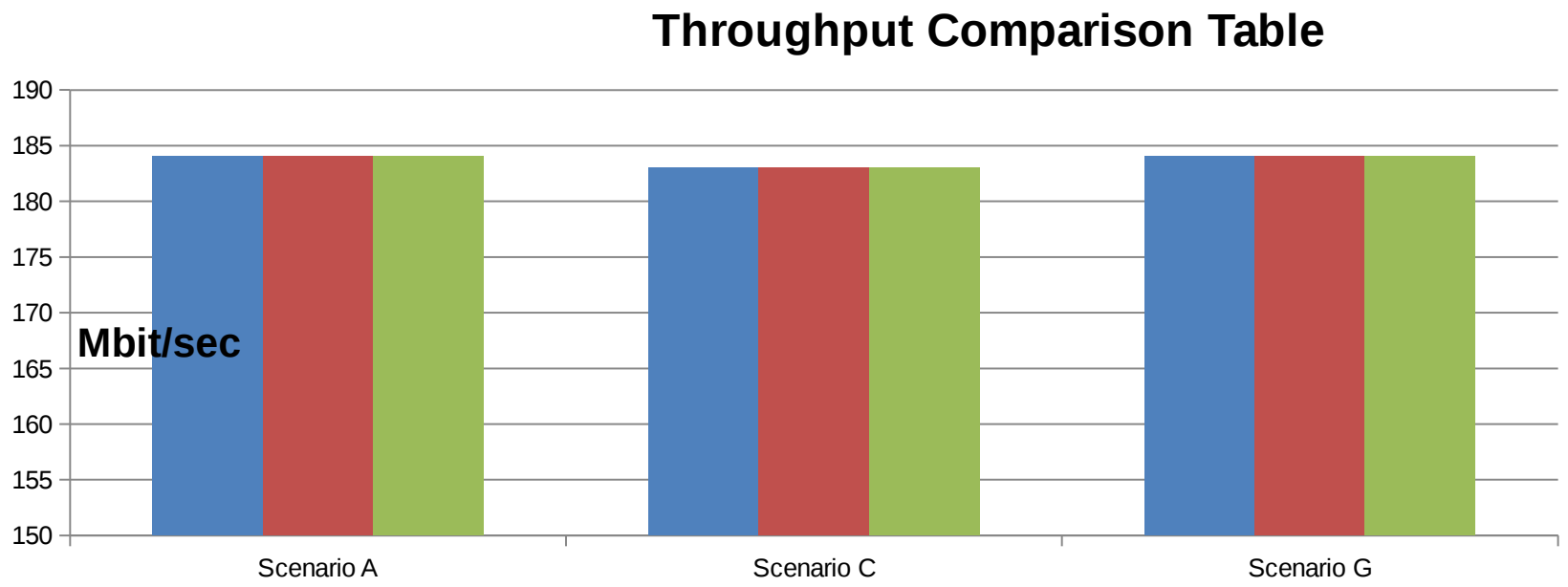
Performance Evaluation - Two Node Testbed with Router

- Configuration :
  - Congestion Control = Reno
  - tc qdisc "add" dev "ethX" root netem delay "Yms" – at router

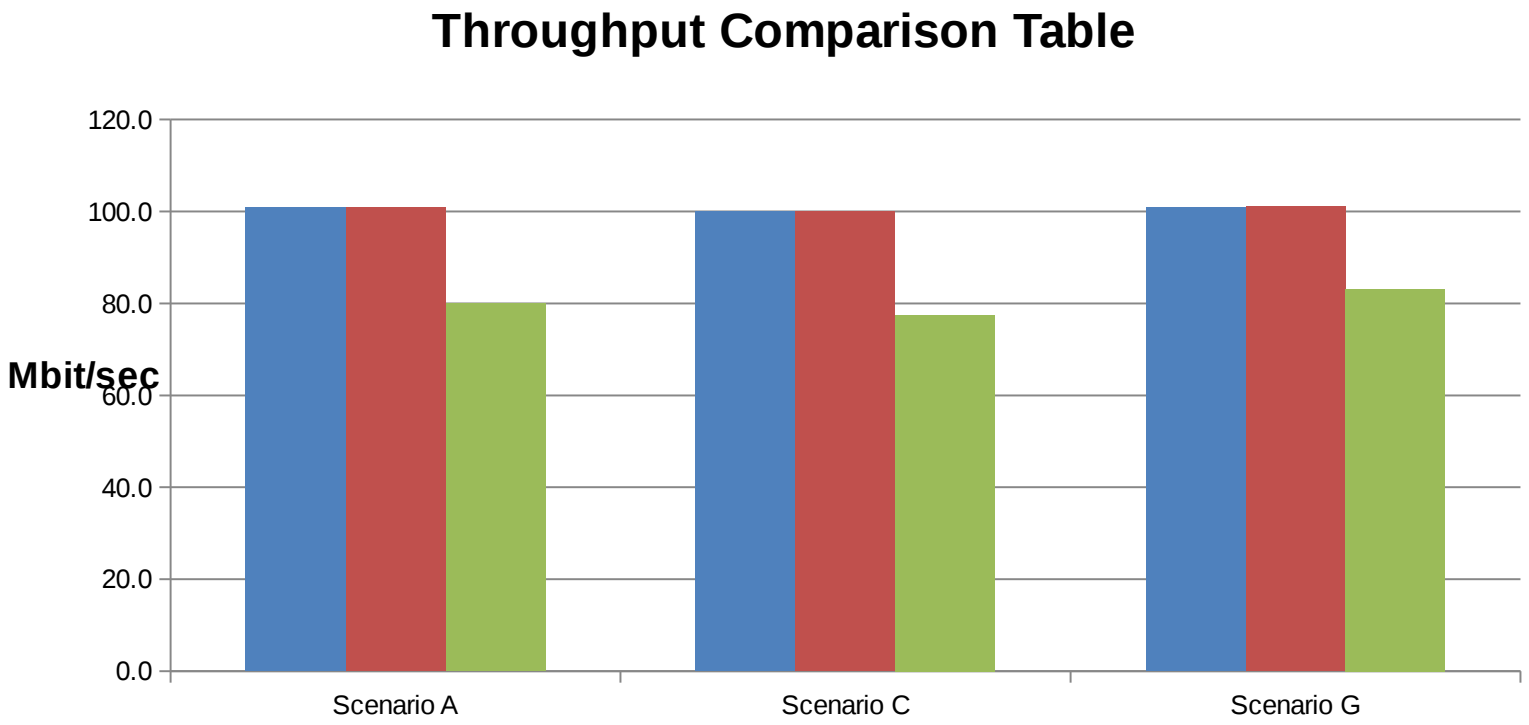


Capacity (Mbit/sec)	Name of Scenario	Subflow 1			Subflow 2		
		FPD (ms)	BPD (ms)	RTT (ms)	FPD (ms)	BPD (ms)	RTT (ms)
100/100 & 100/10 & 10/10	A	10	20	30	20	10	30
	C	10	40	50	20	20	40
	G	10	10	20	10	10	20

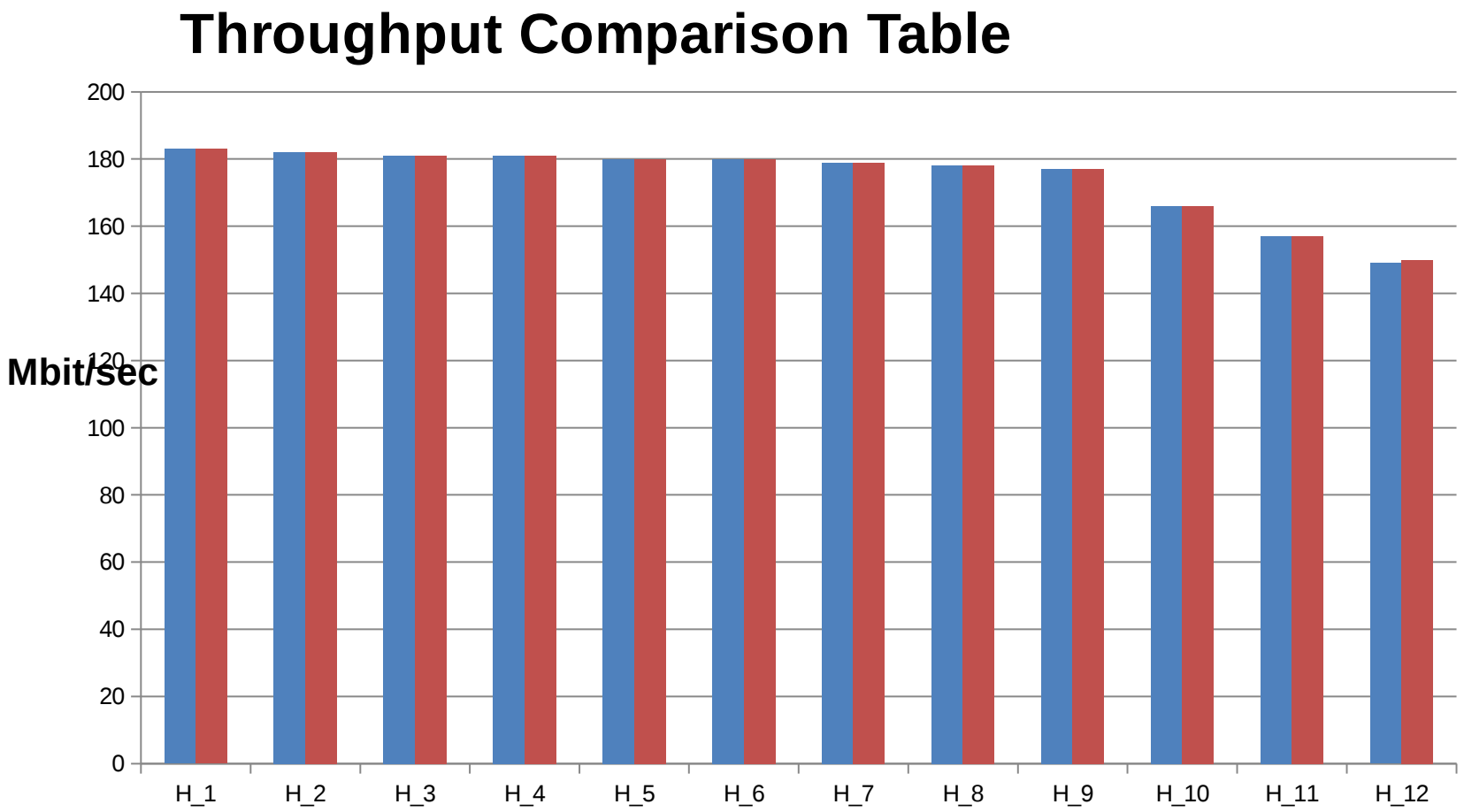
Link Capacity 100/100 (Mbit/sec)



Link Capacity 100/10 (Mbit/sec)



Link Capacity 100/100 (Mbit/sec)



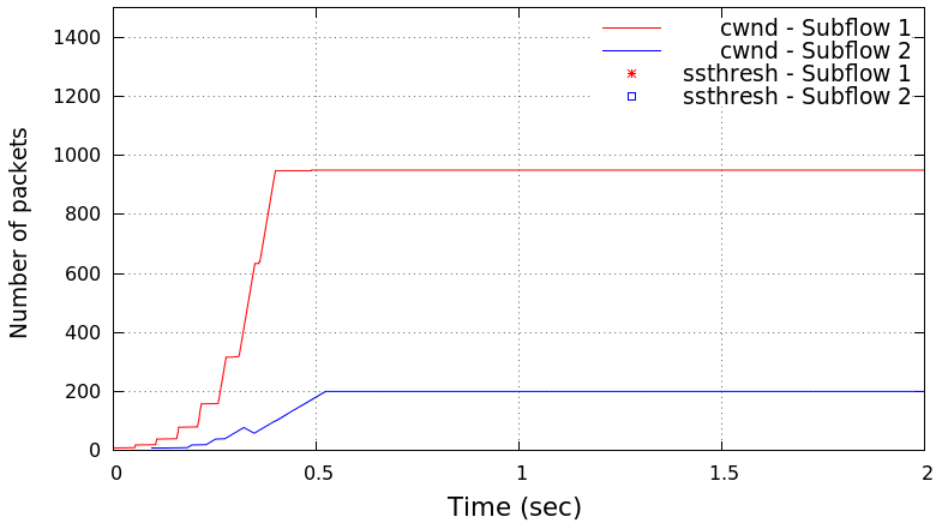
Graphical Analysis

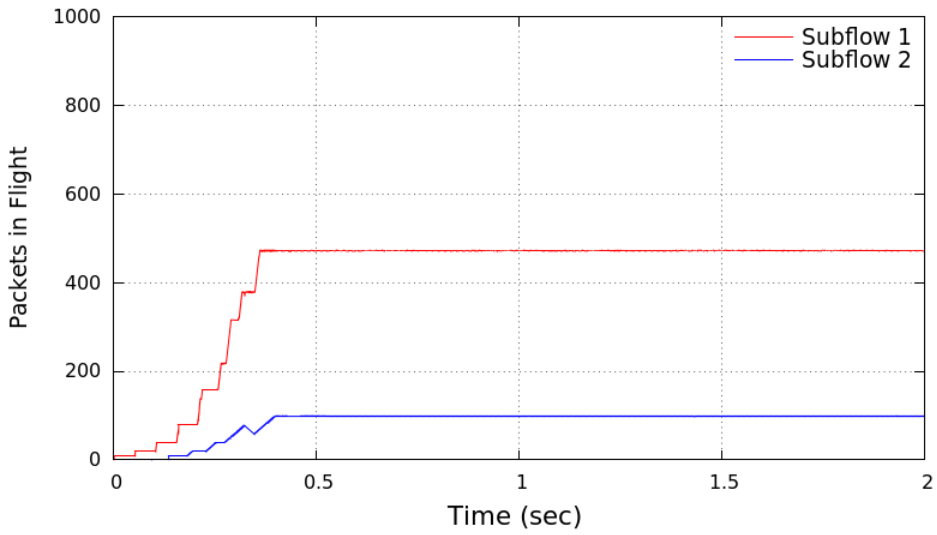
Link Capacity 100/10 (Mbit/sec)

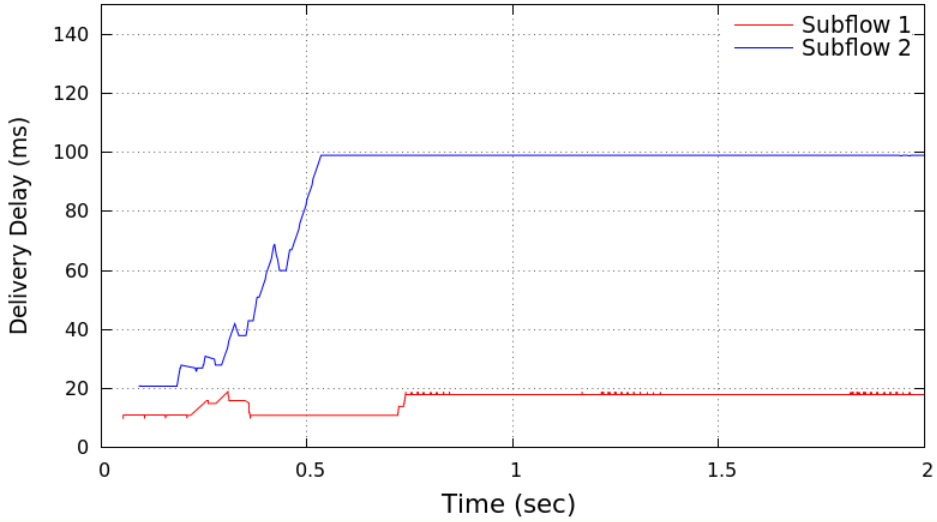
Scenario C

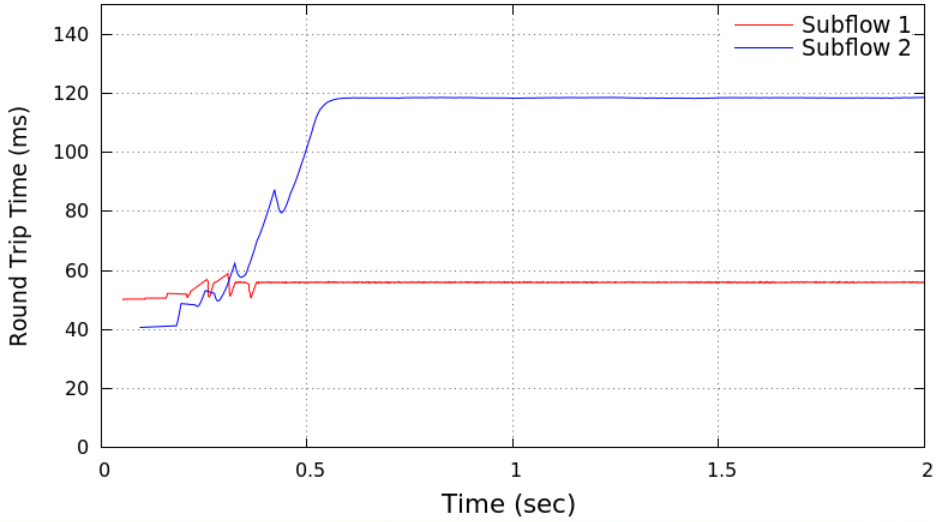
Subflow 1 RTT – 50 ms (10 ms + 40 ms)
Subflow 2 RTT – 40 ms (20 ms + 20 ms)

