On the impact of intrinsic delay variation sources on Iridium LEO constellation

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Context (1/3)

- What are satellite constellations ?
  - Satellite constellations : set of satellites communicating (or not) with each other.
  - and evolving in several adjacent planes in their orbit
    - According to its altitude: VLEO, LEO, MEO ou GEO
    - or type of the orbit: Elliptic, circular, polar, nearly polar etc ..
    - or the use: Satellite positioning system, Telecommunication, Remote sensing etc ..

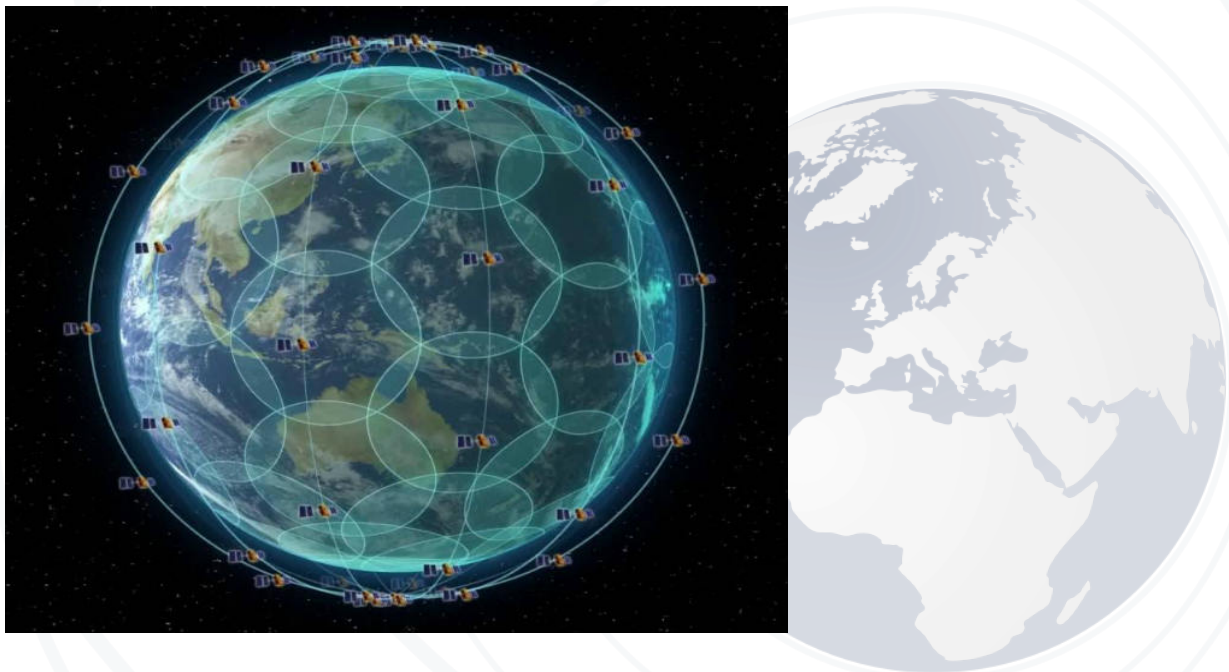
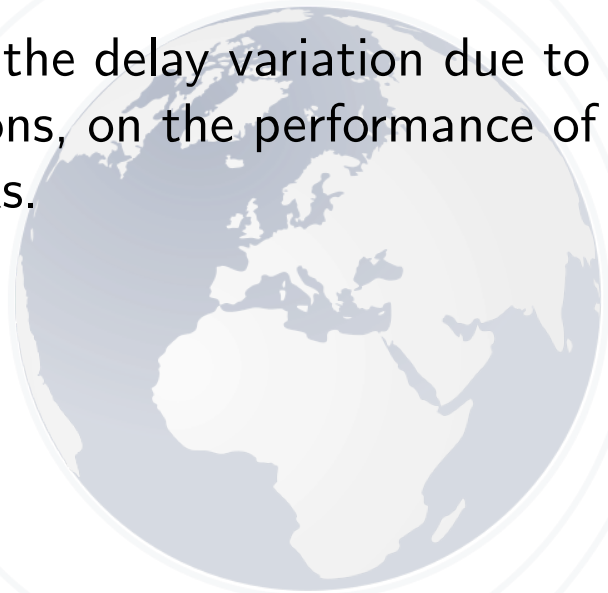