Delivery Delay Scheduler

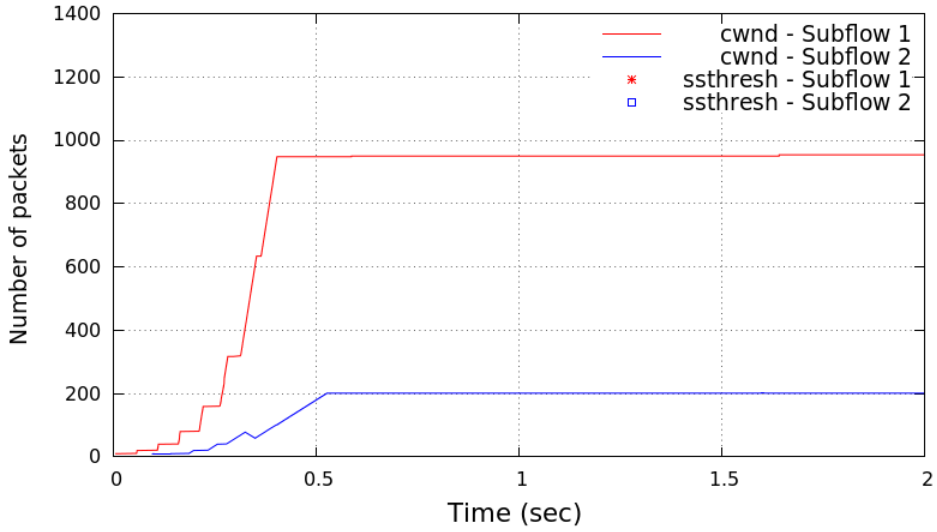


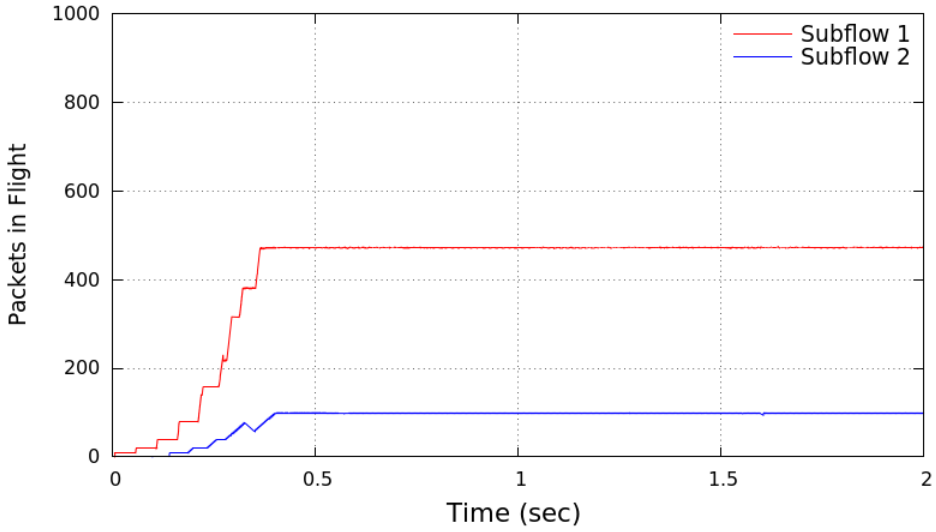


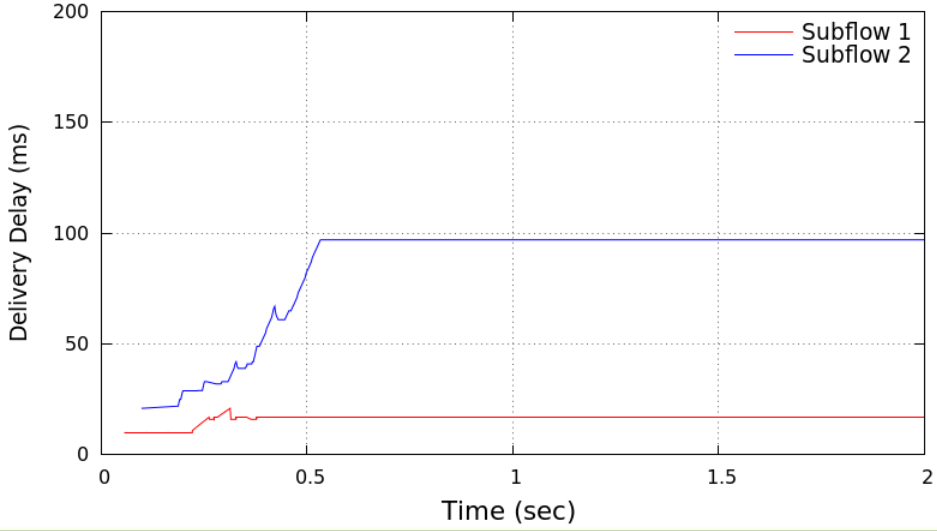


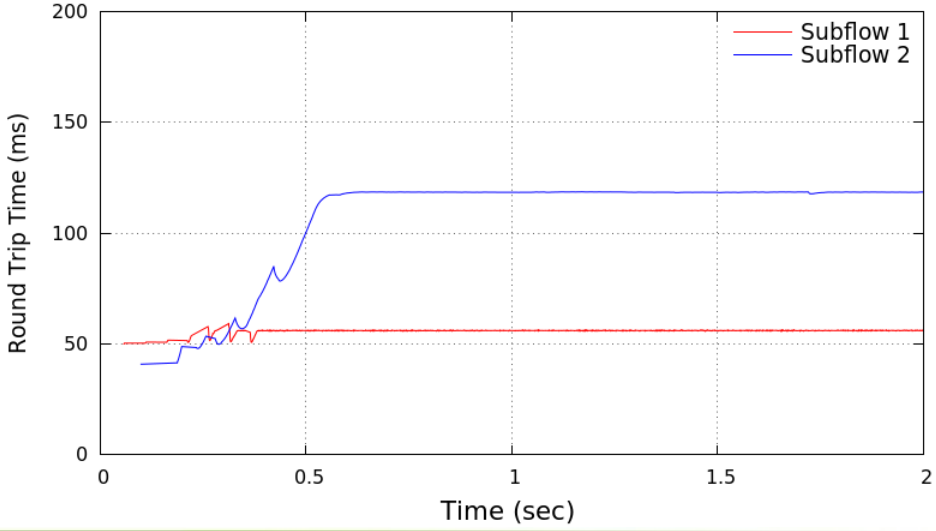


sRTT Scheduler









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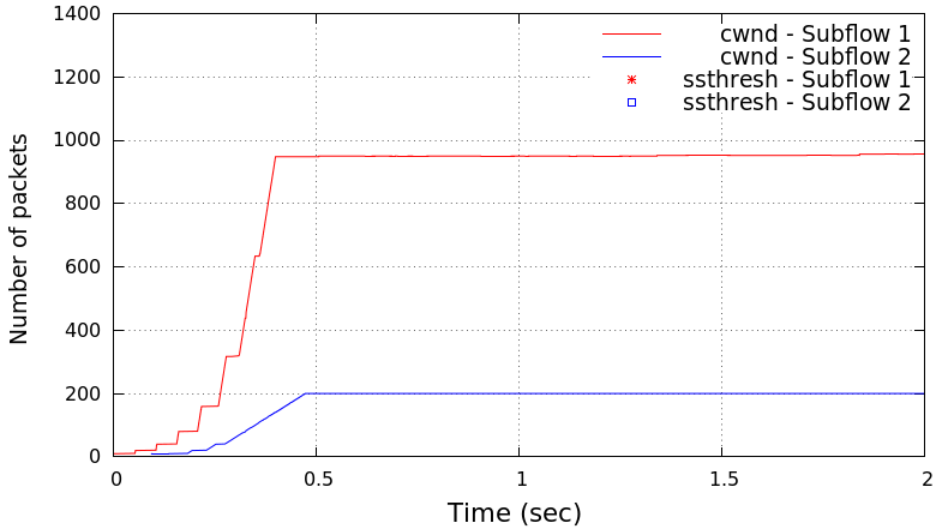
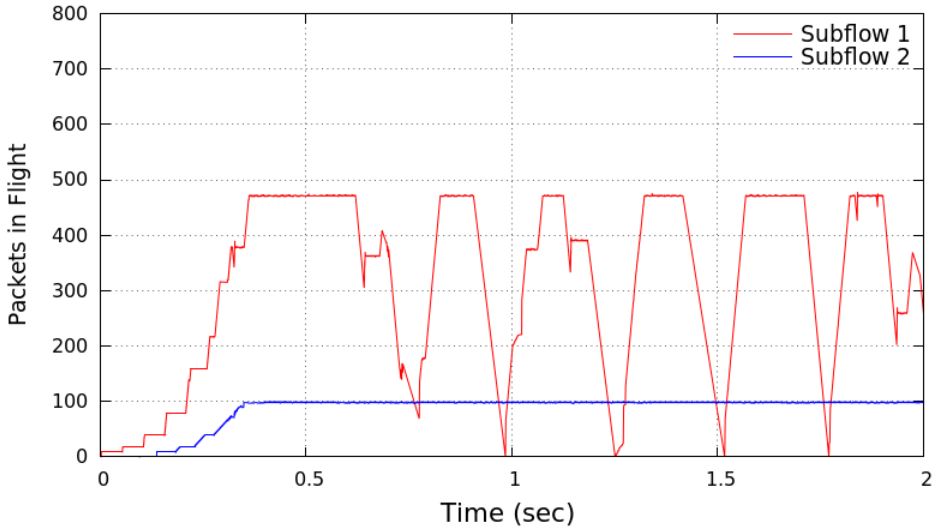
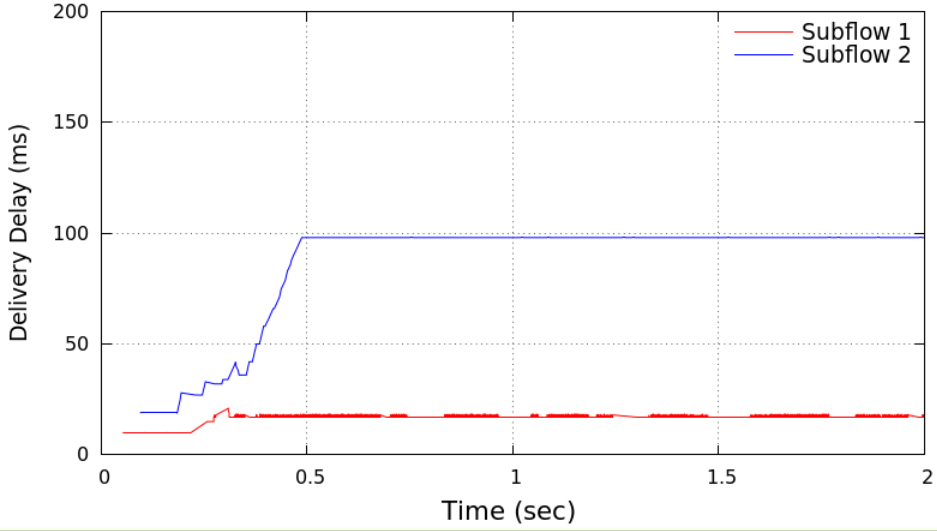
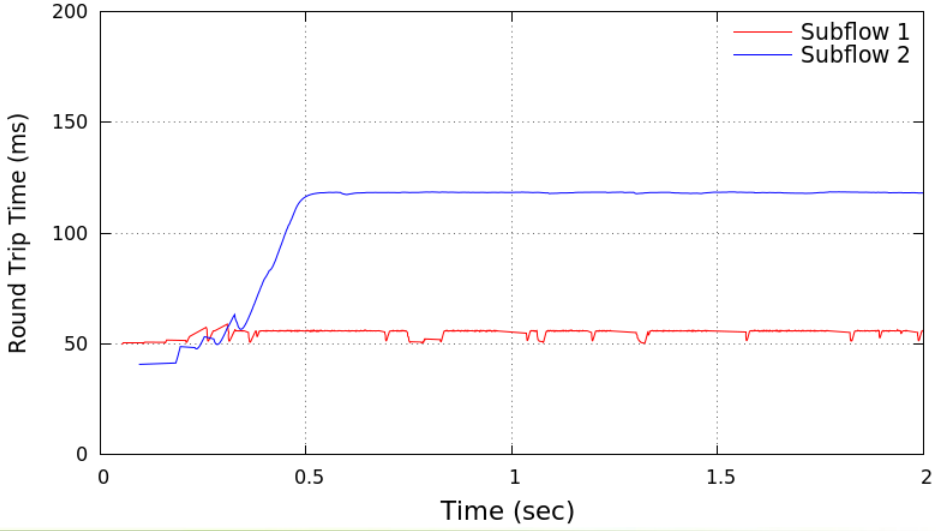
(faridul_alam@ymail.com)

RR Scheduler

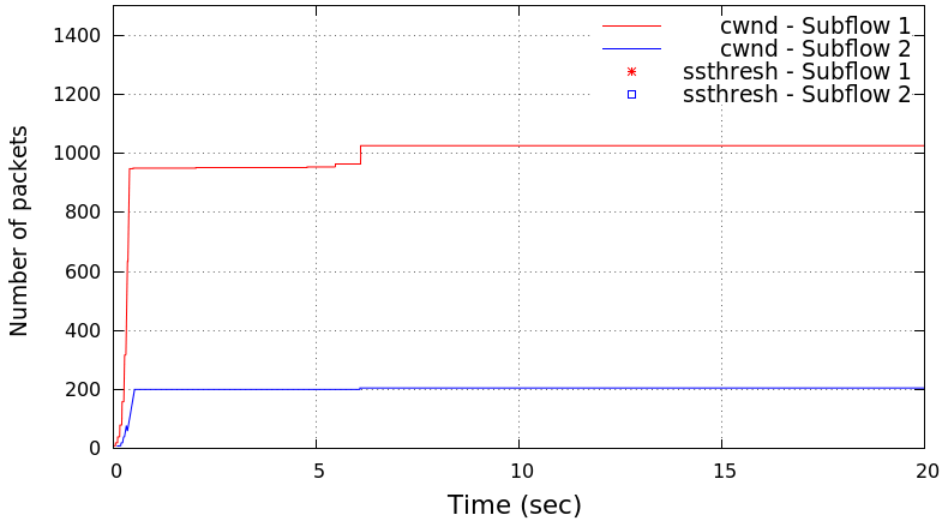


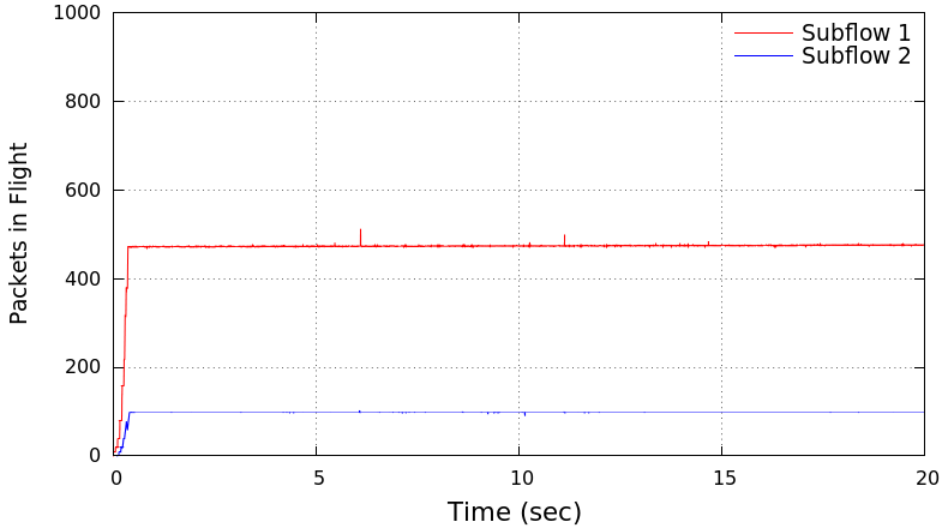


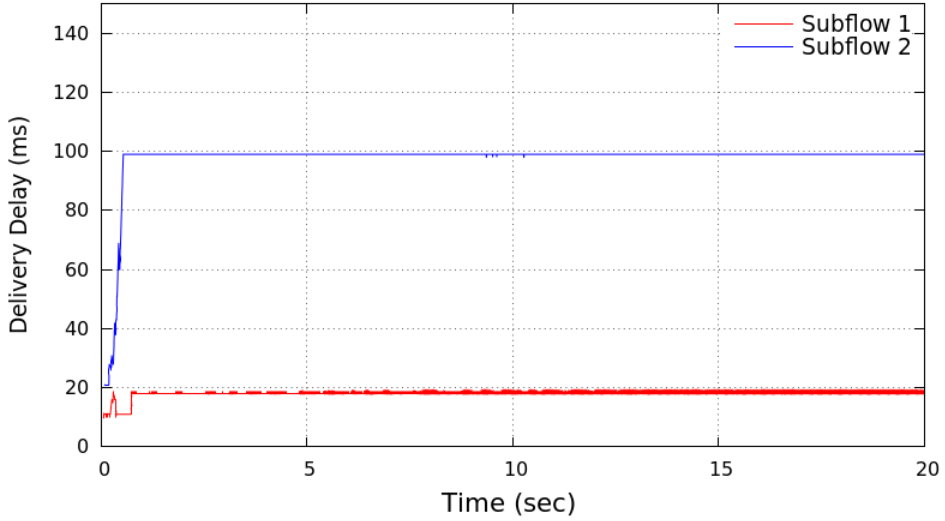


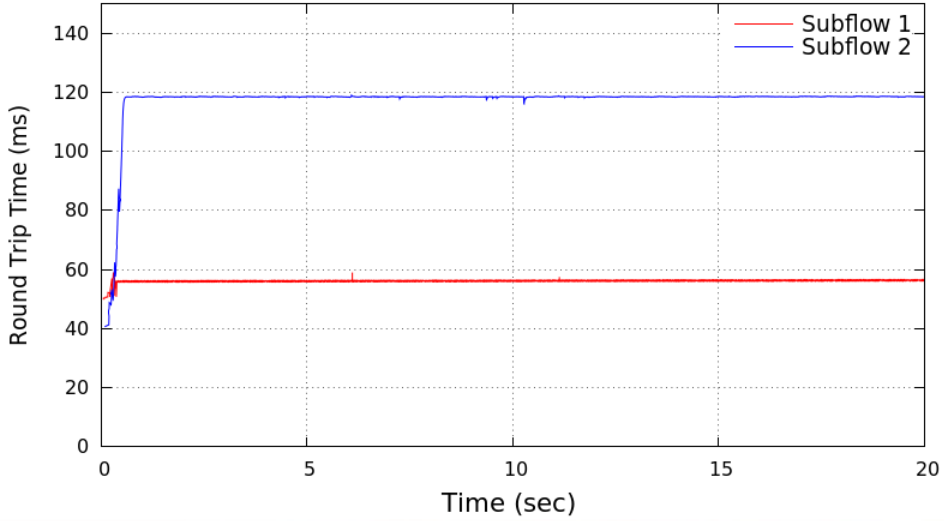


Delivery Delay Scheduler (20 sec)

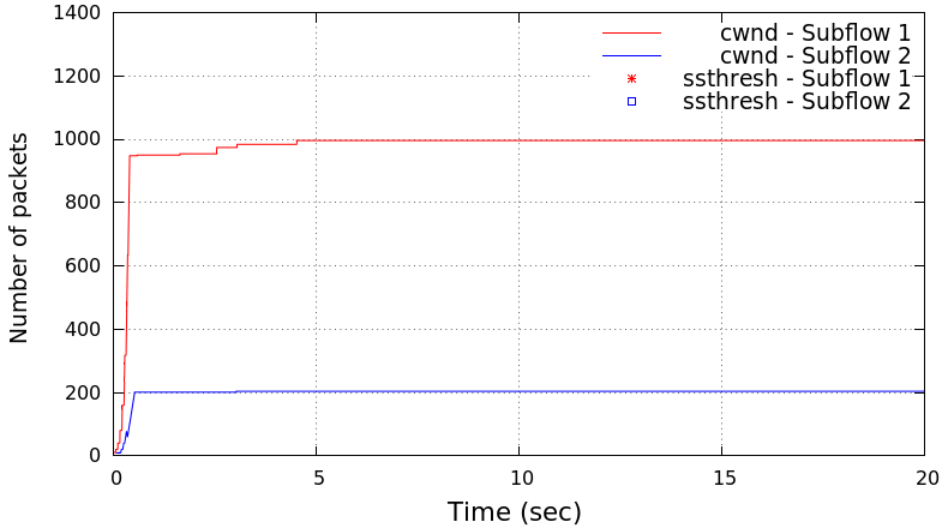


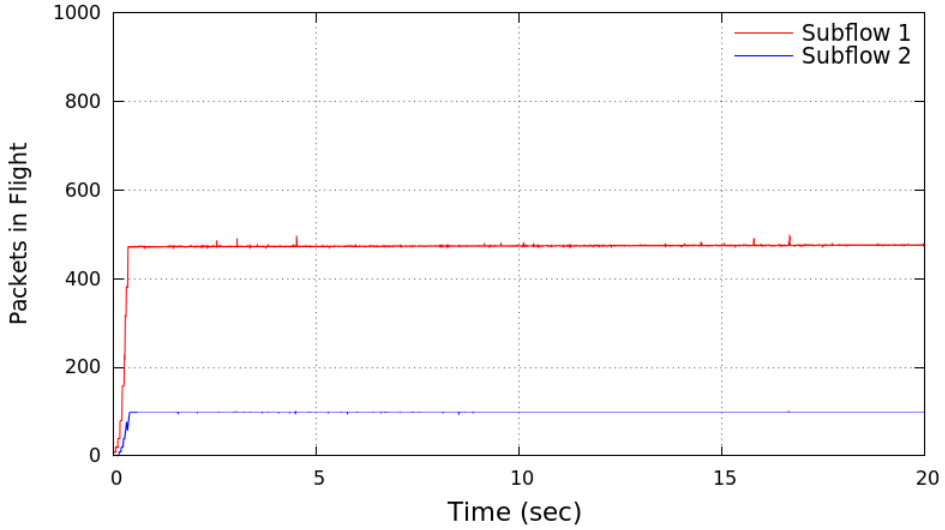


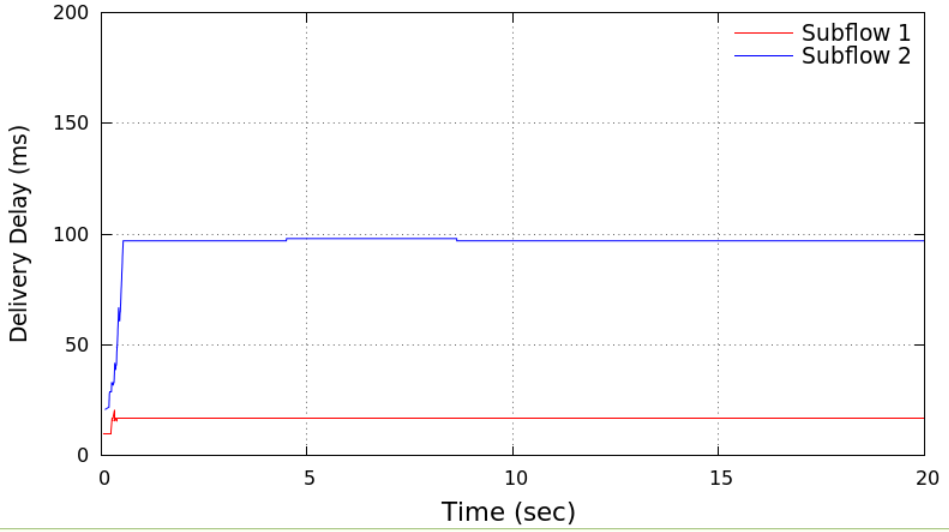


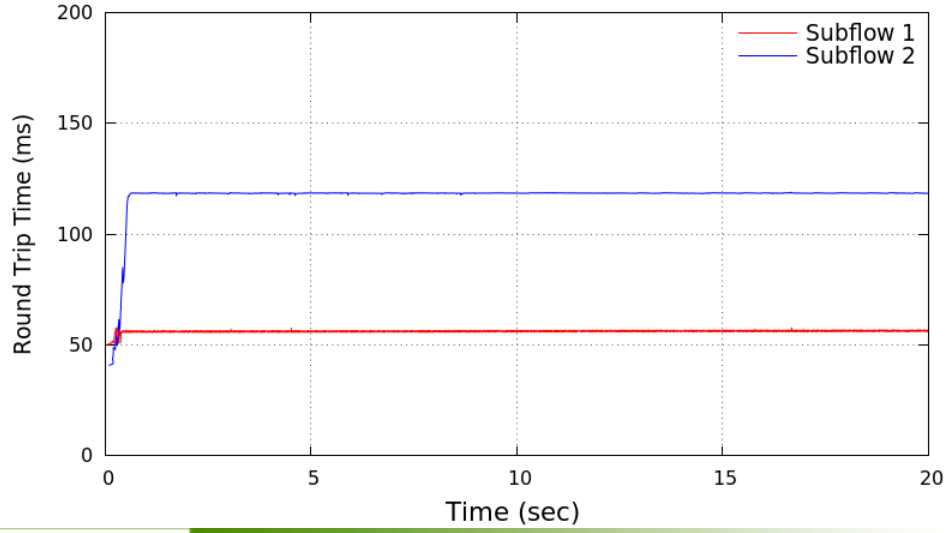


Shortest Round Trip Time Scheduler (20 sec)