Figure: Example of a Satellite Constellation : Iridium

Context (2/3)

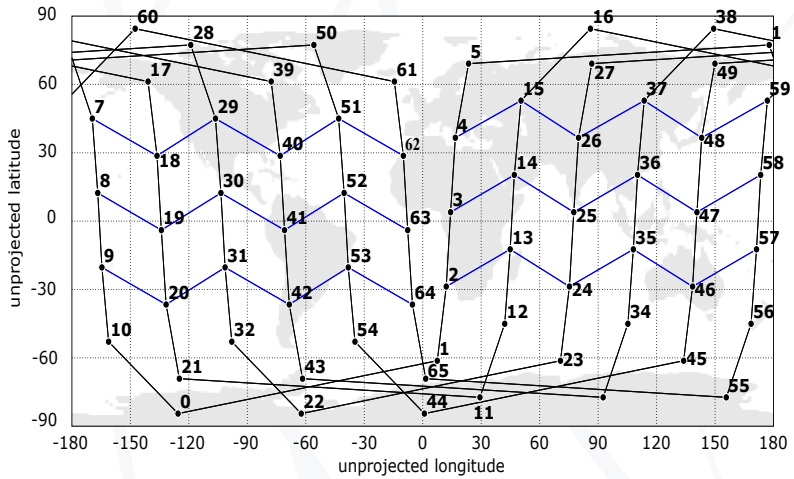
- Why study these constellations ?
  - Several existing (rival) MEO and LEO constellations or future projects.
  - Need for broadband (or even very high) where terrestrial solutions have failed ..
  - Little information on the impact, of the delay variation due to intrinsic sources in these constellations, on the performance of the protocol layers with recent stacks.



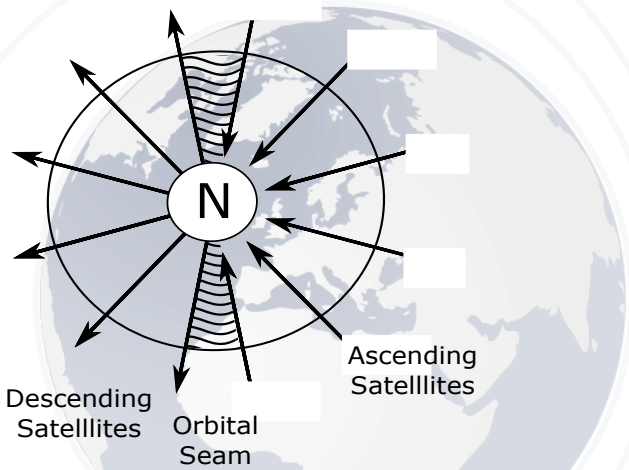
Context (2/3)

Constellation selection criteria :

- LEO orbit, circular and nearly polar.
- 6 orbital planes and 11 satellites per plane.
- With 4 ISL[1](therefore satellites communicating with one another)
- and already deployed



(a) A trace of Iridium's topology



(b) Orbital *seam*

[1]Inter-satellite Links

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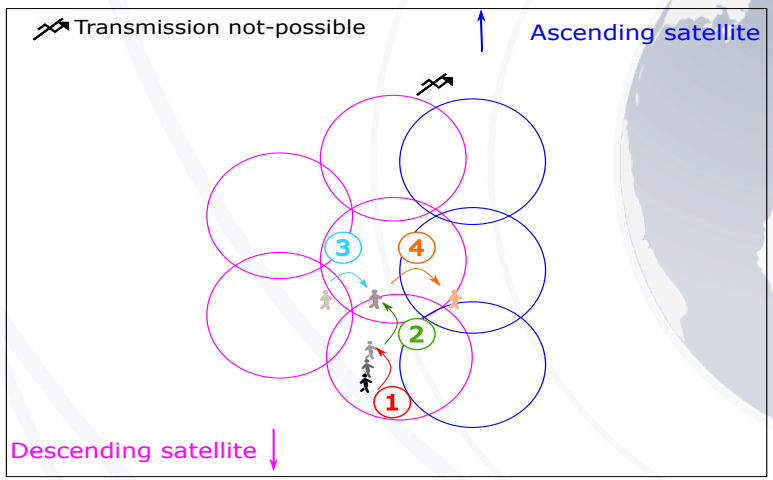
Different intrinsic sources of delay variation (1/4)

LEOs are known for short propagation delays compared to MEO or GEO, however they are subject to higher delay variations (jitter) due to the movement of satellites with respect to other satellites and terrestrial terminals.

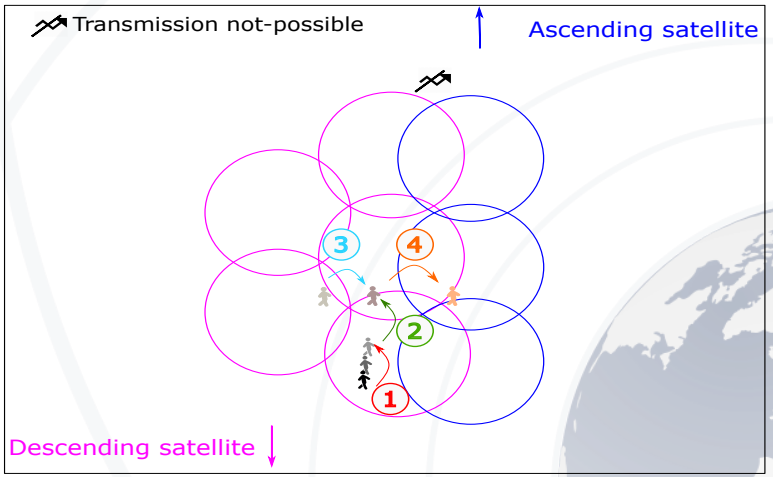
Delay variations are due to:

1. Satellite elevation:
   - Variation of the elevation angle due to the movement of the sat. with respect to the ground terminal.
   - Frequency: During $\sim 10 min$ the delay varies within [2.6 ms; 8.2 ms].



Different intrinsic sources of delay variation (2/4)

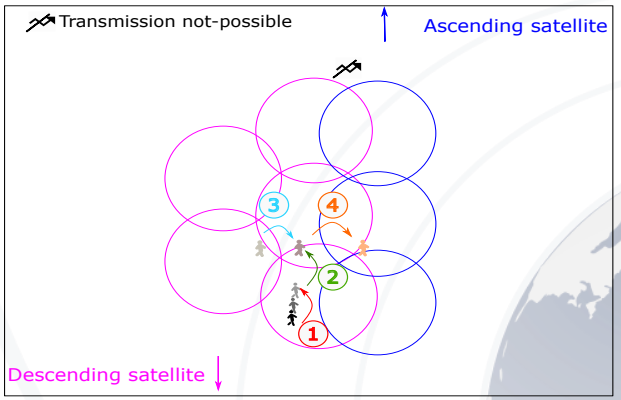
2. Intra-orbital handover:
   - When the satellite drops below the elevation mask of the terminal,(moving or not), the connection is consequently handed over to the following satellite in the same plane (or not)
   - Frequency: Every $\sim$ 10 min.



3. Inter-orbital handover:
   - The rotation of earth on its axis or the movement of the ground terminal along the longitude, give rise to a connection handover to another sat. in the adjacent orbital plane.
   - Frequency: Every $\sim$ 2 hours.

Different intrinsic sources of delay variation (3/4)

4. *Seam* handover:
   - A particularity of the polar or nearly polar satellite constellations is that the satellites in the last and first orbital planes do not have any links with each one another.
   - Frequency: At most 3 times and at least twice a day, the duration depends on the longitudinal separation of the two communicating ends.



5. ISLs changes:
   - For polar or nearly polar orbits the ISLs are deactivated at the pole because of the sats. which pass at very high speeds and in opposite directions.
   - Frequency: Every $\sim$ 10 min. And as seen in the Fig.2a 4 sats. / plane are on the poles' edges.