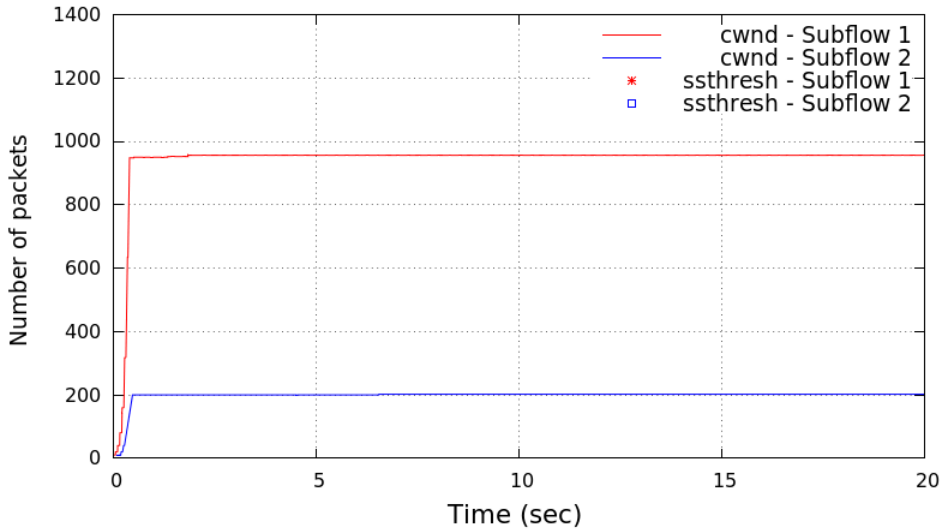


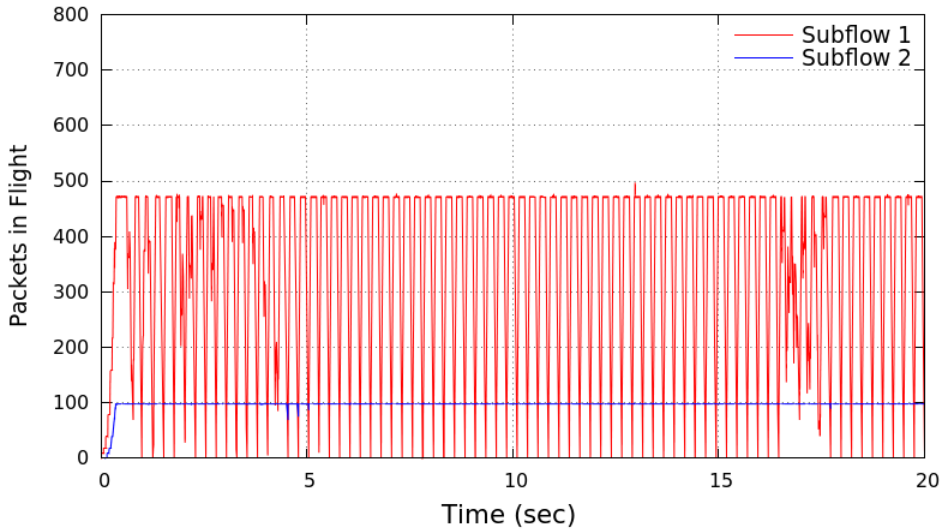


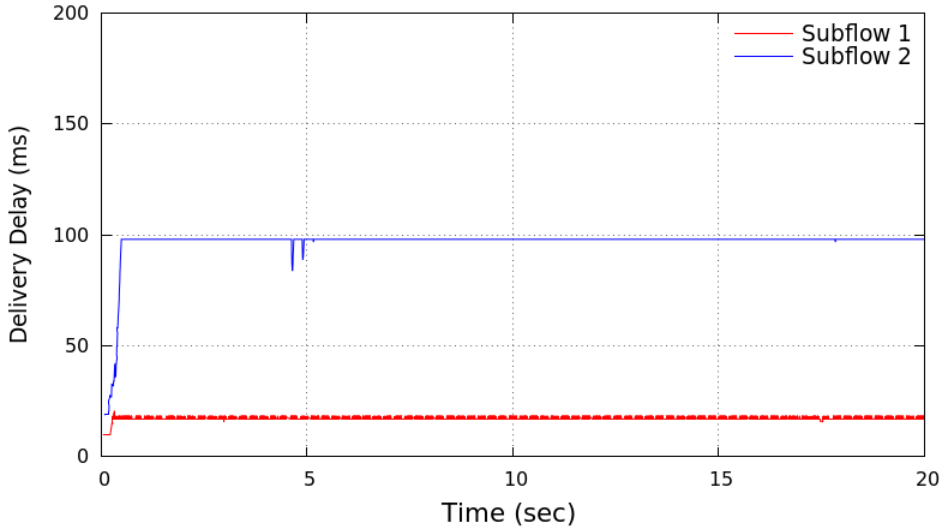


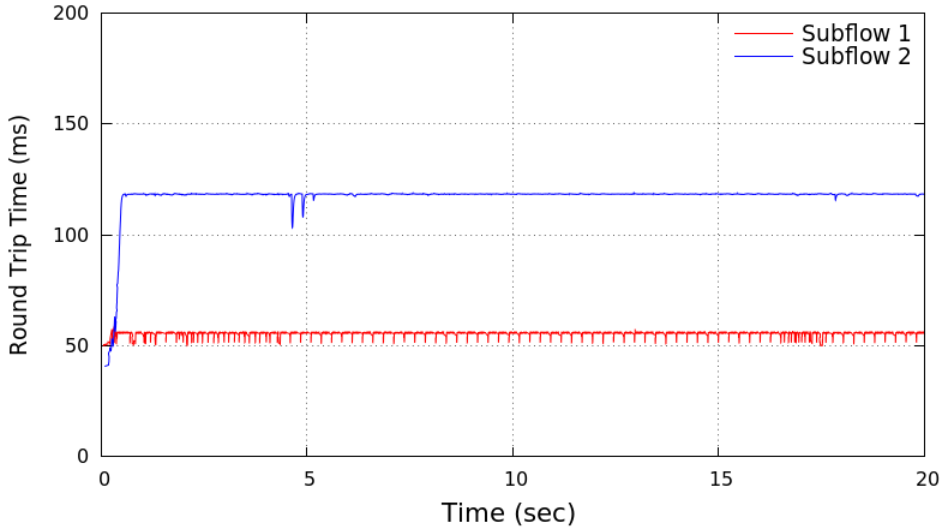


Round Robin Scheduler (20 sec)









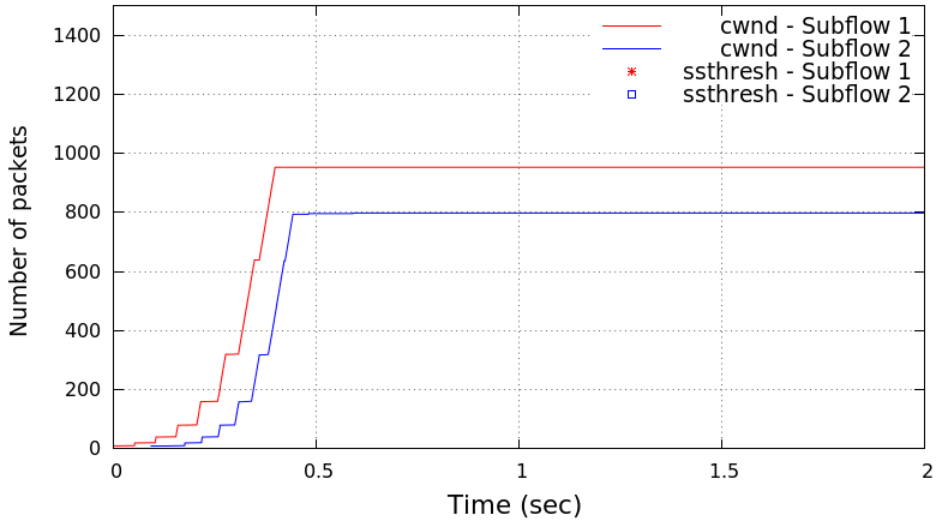
Graphical Analysis

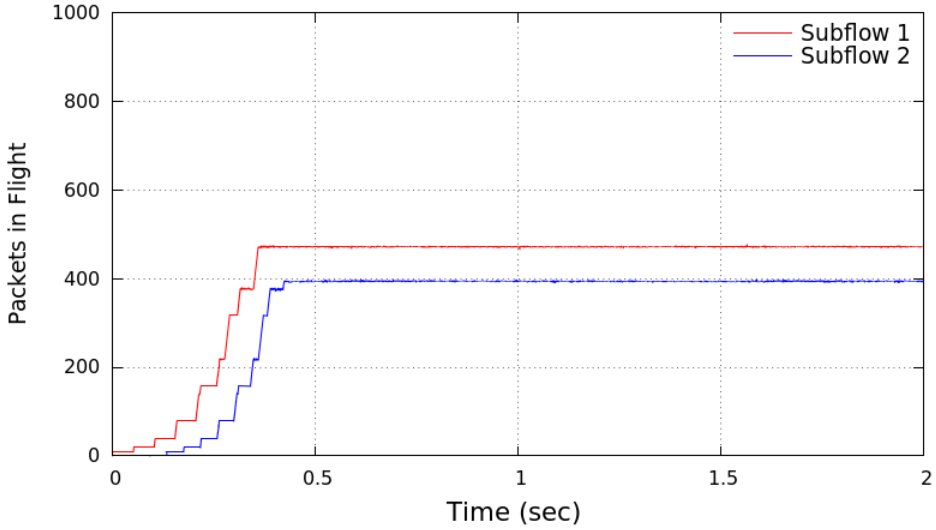
Link Capacity 100/100 (Mbit/sec)

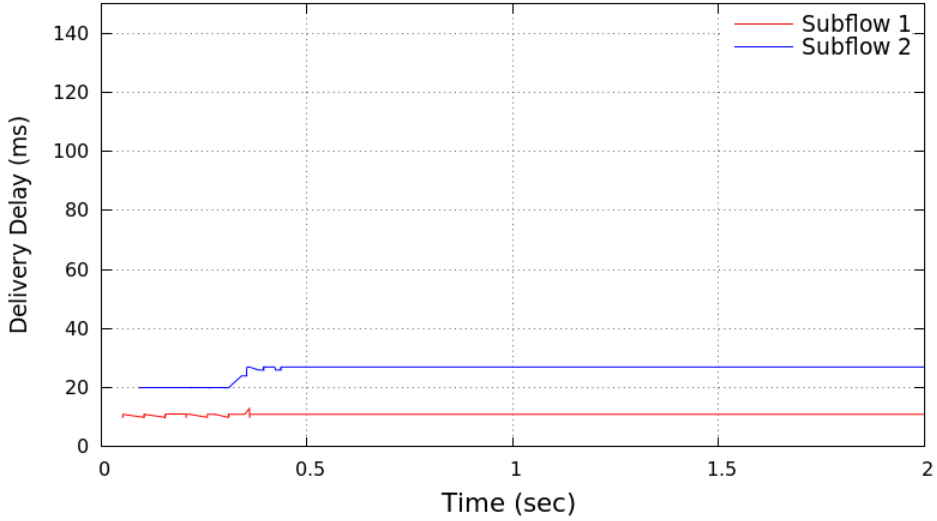
Scenario C

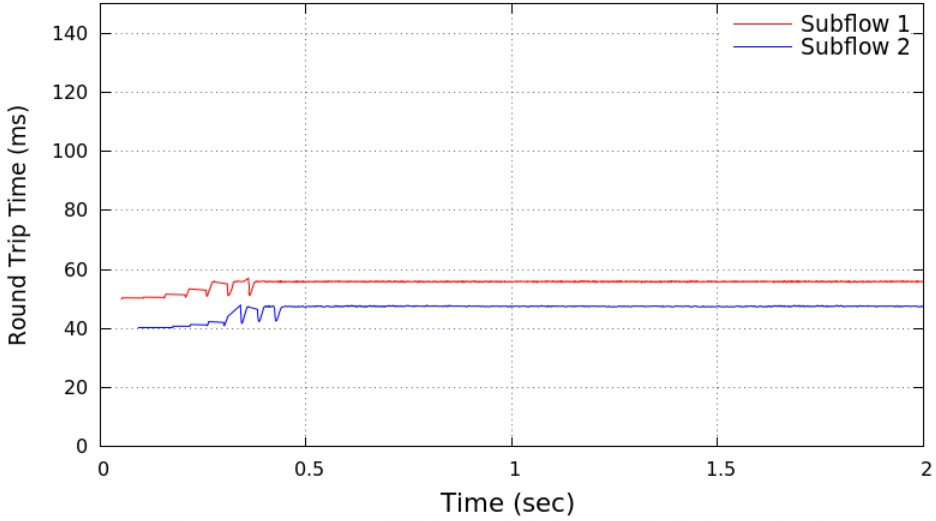
Subflow 1 RTT – 50 ms (10 ms + 40 ms)
Subflow 2 RTT – 40 ms (20 ms + 20 ms)