Different intrinsic sources of delay variation (3/4)

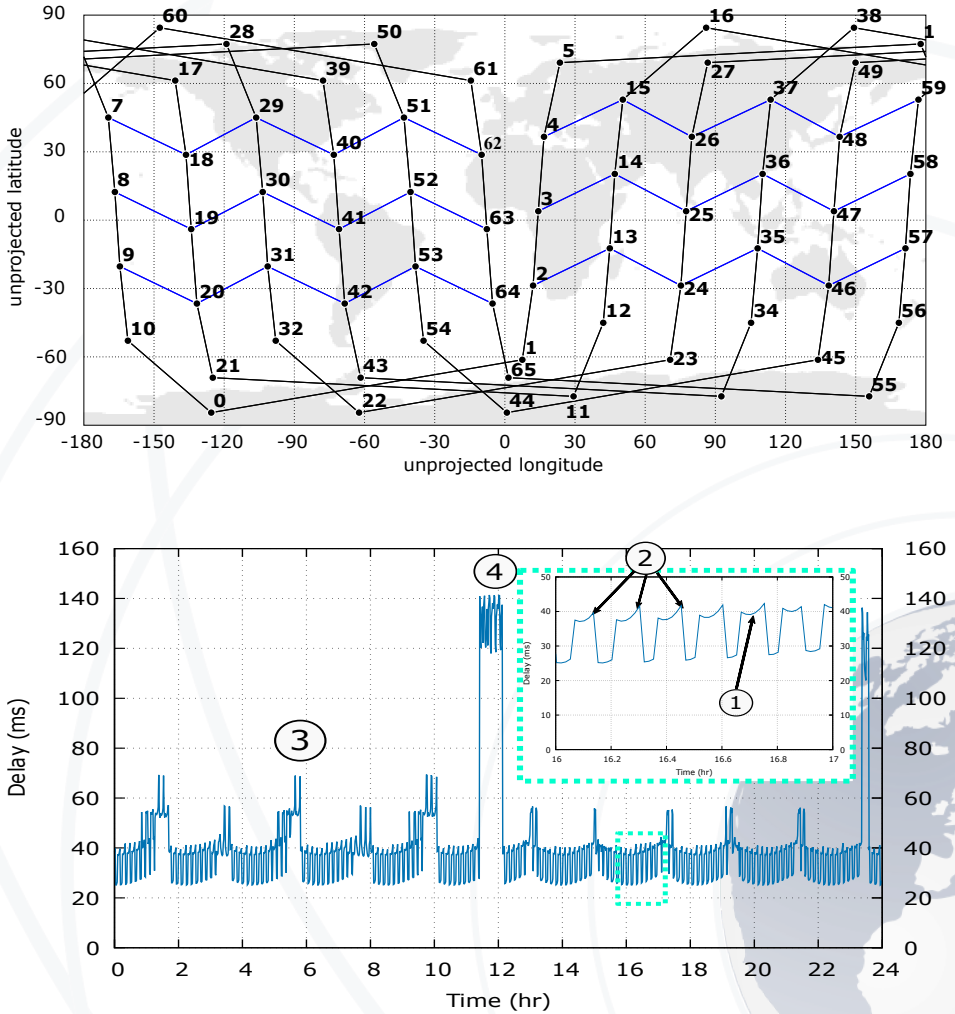


Figure: The evolution of the OWD[2] in Iridium and the factors of delay

[2] One-Way Delay

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NS-2 : one flow (1/12)

NS-2[3]settings:

- Iridium:
  - Plane : 6.
  - Sat. per plane : 11.
  - Up/Downlink bandwidth : 1.5 Mbps.
  - ISL bandwidth : 25 Mbps.
  - Buffer size : BDP[4]
- TCP:
  - CUBIC (Sender)
  - SACK (Receiver)
  - TCP IW[5]= 10 packets
  - Size of the file sent:
    - 9kB
    - 15MB

[3]Network Simulator
[4]Bandwidth-Delay Product
[5]Initial Window

NS-2 : one flow (2/12)

- Choice of the Iridium gateway:

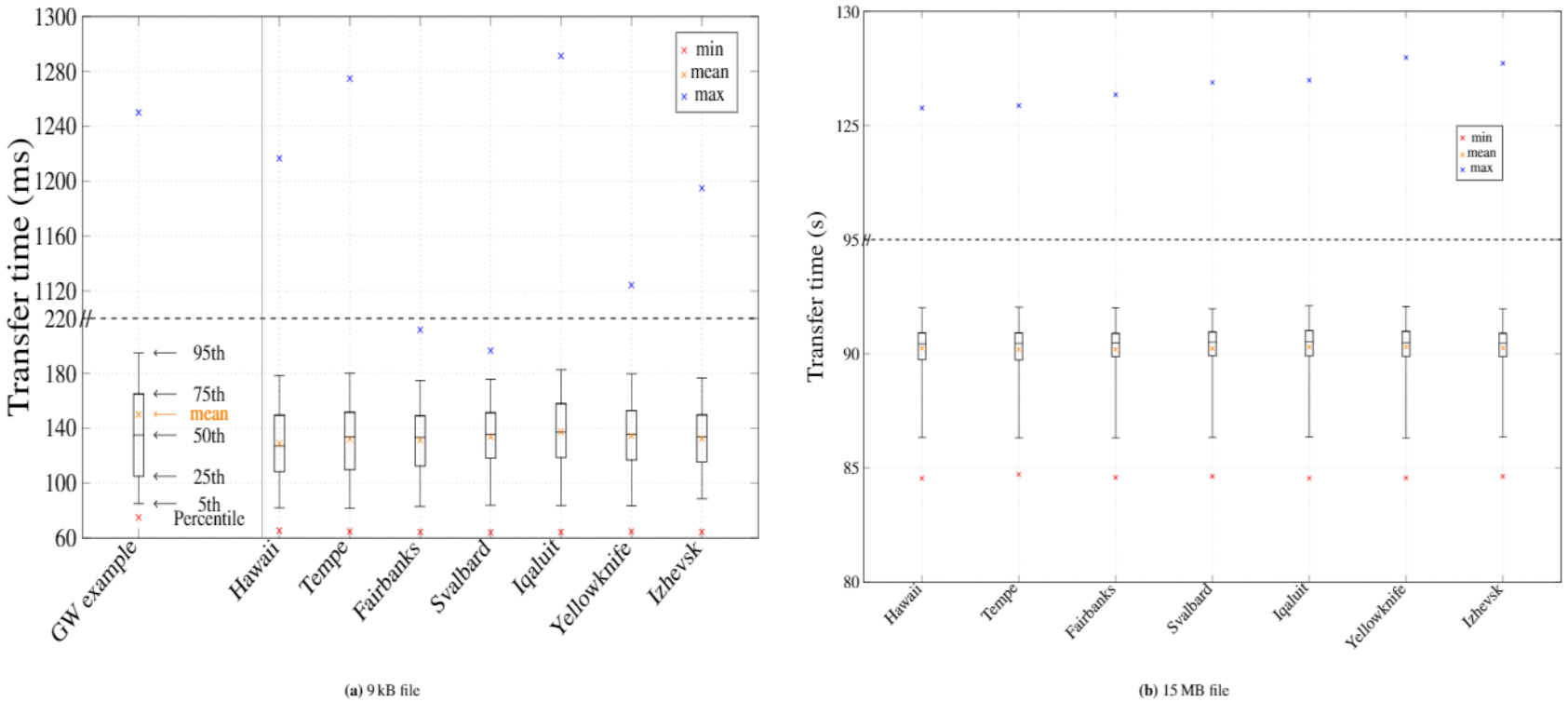
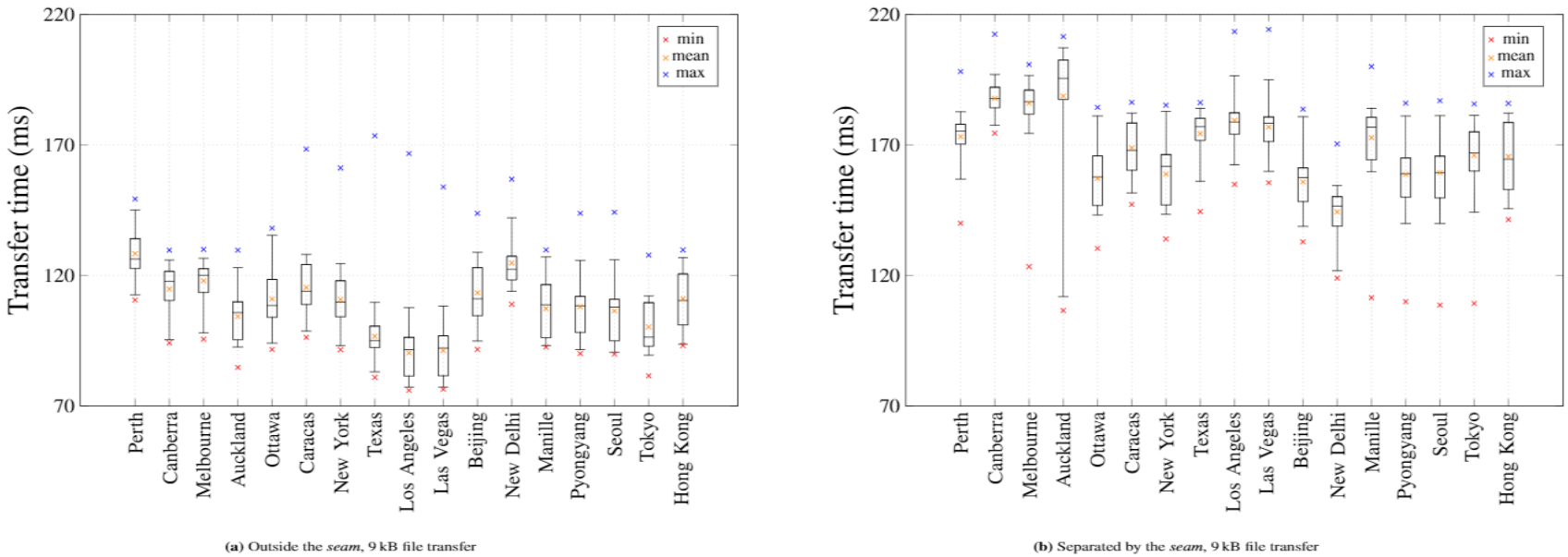


Figure: Transfer time for random starting time and terminal positions

$\Rightarrow$ Hawaii's gateway

NS-2 : one flow (3/12)

- Impact of the *seam* (n°4)
  - Small file (9kB)



(a) Outside the *seam*, 9 kB file transfer

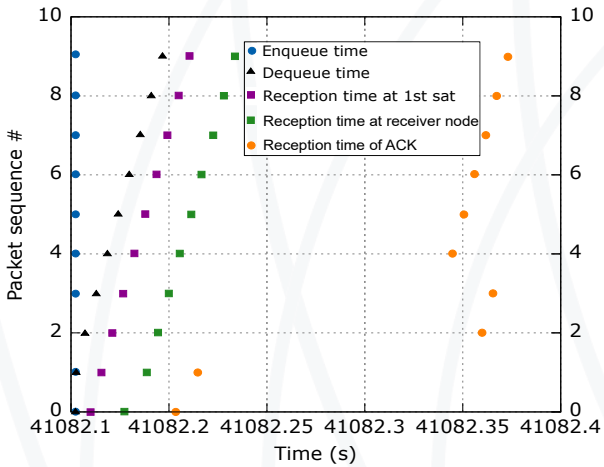
(b) Separated by the *seam*, 9 kB file transfer

Figure: Transfer time simulations of a 9 kB file

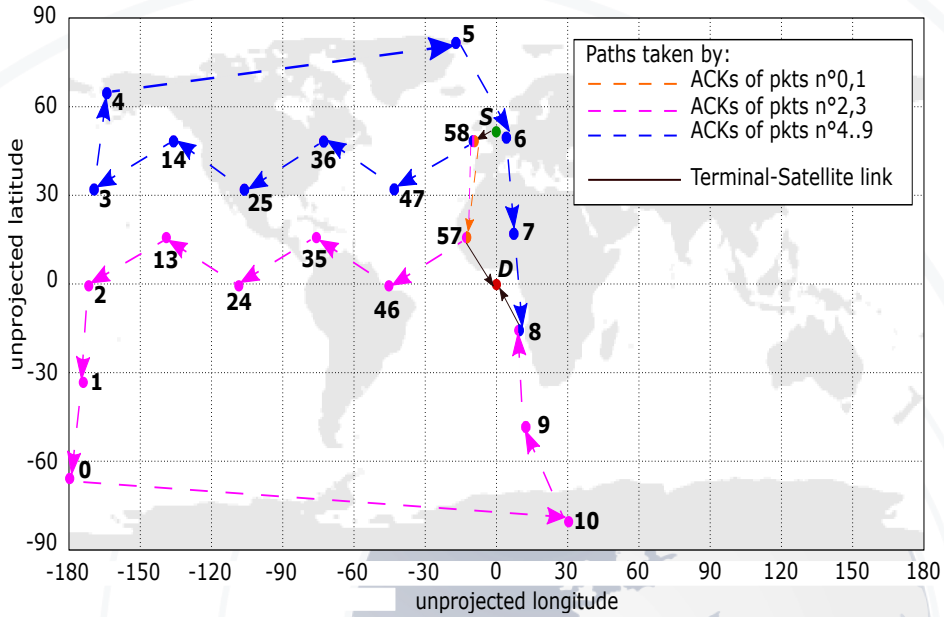
⇒ New Delhi 124 ms outside the *seam* → 144 ms, an increase of 15.6%.
⇒ LA 90 ms outside the *seam* → 179 ms, an increase of 98%.