Delivery Delay Scheduler

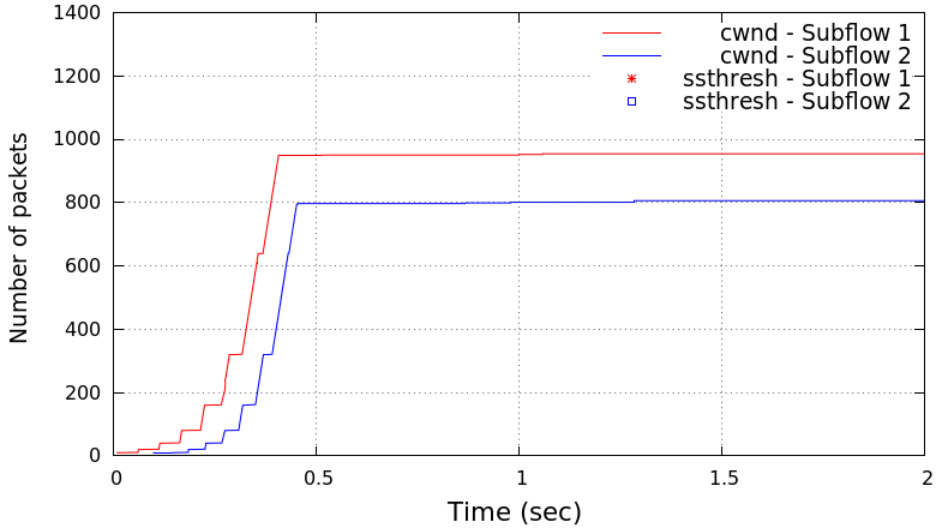


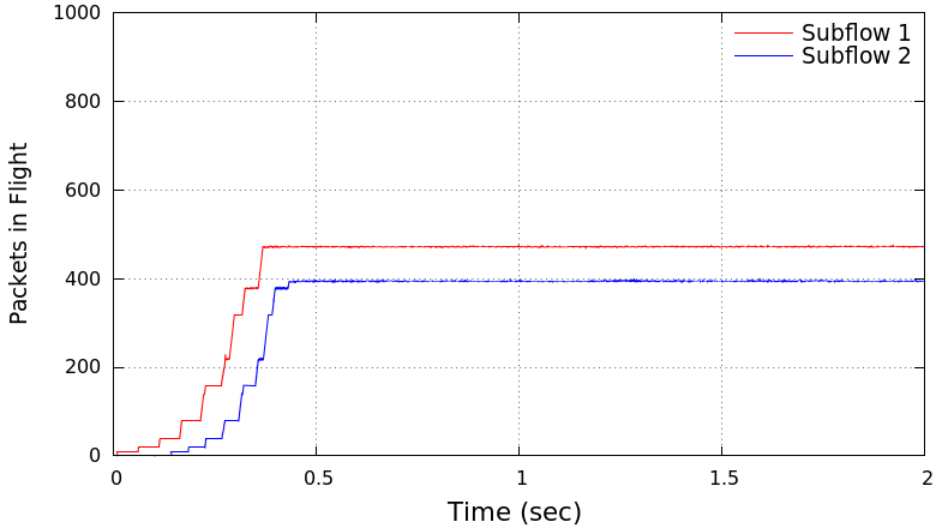


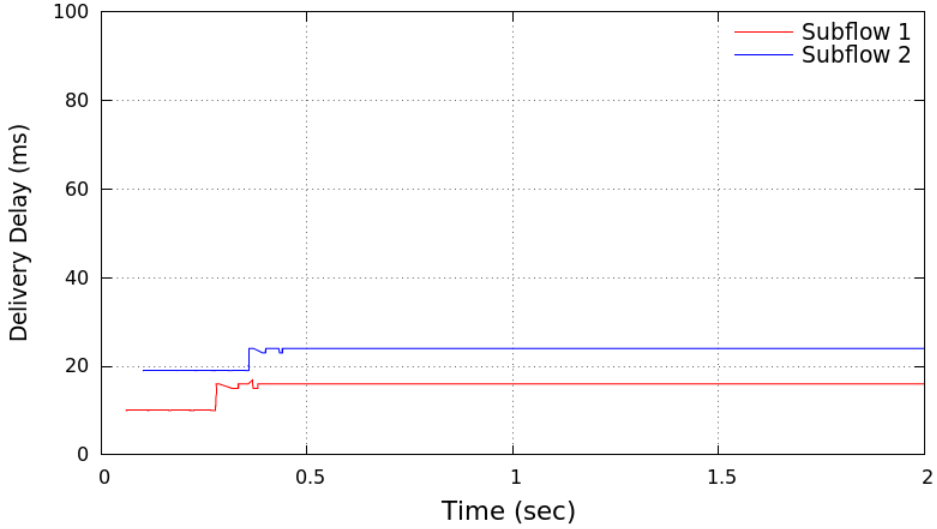


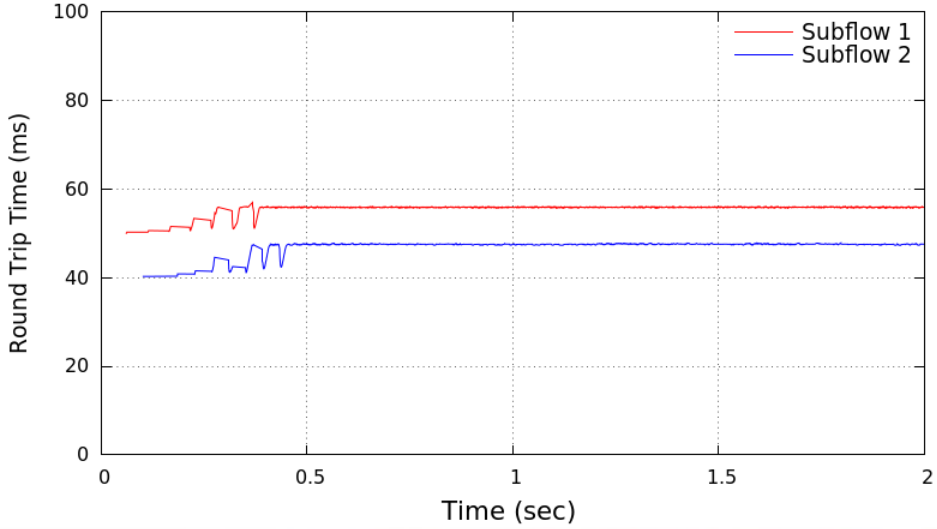


Shortest Round Trip Time Scheduler

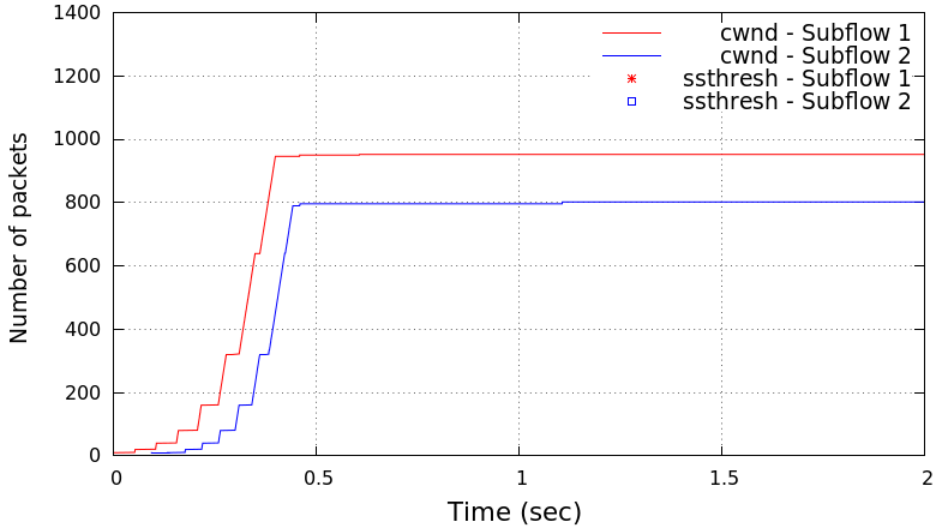


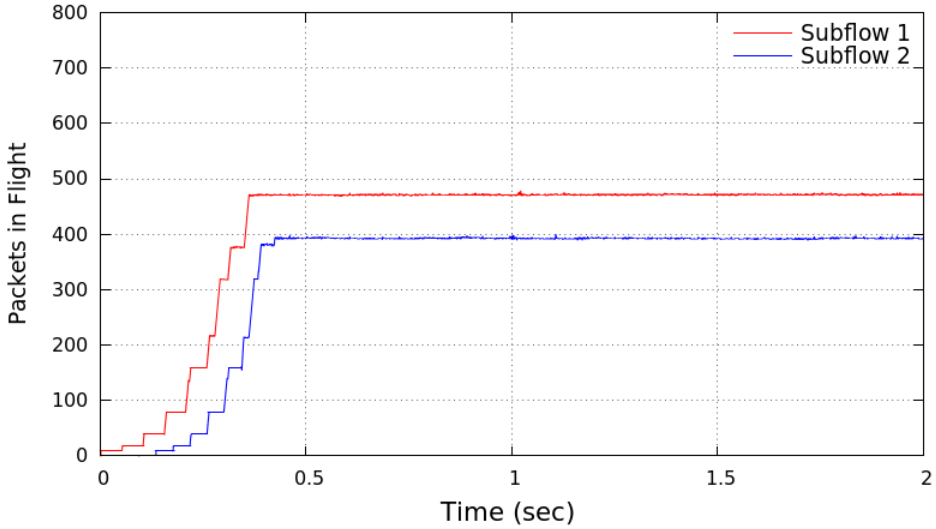


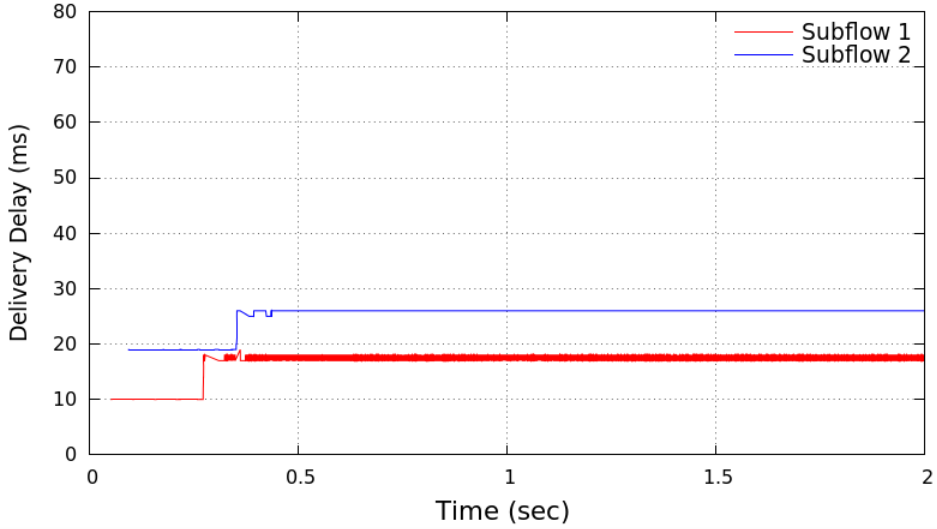


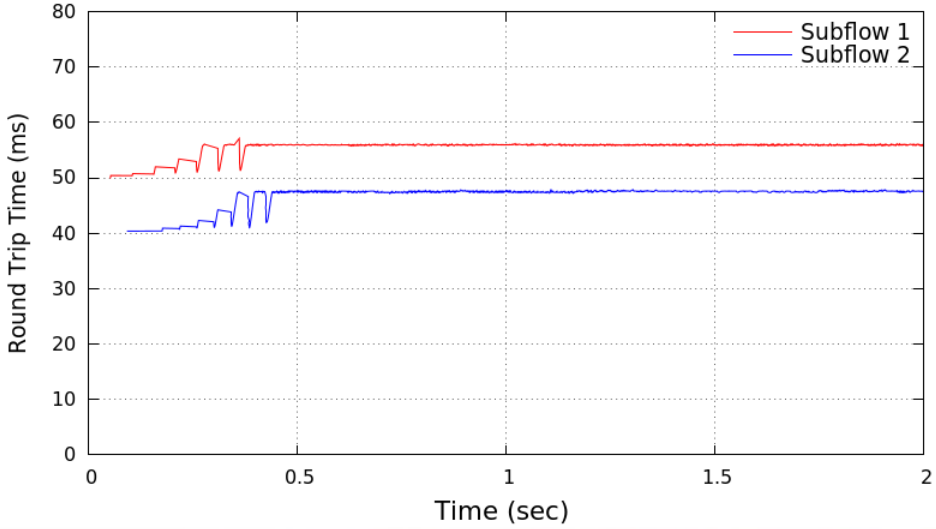


Round Robin Scheduler

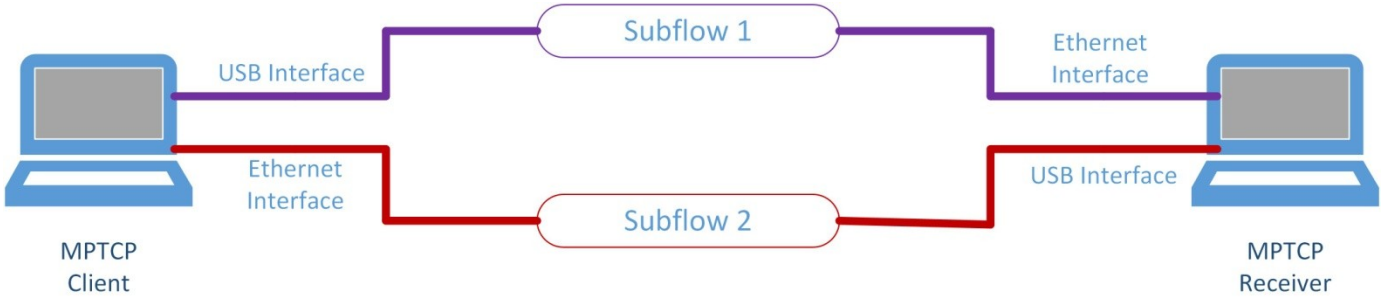








Graphical Analysis – 2 Node without Router



Link Capacity 100/10 (Mbit/sec)

Scenario B

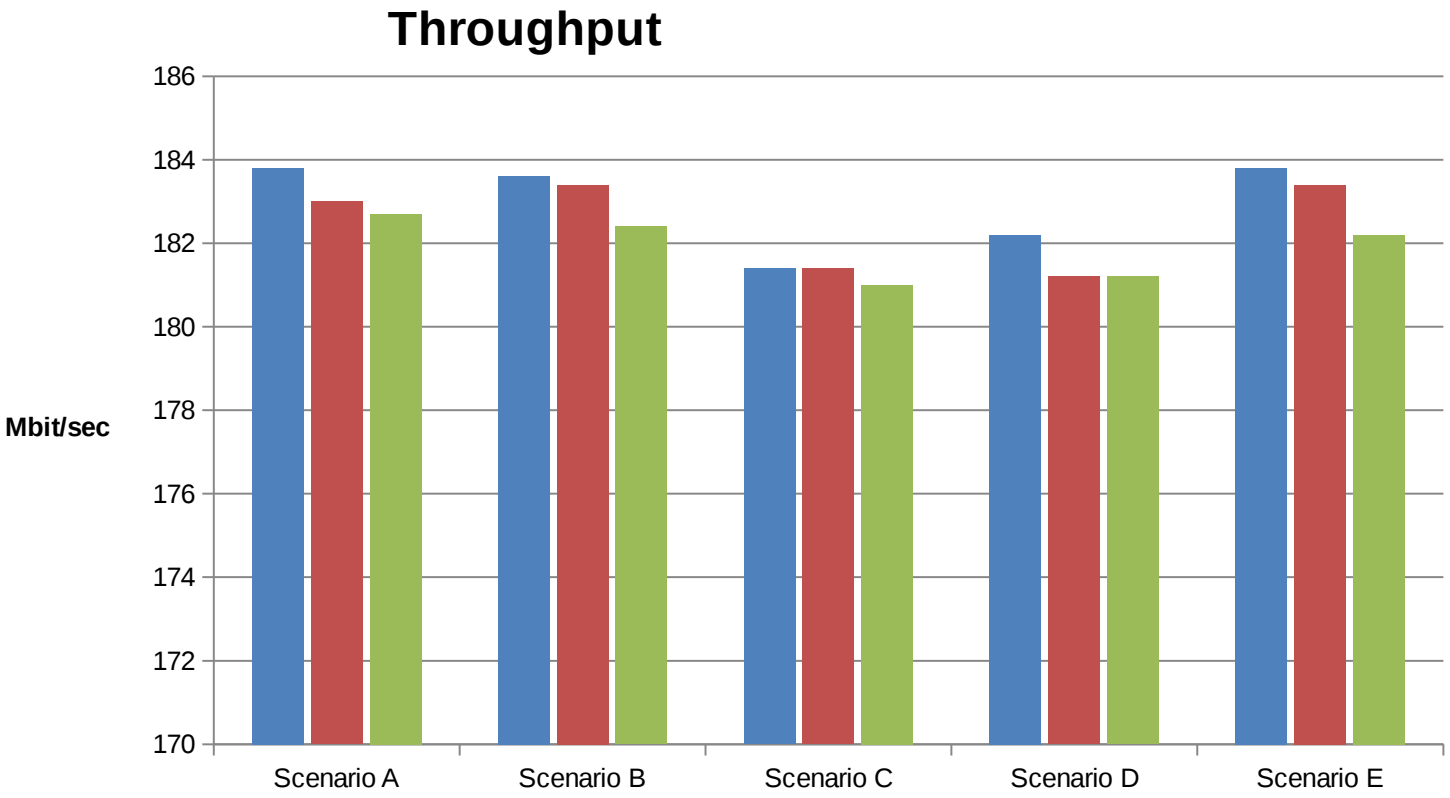
Subflow 1 RTT – 20 ms (10 ms + 10 ms)

Subflow 2 RTT – 30 ms (20 ms + 10 ms)

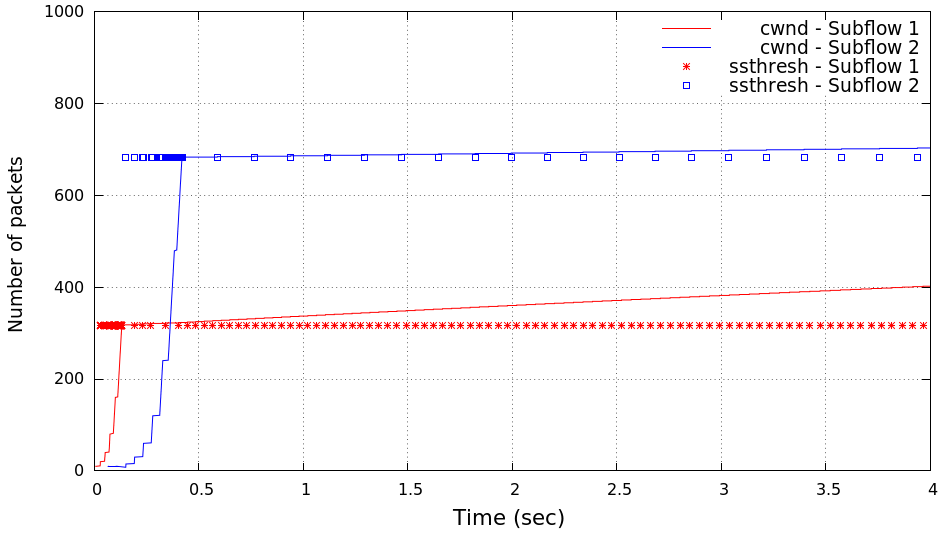
Scenarios

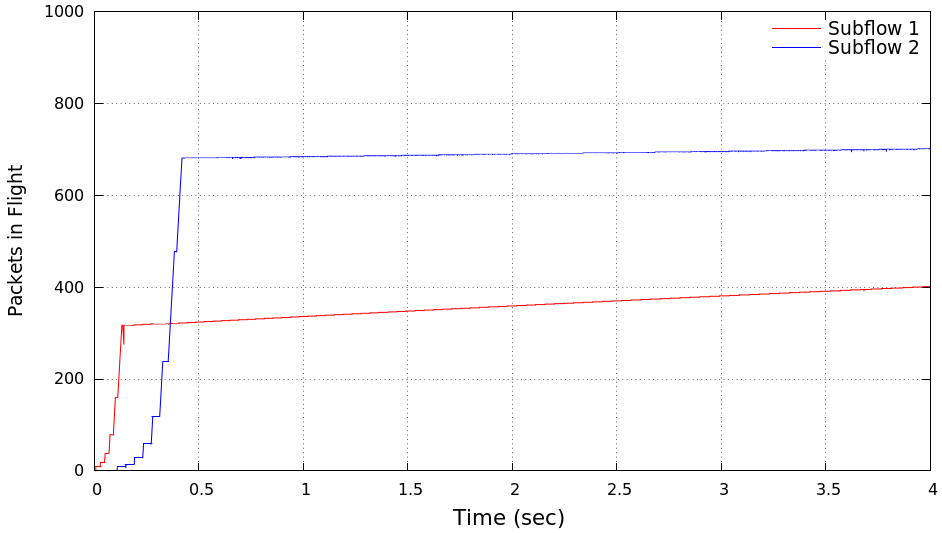
Capacity	Name Of scenarios	Subflow 1			Subflow 2			TCP Flow		
		FPD (ms)	BPD (ms)	RTT (ms)	FPD (ms)	BPD (ms)	RTT (ms)	FPD (ms)	BPD (ms)	RTT (ms)
100/100 & 100/10 & 10/10	A	10	20	30	20	10	30	10	20	30
	B	10	10	20	20	10	30	10	10	20
	C	10	40	50	20	20	40	10	40	50
	D	10	20	30	20	40	60	10	20	30
	E	10	10	20	20	20	40	10	10	20

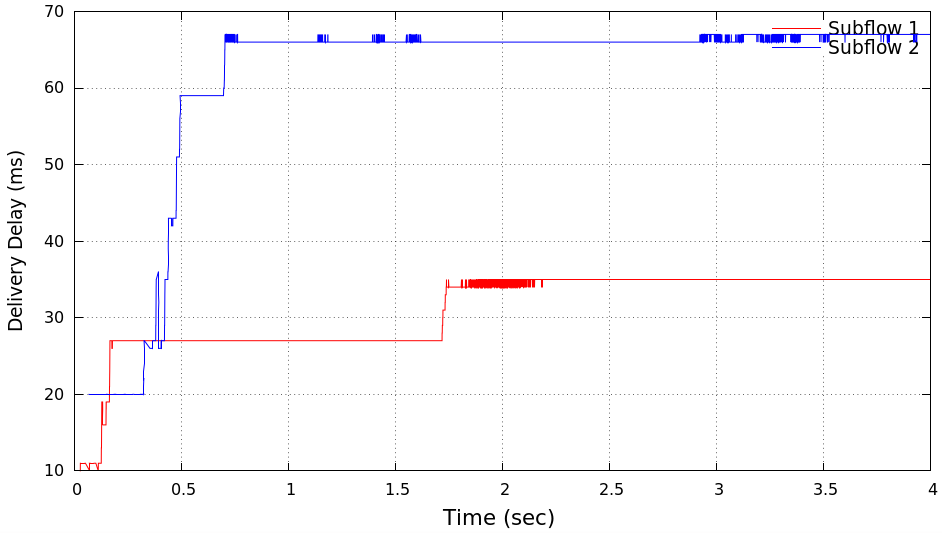
Link Capacity 100/100 (Mbit/sec)

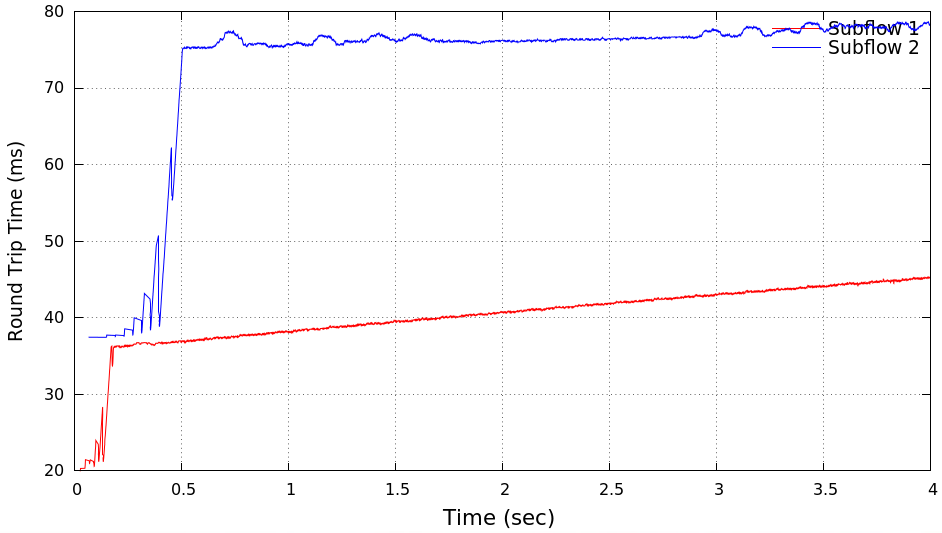


Shortest Round Trip Time Scheduler – E (100/100)

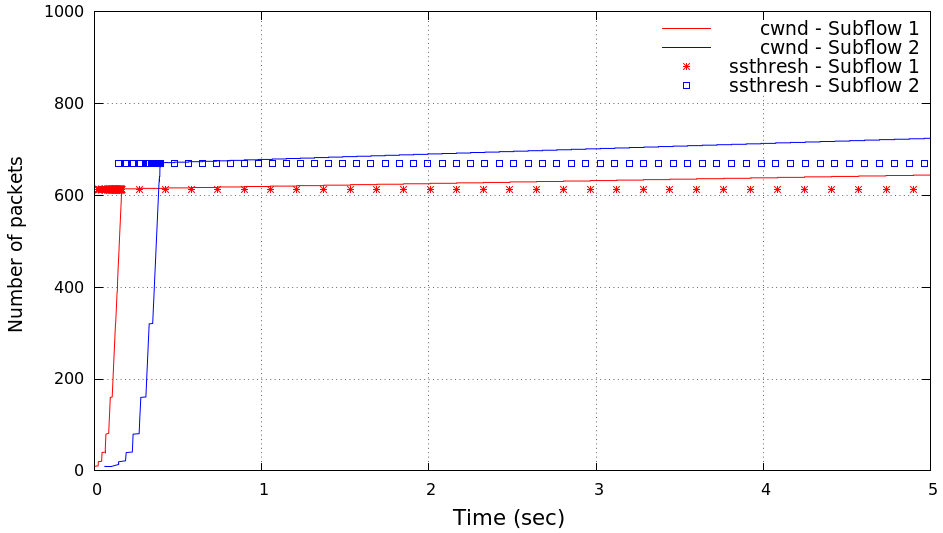


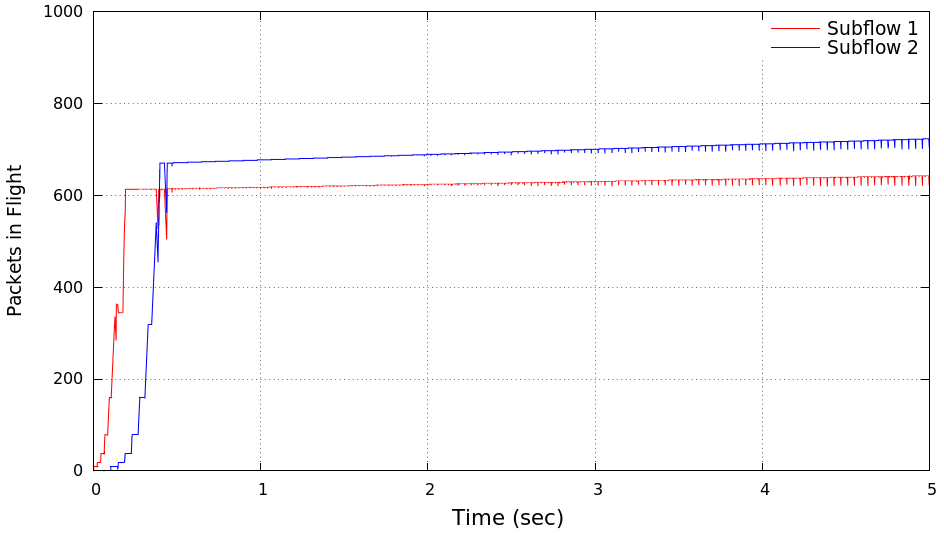


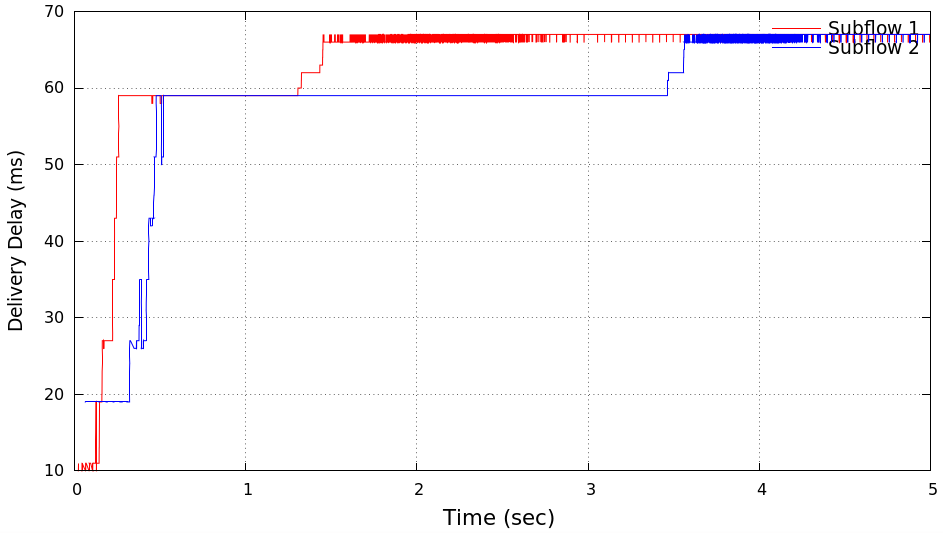


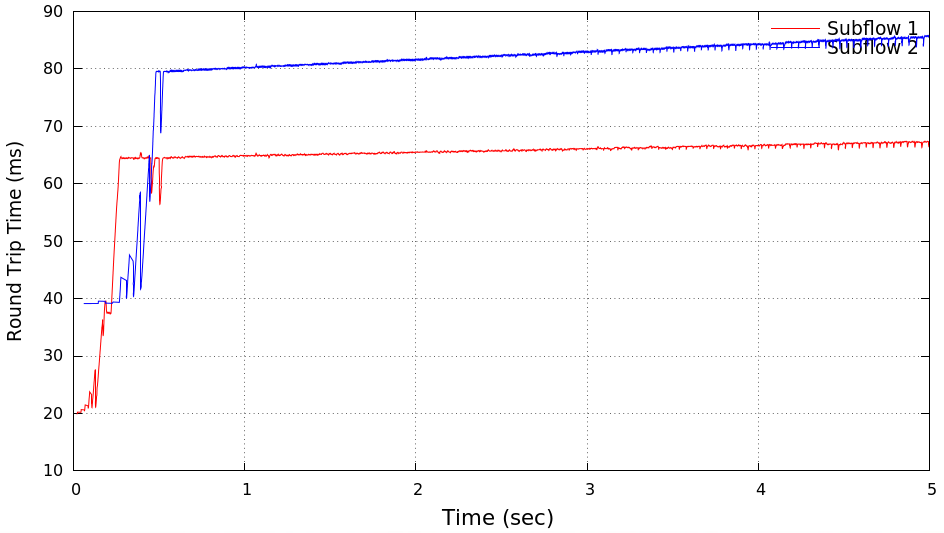


Round Robin Scheduler - E (100/100)

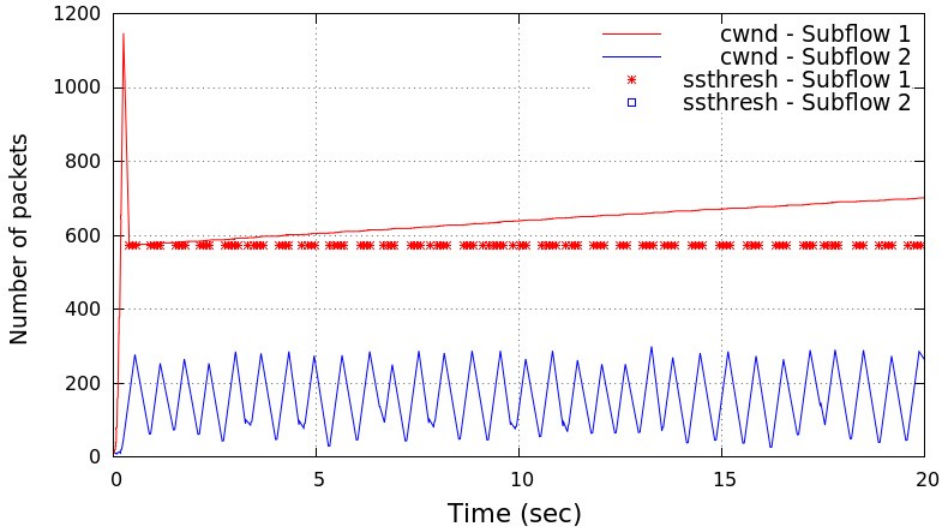


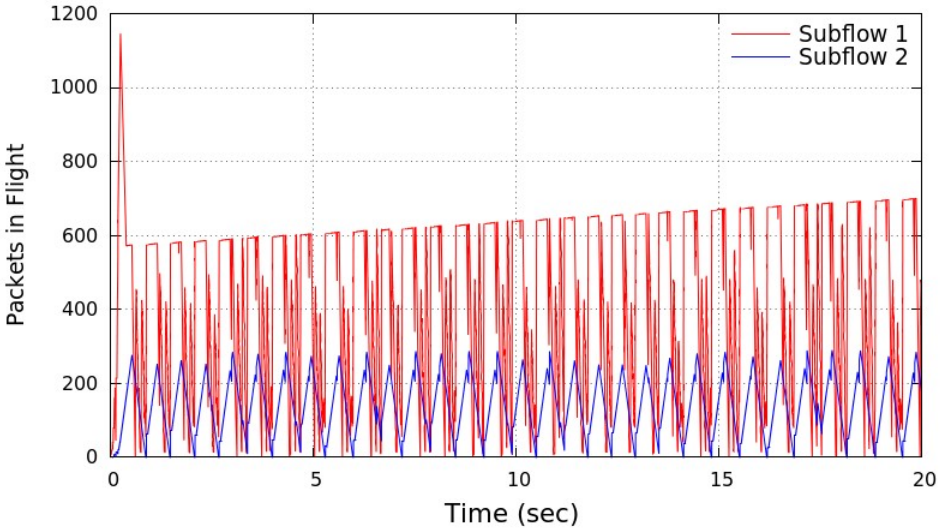


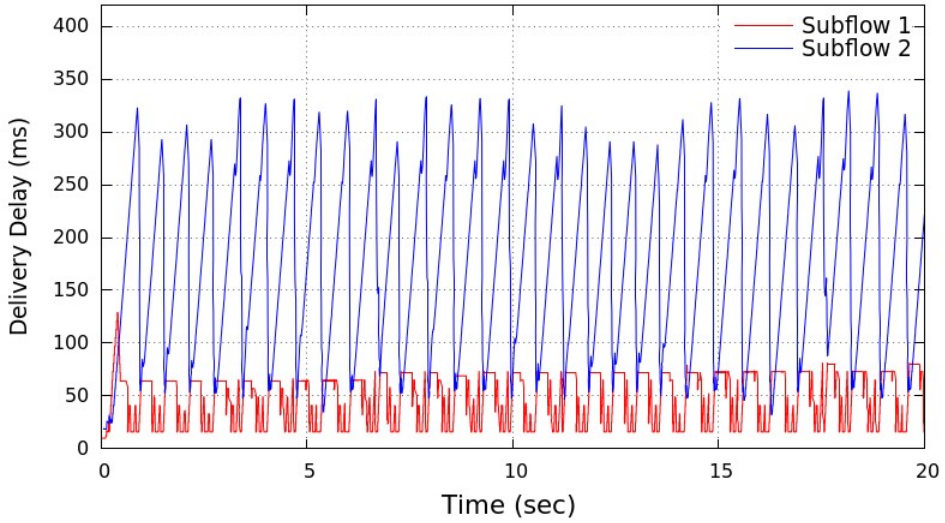


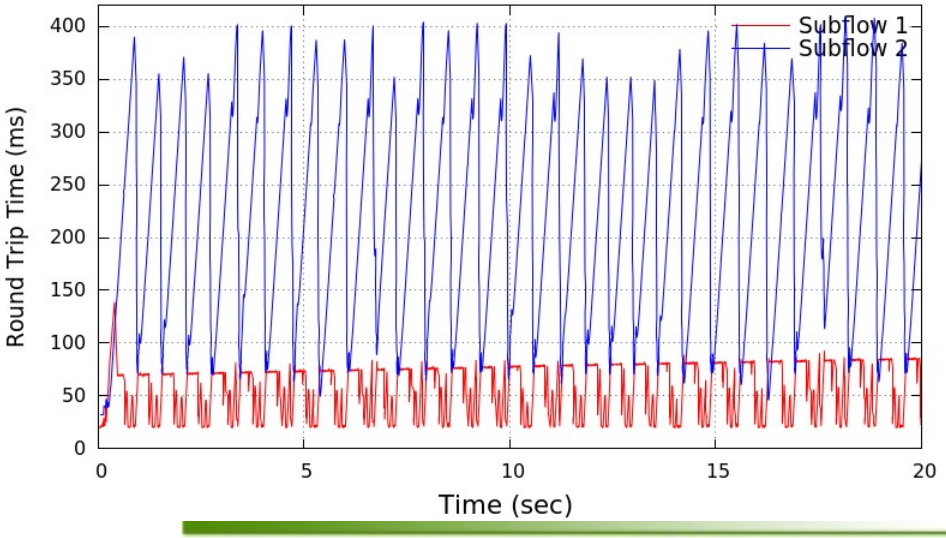


Delivery Delay Scheduler

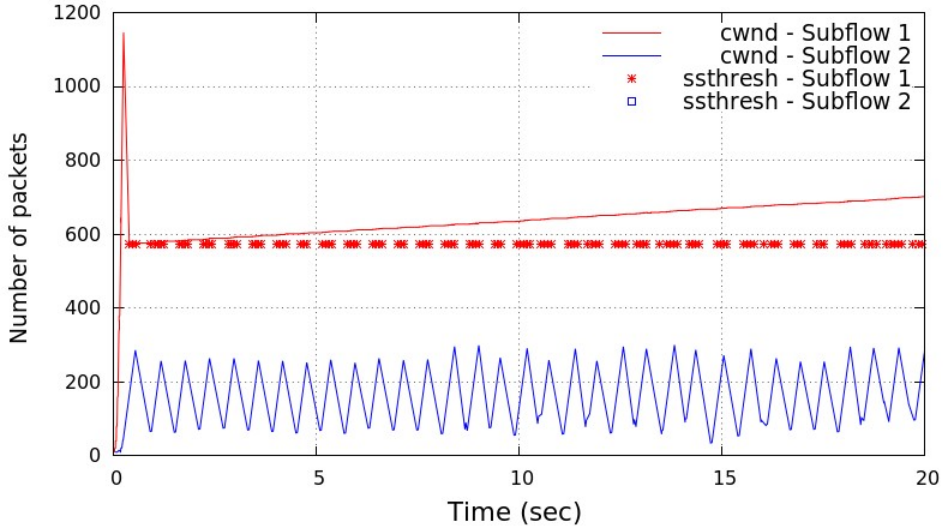


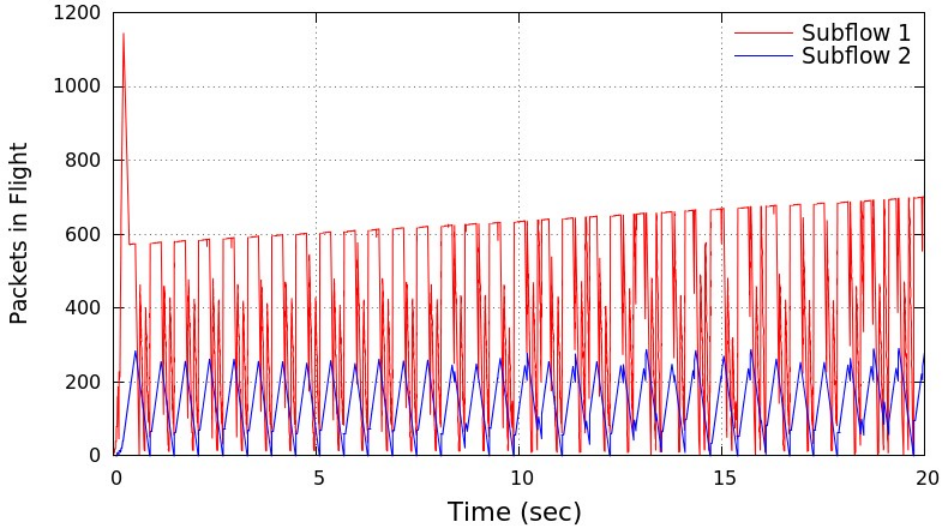


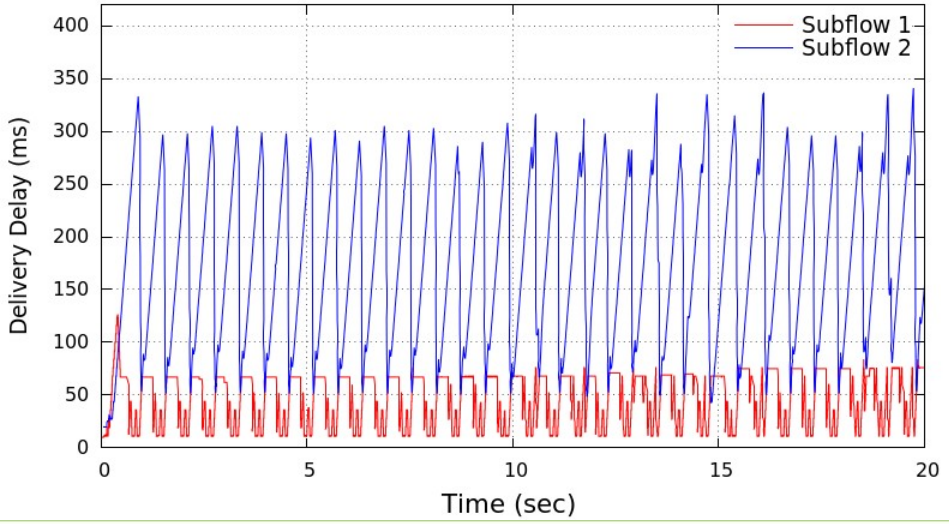


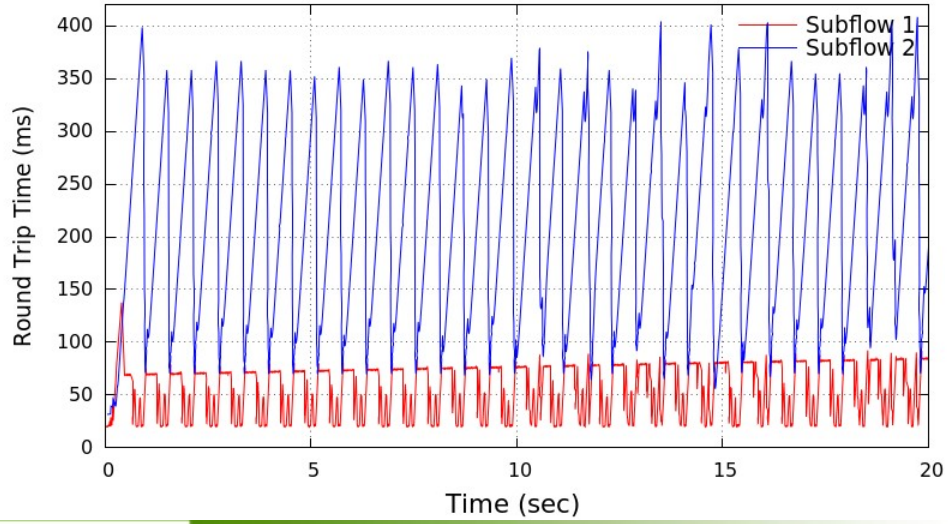


Shortest Round Trip Scheduler Scheduler

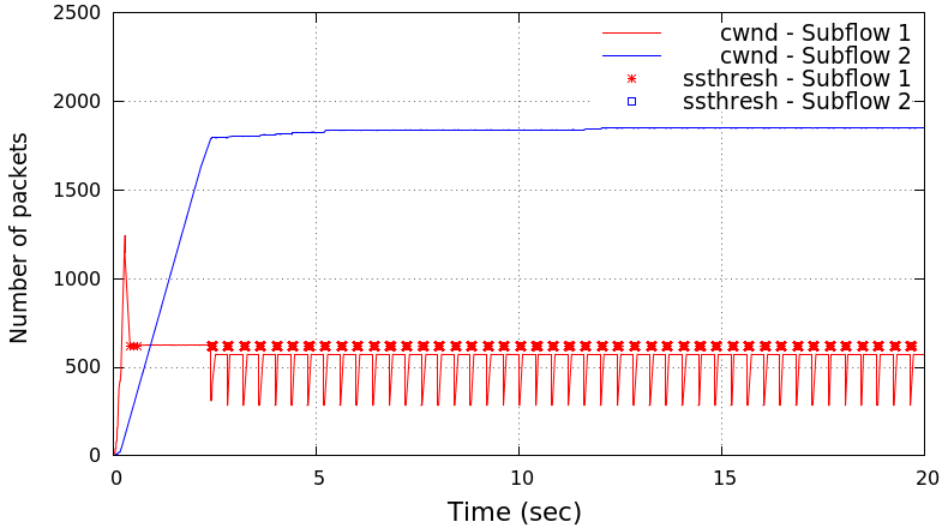


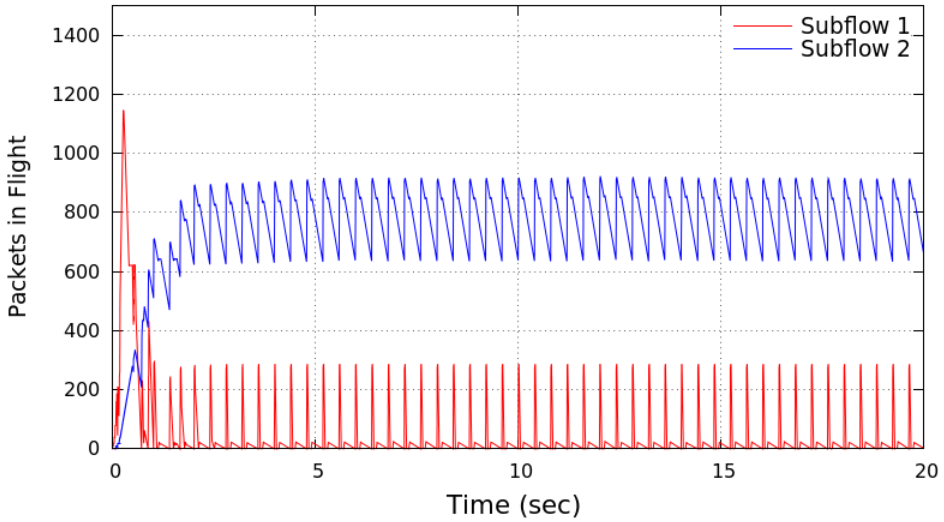


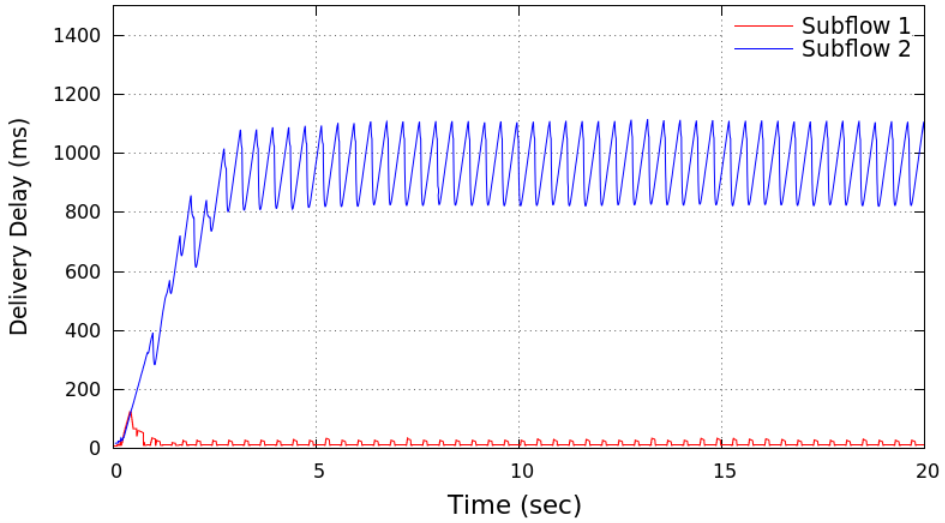


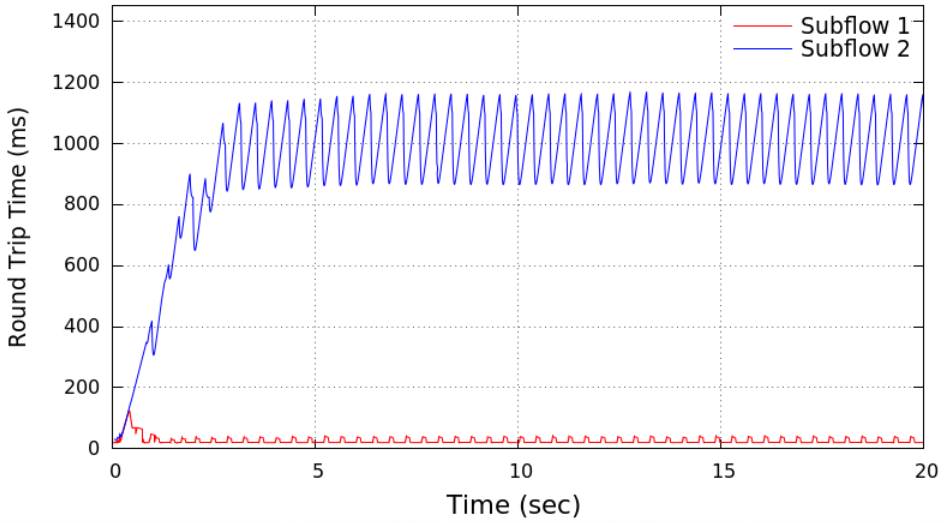


Round Robin Scheduler









Test Topology – Extended Testbed

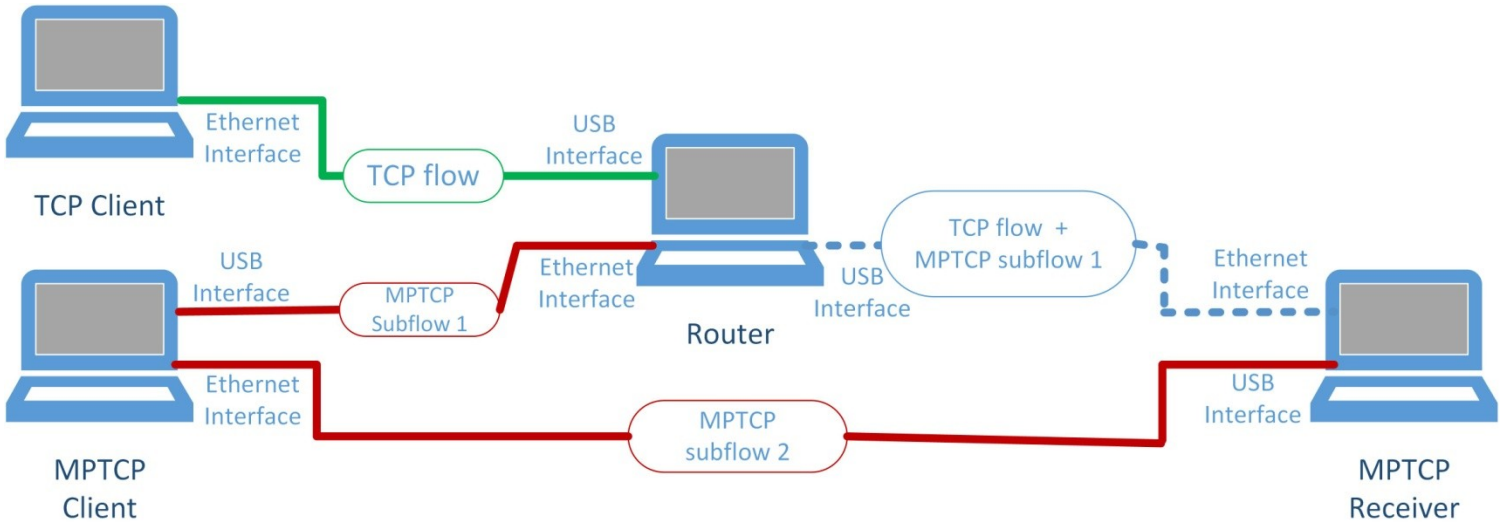
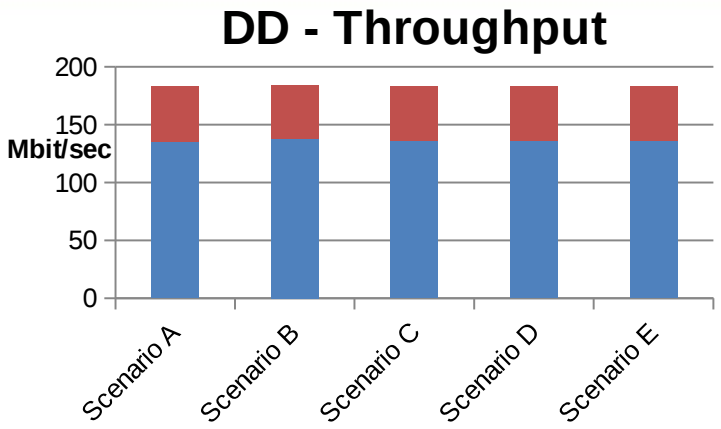
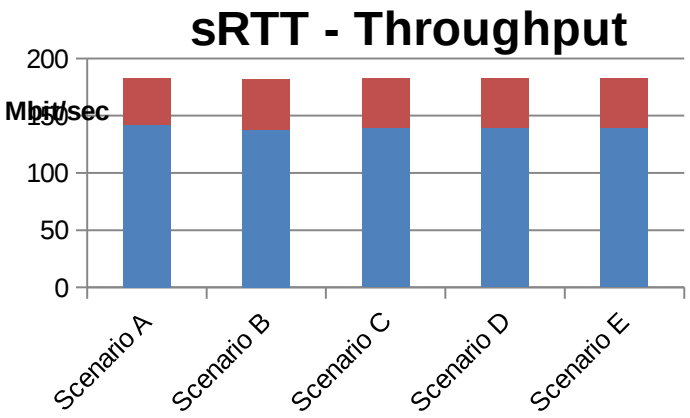
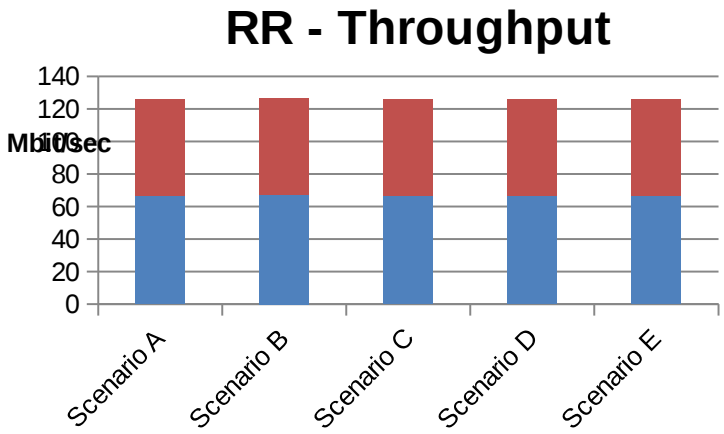


Figure : Extended Testbed

Throughput Comparison







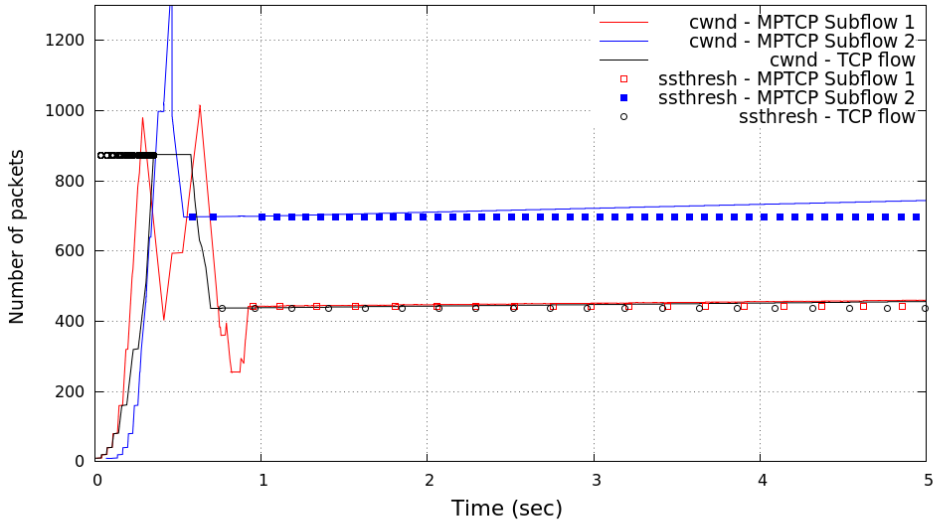
Graphical Analysis – Extended Testbed

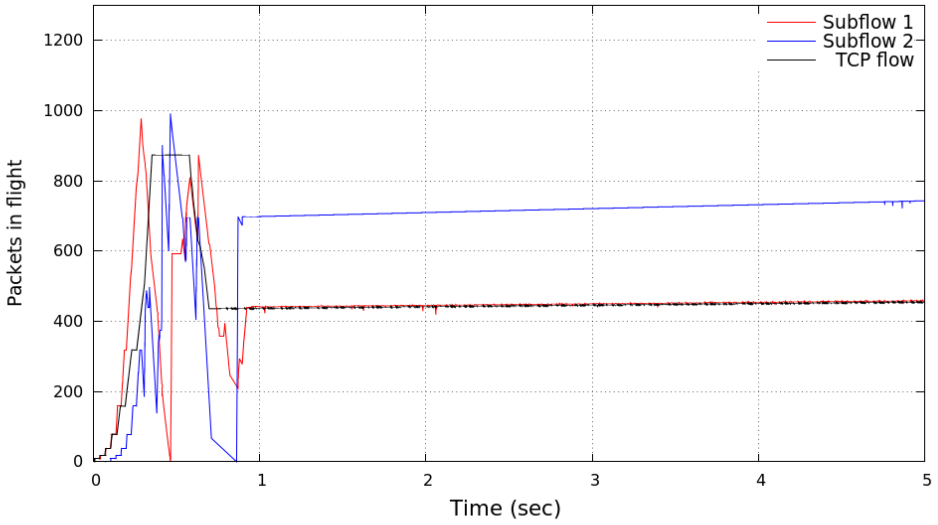
Link Capacity 100/100 (Mbit/sec)

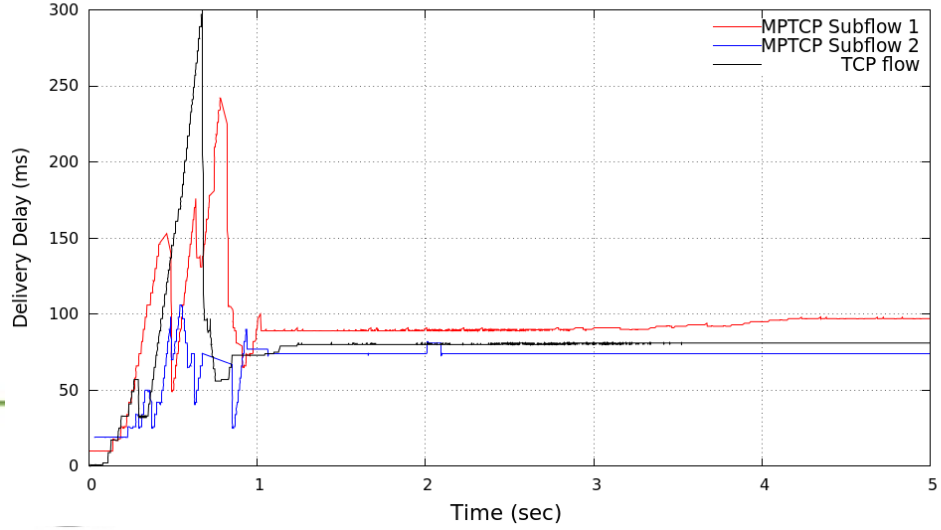
Scenario A

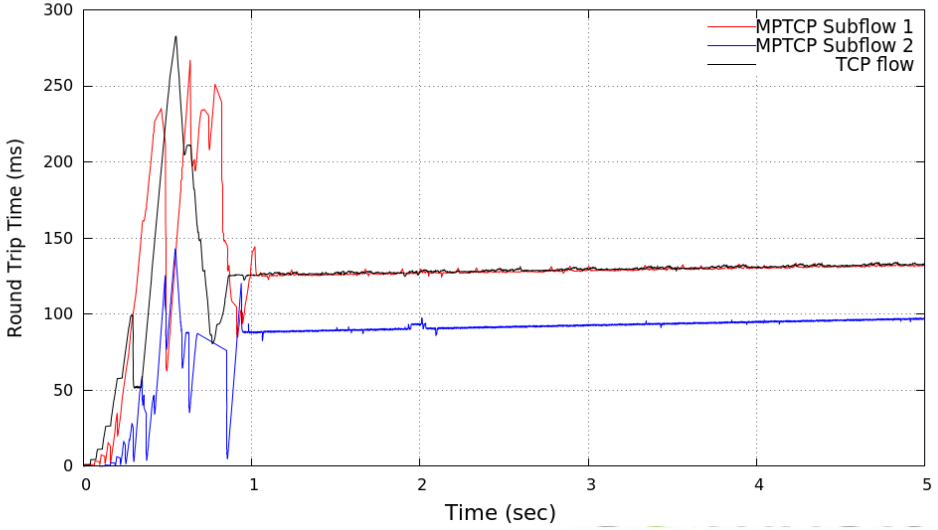
Subflow 1 RTT – 30 ms (10 ms +20 ms)
Subflow 2 RTT – 30 ms (20 ms + 10 ms)

Delivery Delay Scheduler

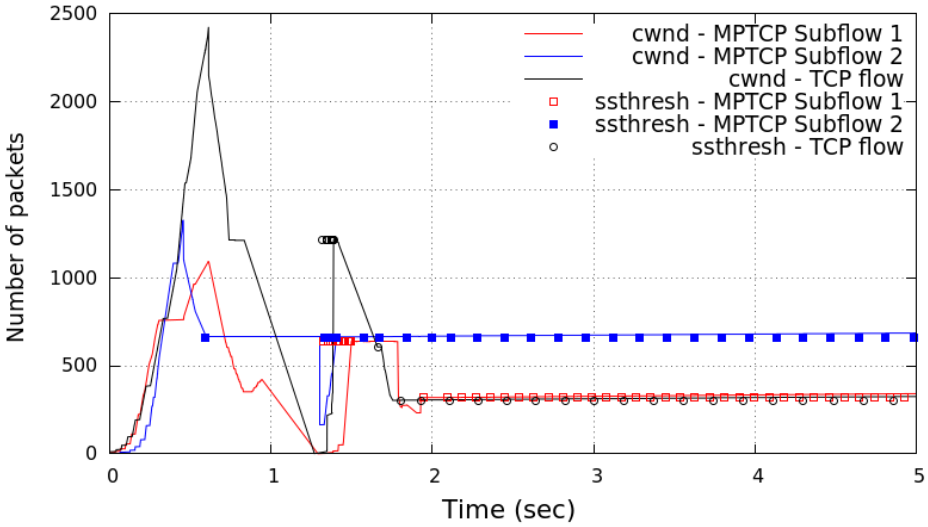


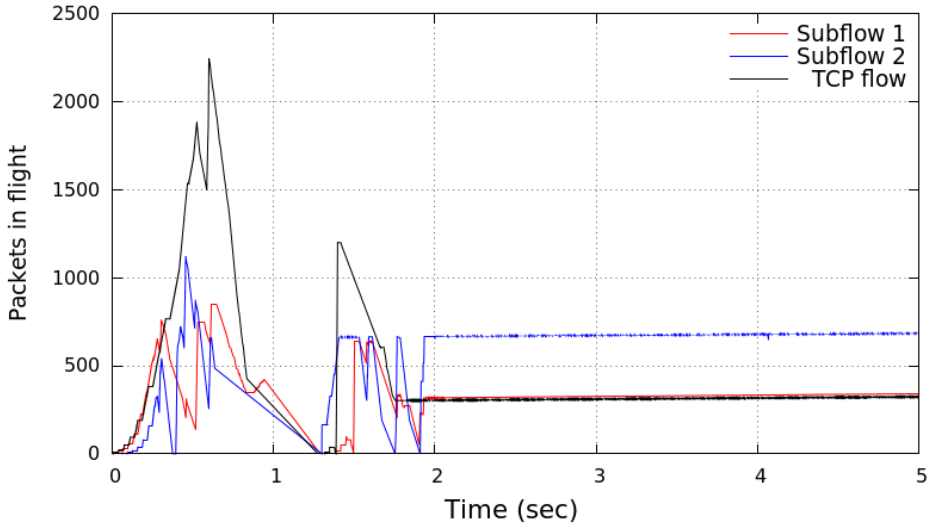


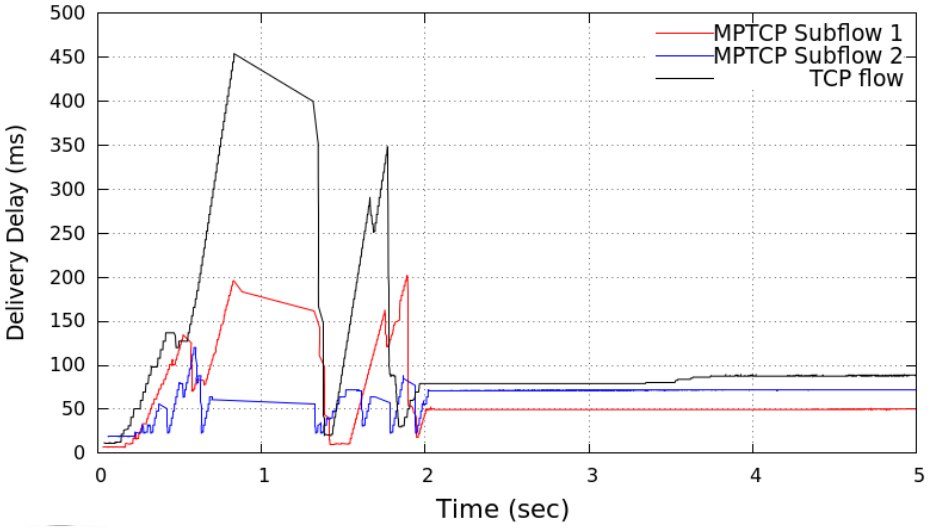


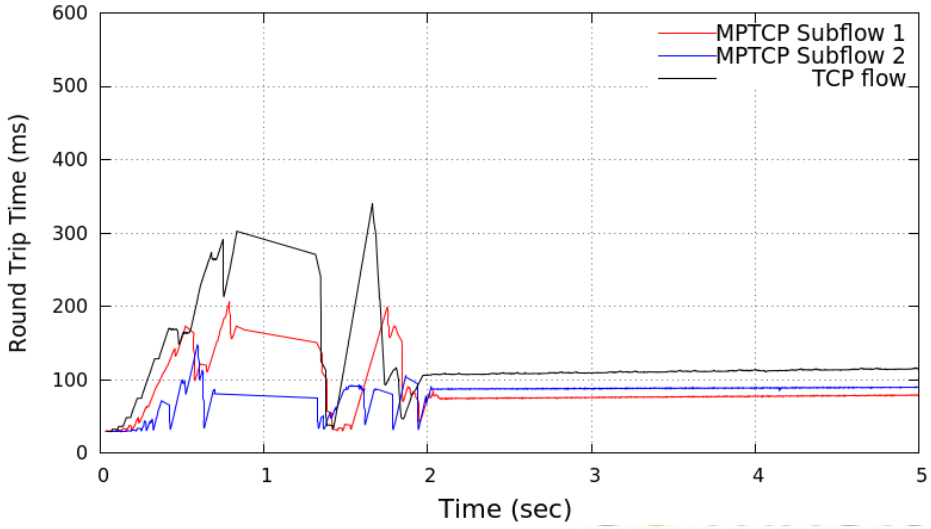


Round Trip Time Scheduler

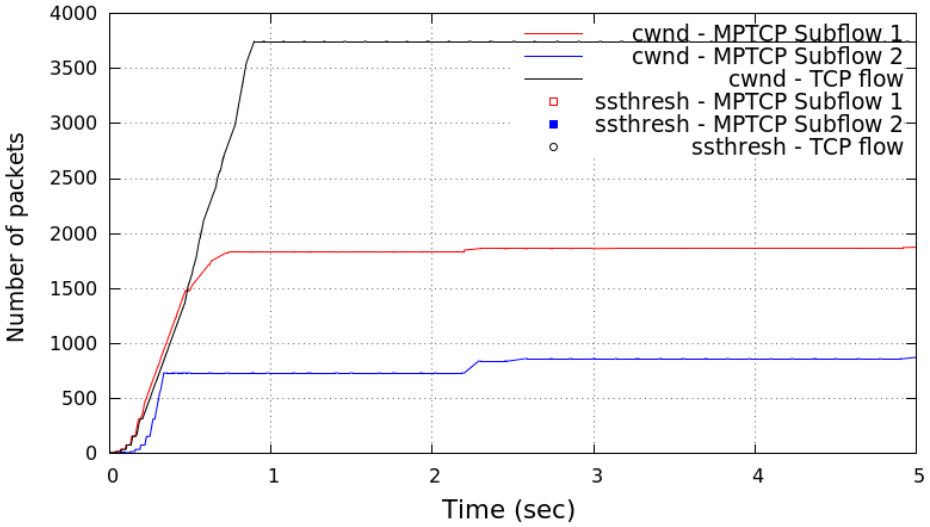


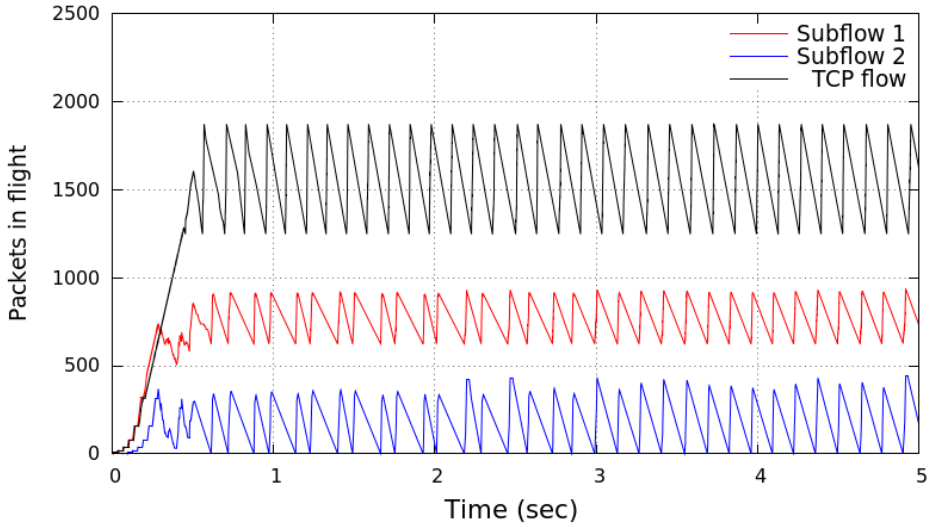


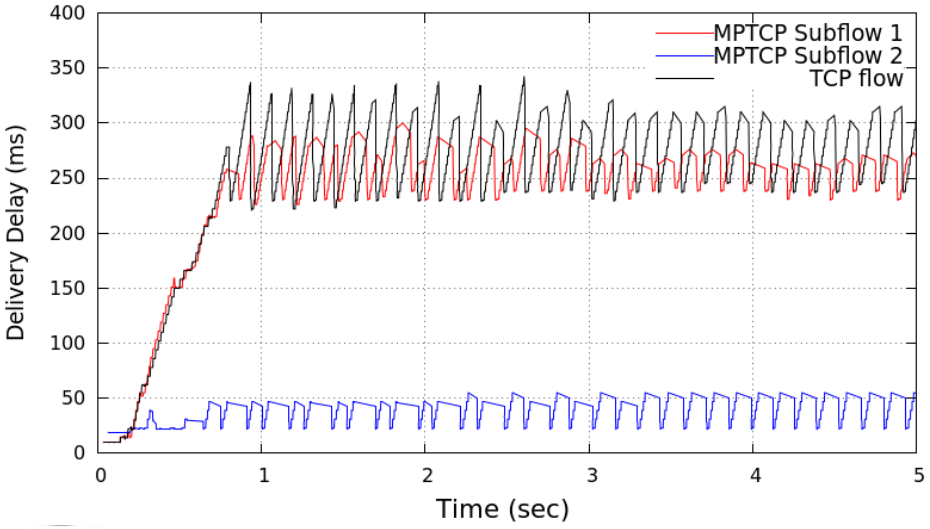


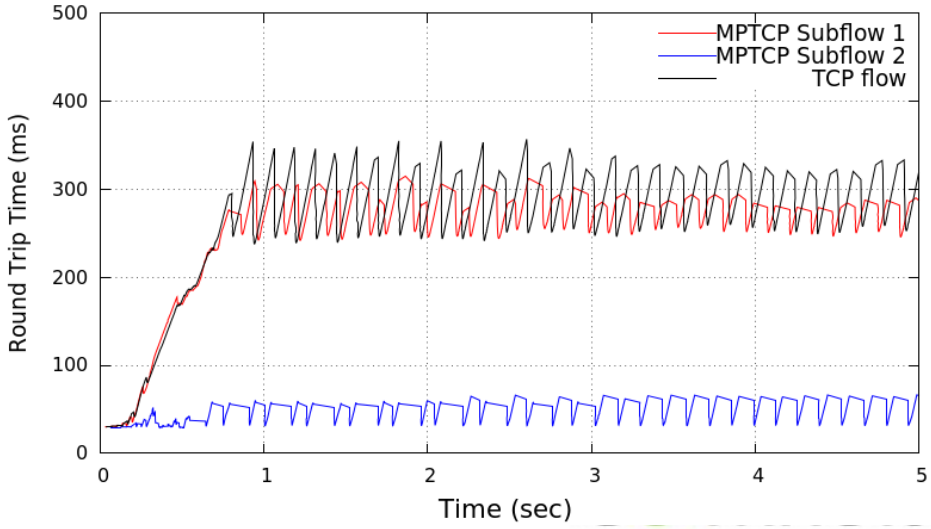


Round Robin Scheduler

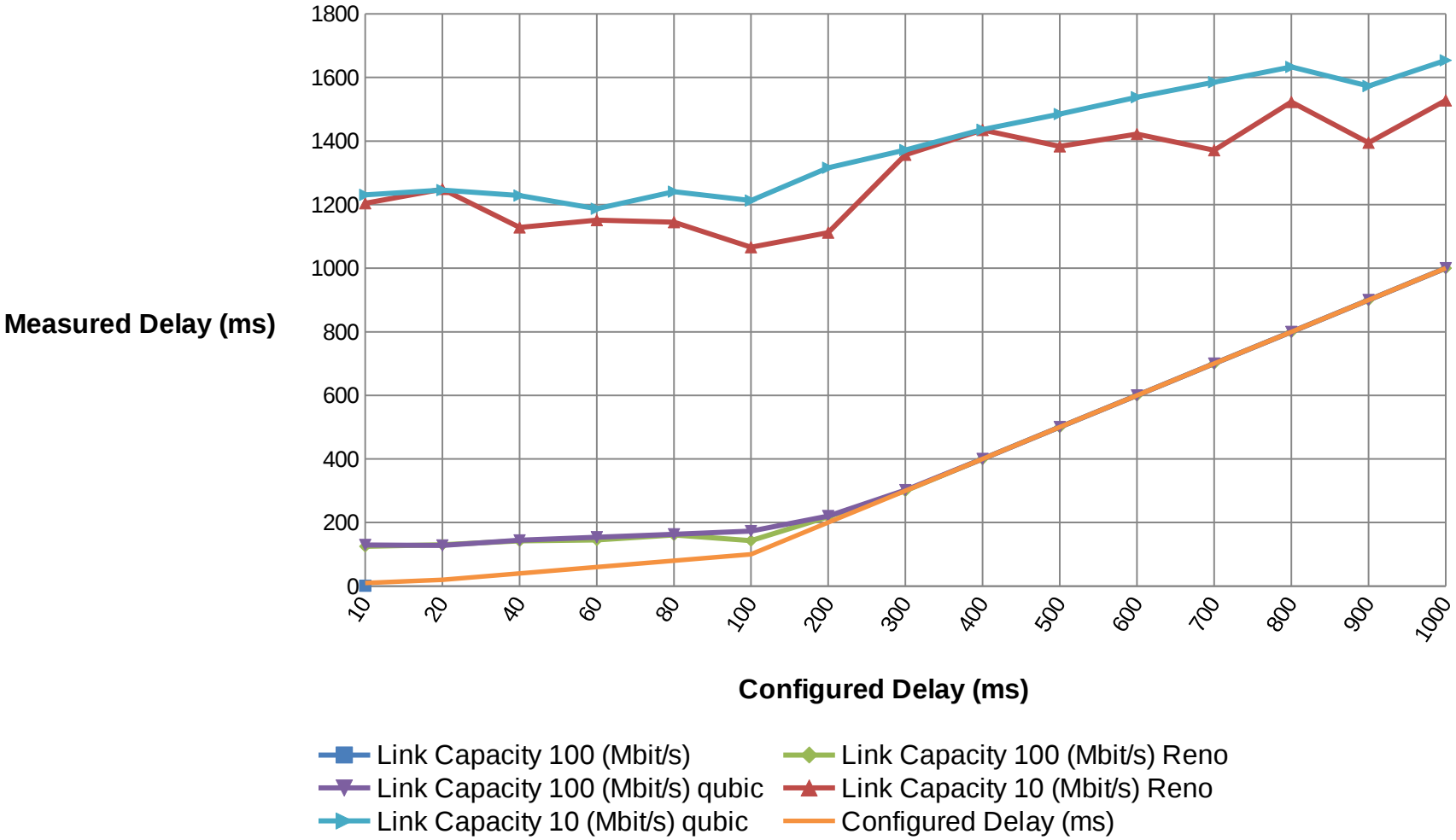




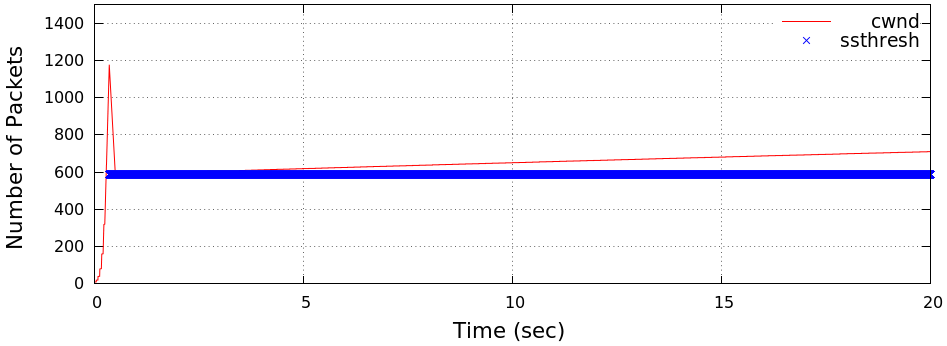


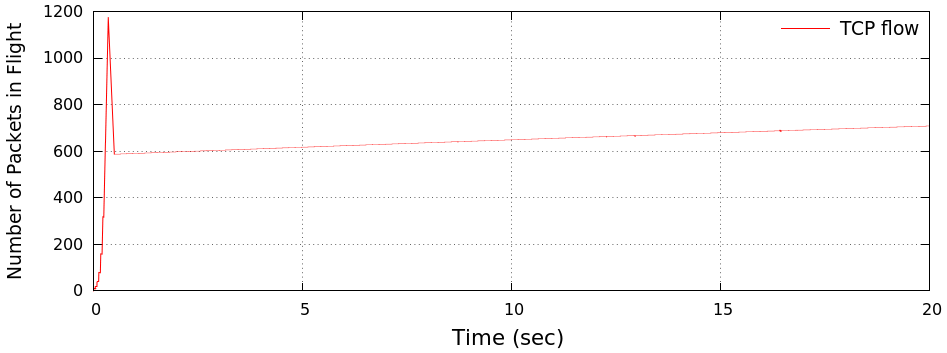


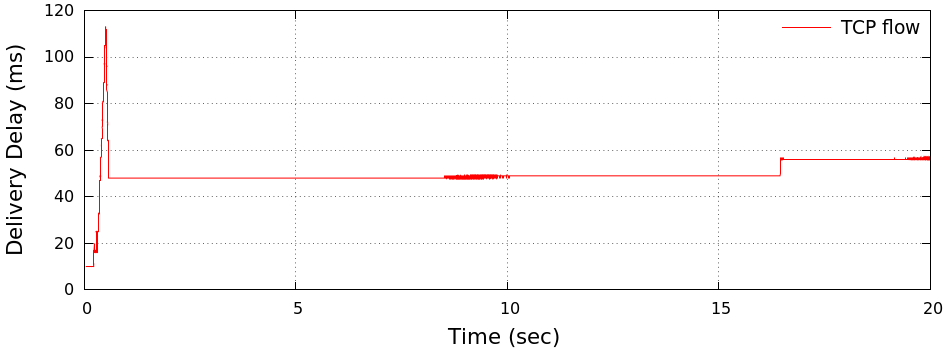
TCP – Measured Delay Vs Configured Delay

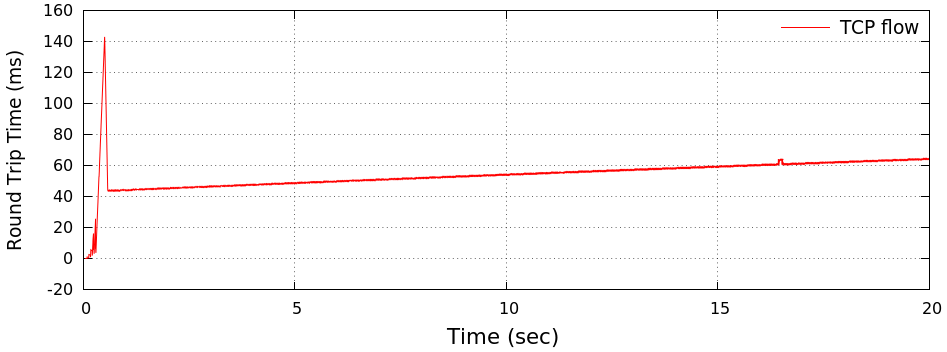


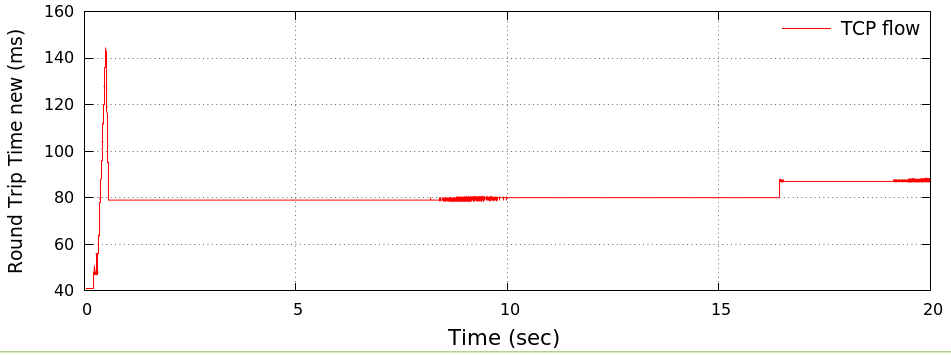
TCP – Link Capacity 100 (Mbit/sec), Delay - 40ms (20ms + 20ms)

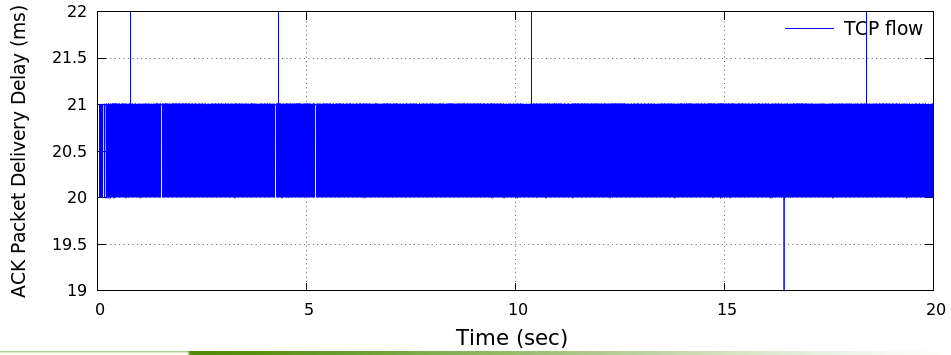




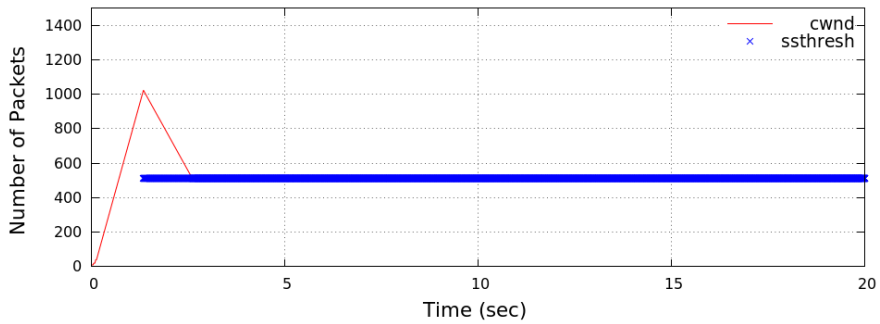


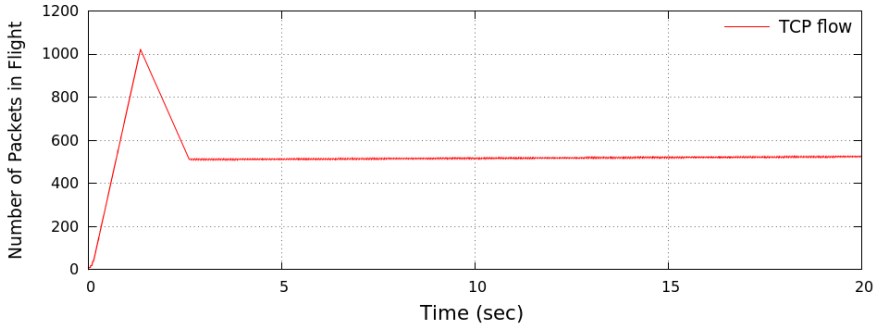


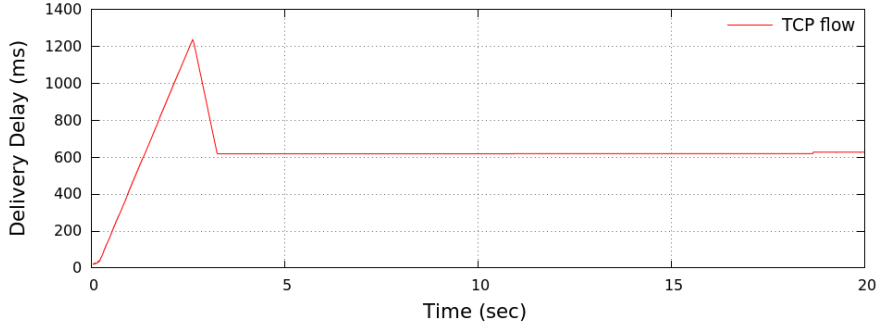


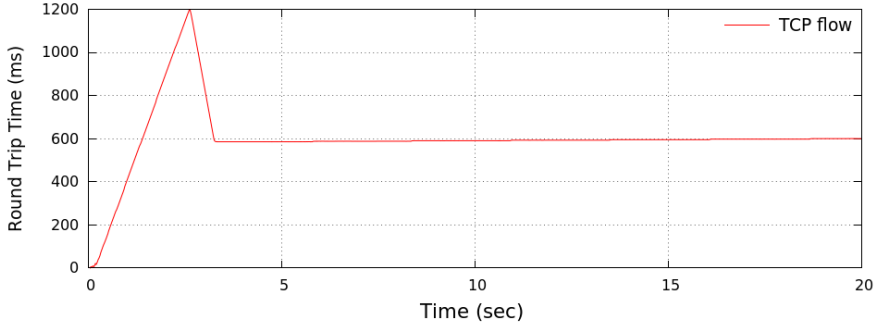


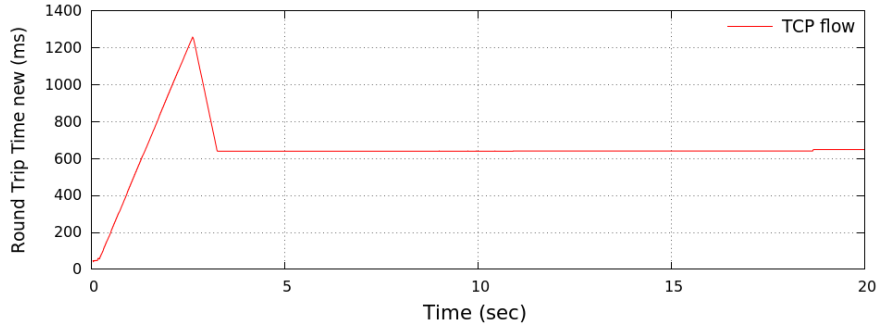
TCP – Link Capacity 10 (Mbit/sec), Delay - 40ms (20ms + 20ms)

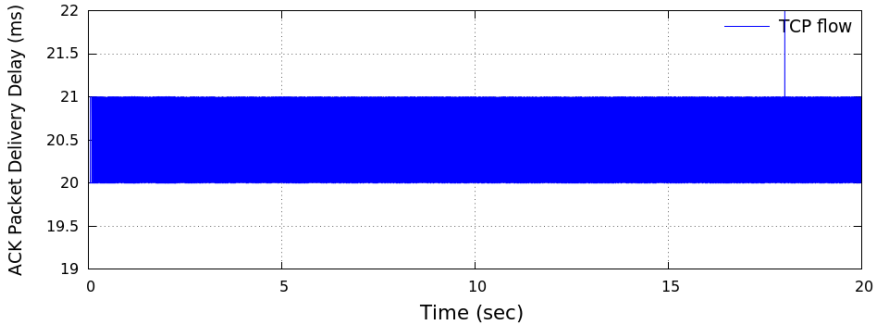






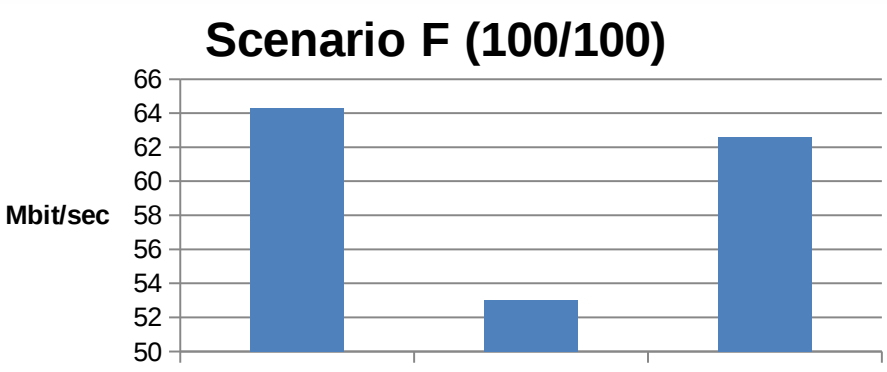


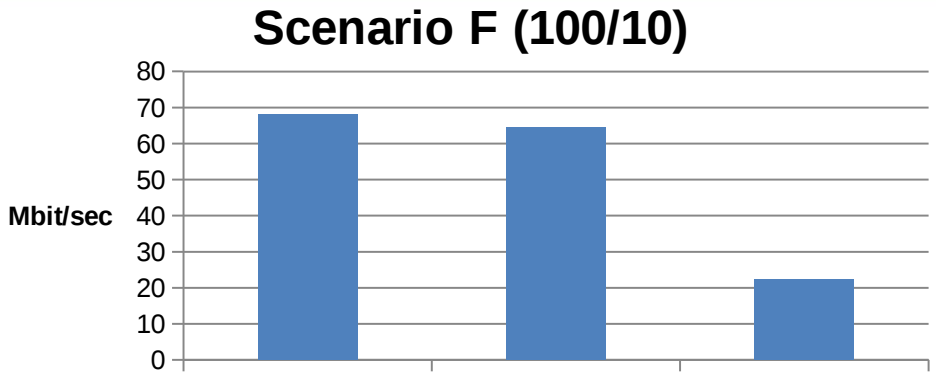


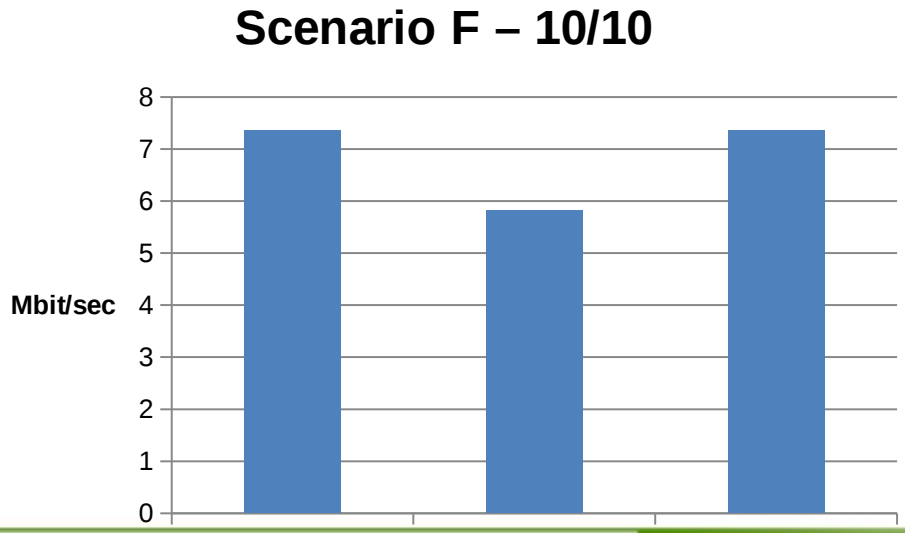


Simple Testbed
Link Capacity – 100 / 100 (Mbit/sec)
Scenario F

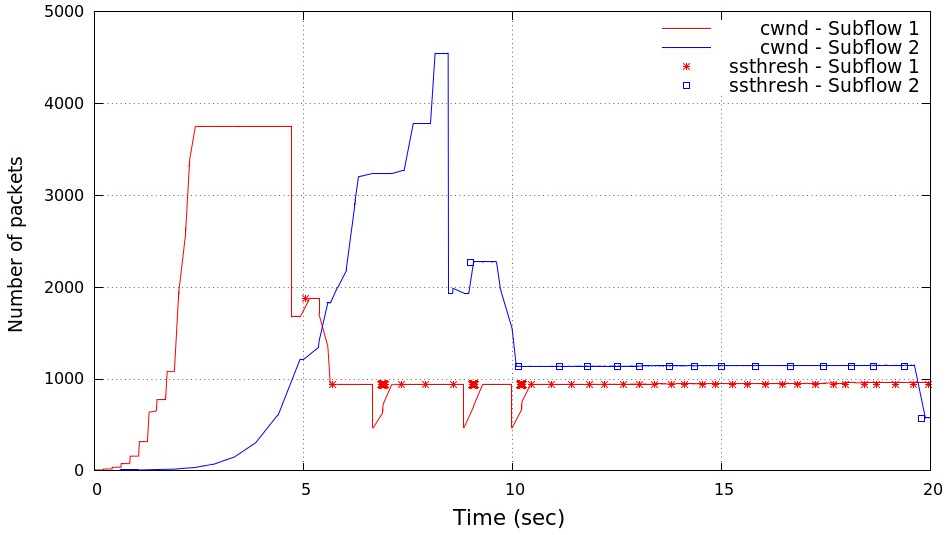
Hypothetical Scenario F

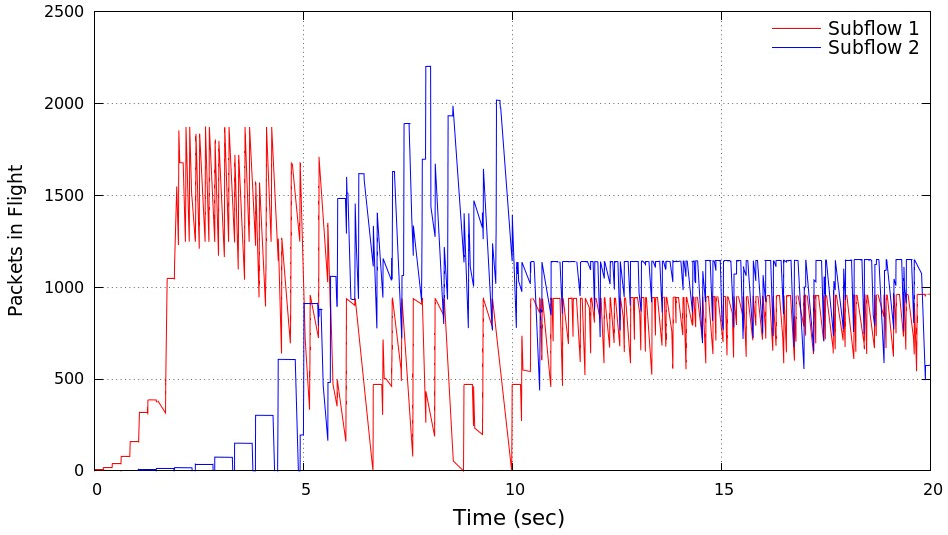


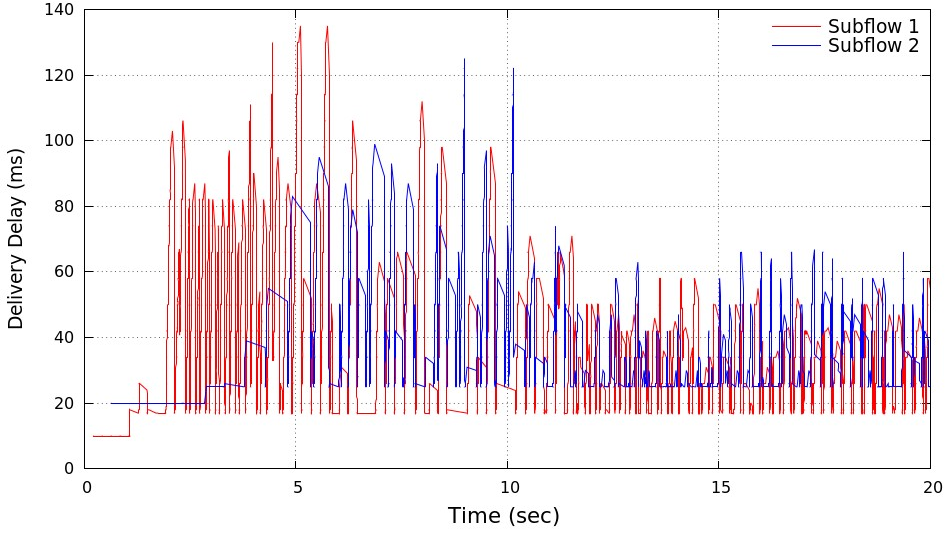


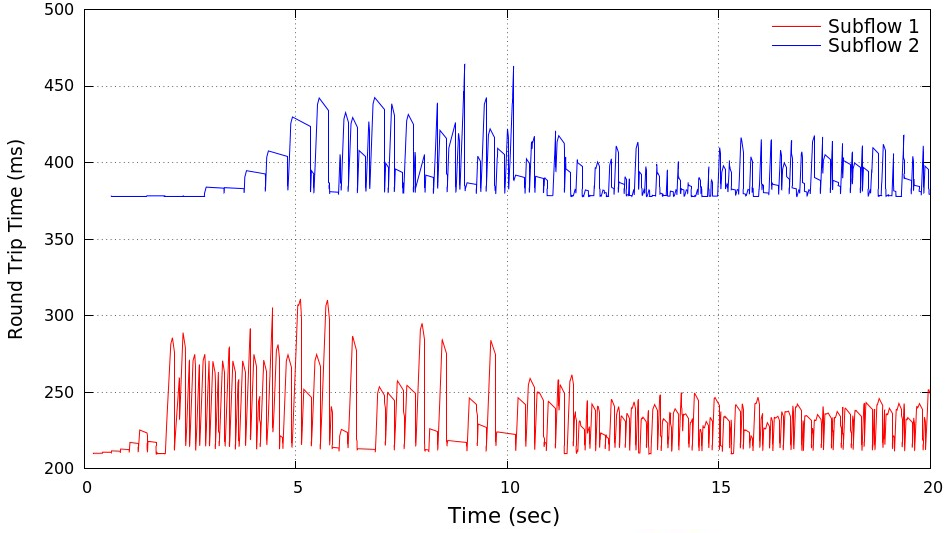


DD

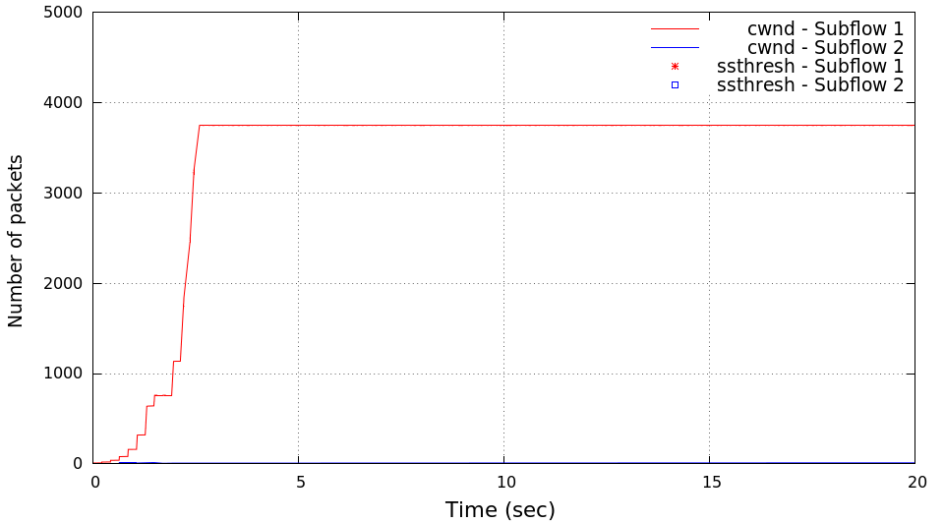

cwnd - Subflow 1
cwnd - Subflow 2
ssthresh - Subflow 1
ssthresh - Subflow 2
Number of packets
Time (sec)
0
1000
2000
3000
4000
5000
0
5
10
15
20

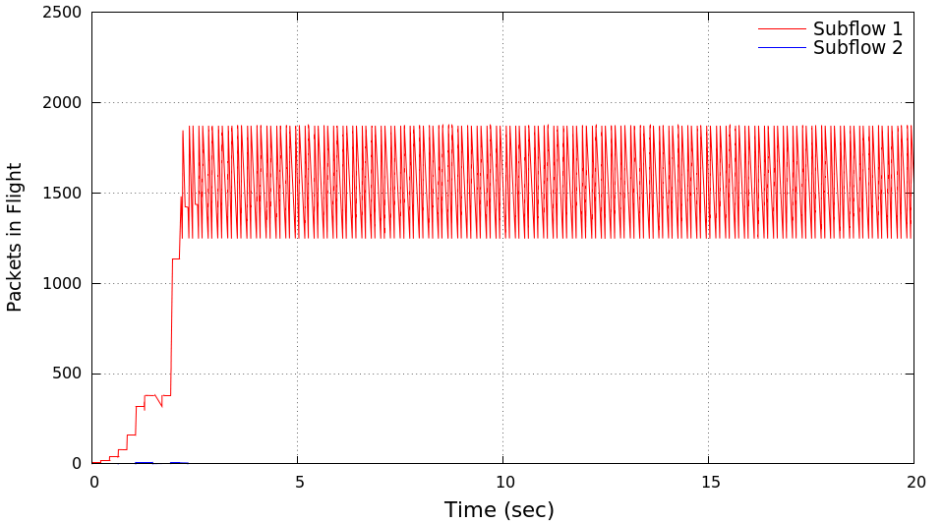

Subflow 1
Subflow 2
Packets in Flight
Time (sec)
0
500
1000
1500
2000
2500
0
5
10
15
20

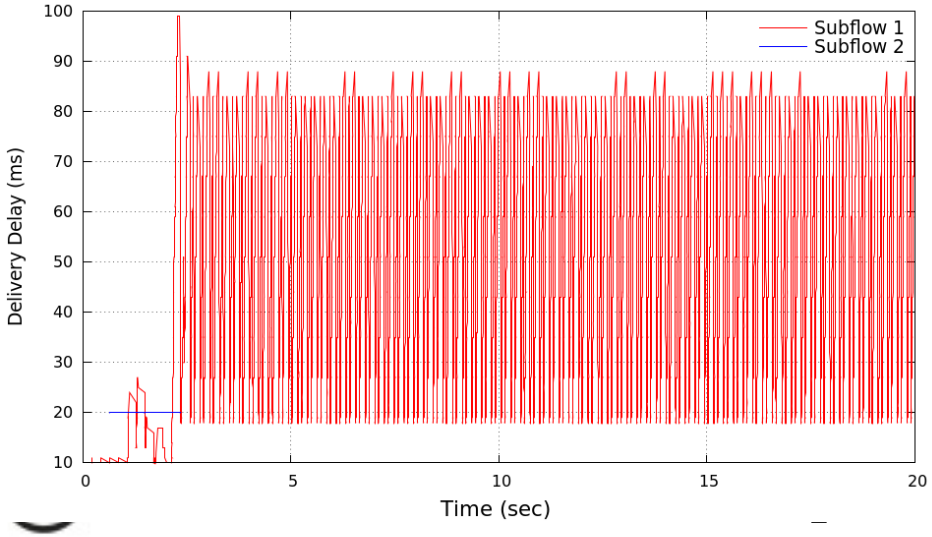

Subflow 1
Subflow 2
Delivery Delay (ms)
Time (sec)
0
20
40
60
80
100
120
140
0
5
10
15
20

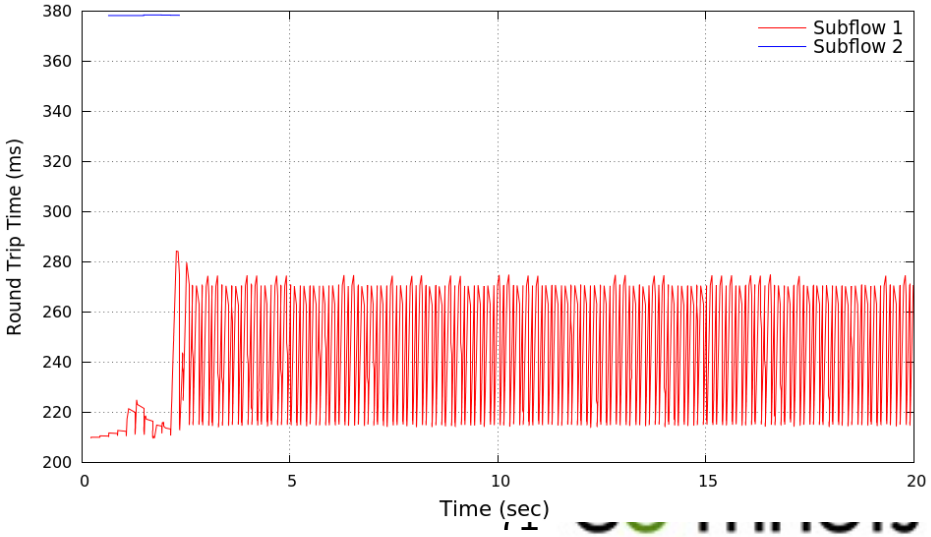

Subflow 1
Subflow 2
Round Trip Time (ms)
Time (sec)
200
250
300
350
400
450
500
0
5
10
15
20

sRTT

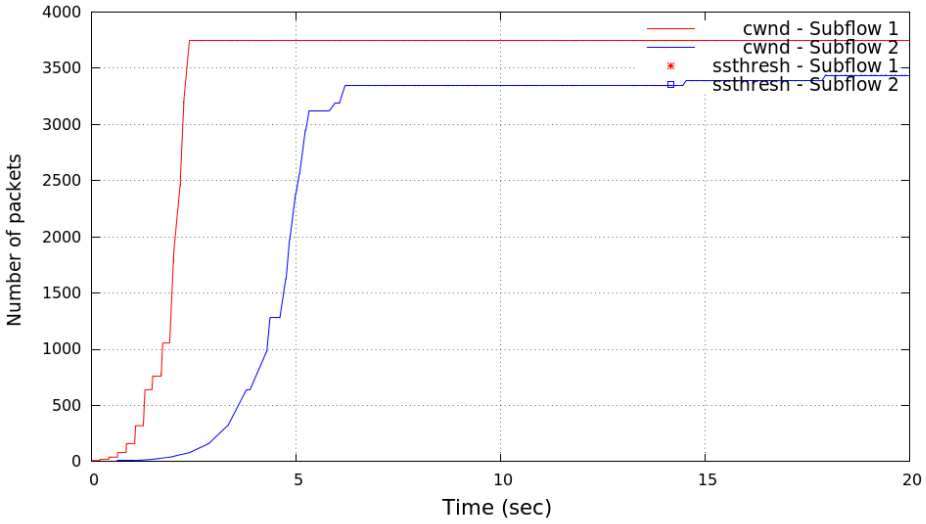

cwnd - Subflow 1
cwnd - Subflow 2
ssthresh - Subflow 1
ssthresh - Subflow 2
Number of packets
Time (sec)
0
1000
2000
3000
4000
5000
0
5
10
15
20

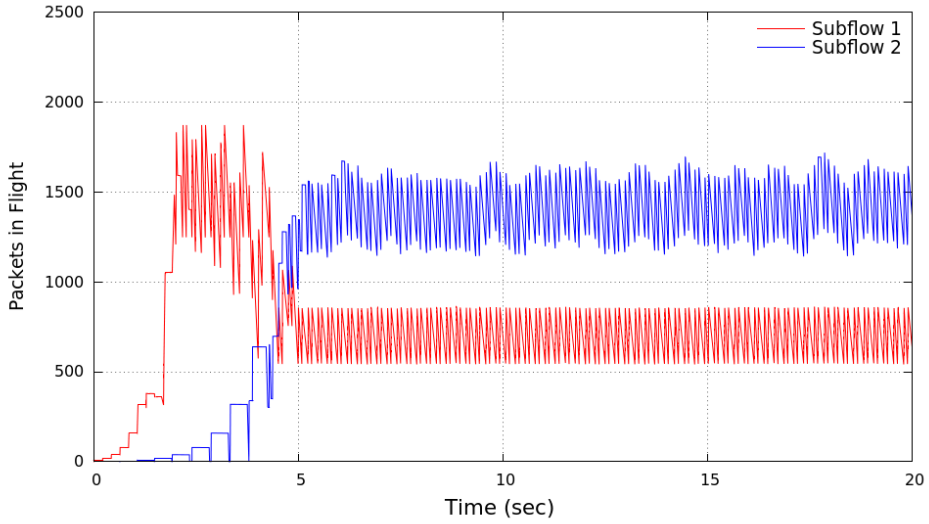

Subflow 1
Subflow 2
Packets in Flight
Time (sec)
0
500
1000
1500
2000
2500
0
5
10
15
20

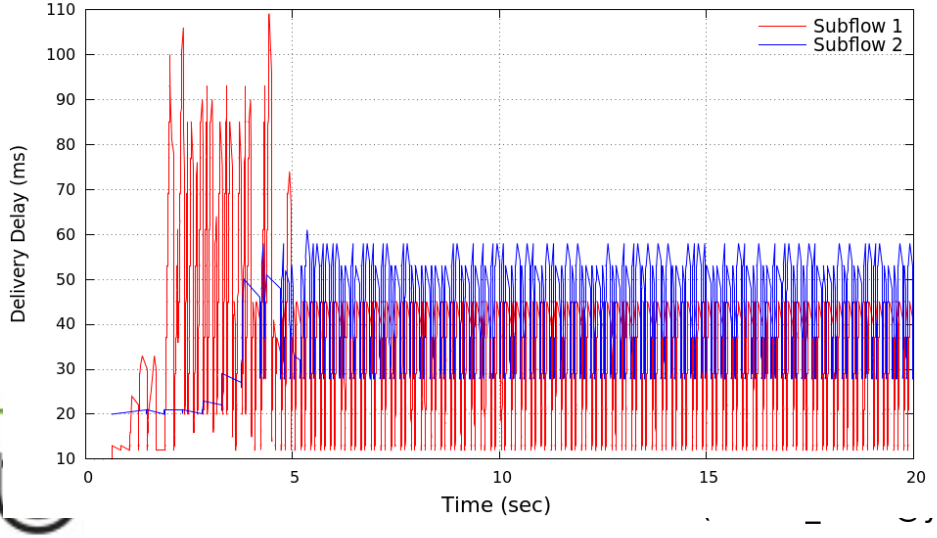

Subflow 1
Subflow 2
Delivery Delay (ms)
Time (sec)
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20

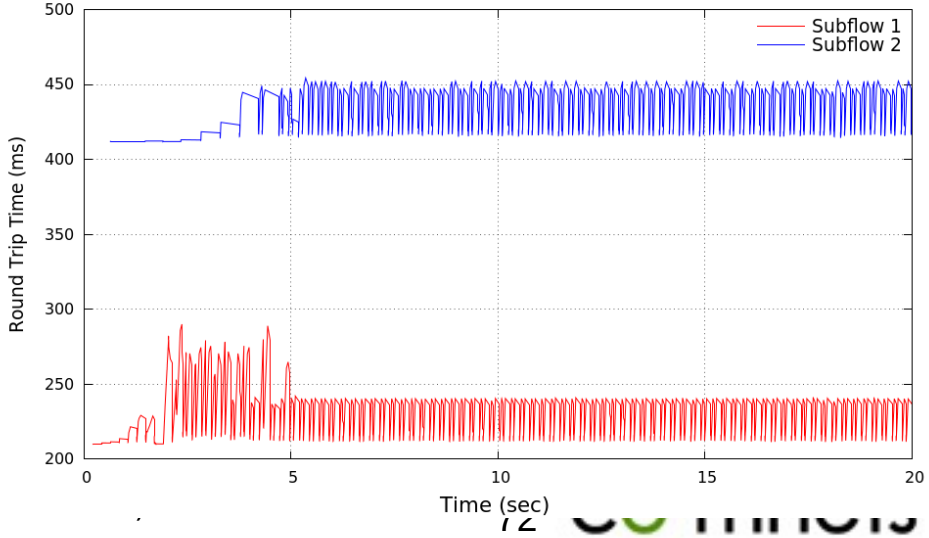

Subflow 1
Subflow 2
Round Trip Time (ms)
Time (sec)
200
220
240
260
280
300
320
340
360
380
0
5
10
15
20

RR


cwnd - Subflow 1
cwnd - Subflow 2
ssthresh - Subflow 1
ssthresh - Subflow 2
Number of packets
Time (sec)
0
500
1000
1500
2000
2500
3000
3500
4000
0
5
10
15
20


Subflow 1
Subflow 2
Packets in Flight
Time (sec)
0
500
1000
1500
2000
2500
0
5
10
15
20


Subflow 1
Subflow 2
Delivery Delay (ms)
Time (sec)
10
20
30
40
50
60
70
80
90
100
110
0
5
10
15
20


Subflow 1
Subflow 2
Round Trip Time (ms)
Time (sec)
200
250
300
350
400
450
500
0
5
10
15
20

Outlook (DD Scheduler)

Packet no	Reordering Delay (ms)	End-to-end Delay (ms)
1	0	50
2	0	50
3	0	50
4	0	100
5	0	100
6	0	100
7	0	100
8	0	100
9	40	50 + 40
10	30	50 + 30
11	20	50 + 20
12	0	50