NS-2 : one flow (4/12)

⇒ See what's happening on the *seam* ?



(a) 9kB file transfer through the *seam*

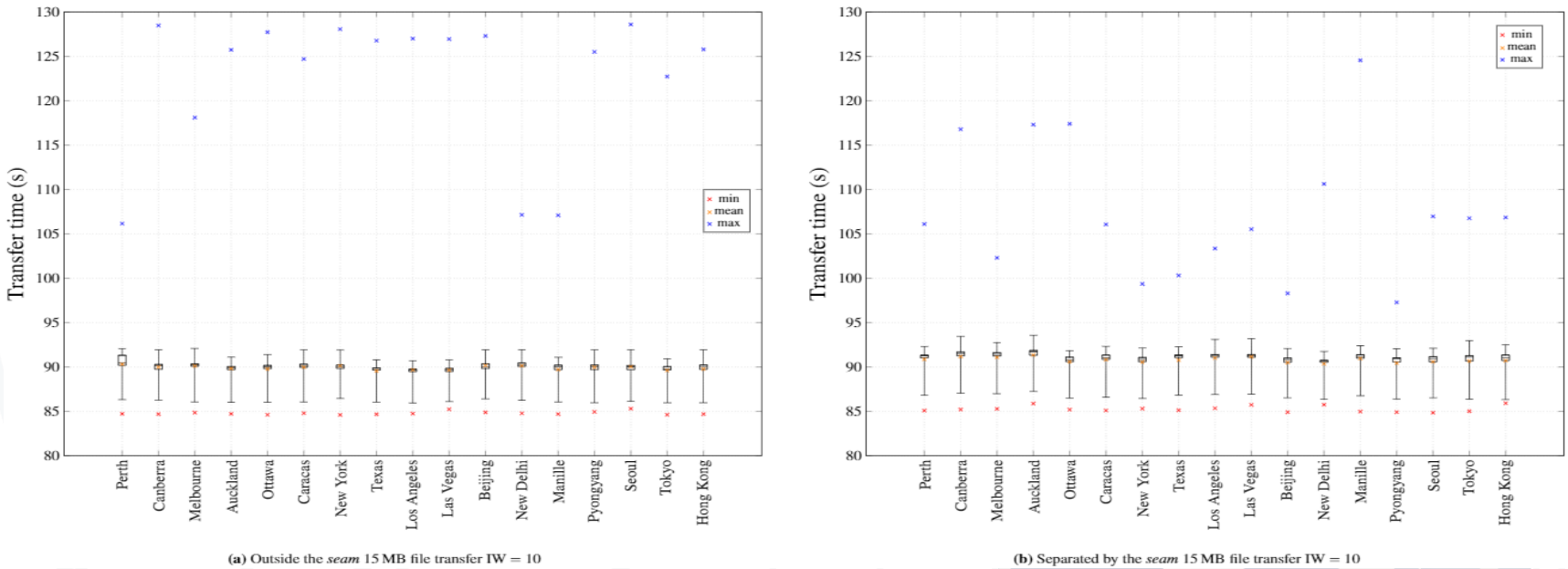


(b) Paths taken by ACK[6] packets during transmission

[6] ACKnowledgement

NS-2 : one flow (5/12)

- Impact of the *seam* (n°4)
  - Big file (15MB)



(a) Outside the *seam* 15 MB file transfer IW = 10

(b) Separated by the *seam* 15 MB file transfer IW = 10

Figure: Transfer time simulations of a 15 MB file

⇒ No fatal impact on the duration of transfer. From which file size does it become noticeable ?

NS-2 : one flow (6/12)

Seam VS file sizes:

Parameter \ File size (kB)	25	50	100	500	1000	5000	10000
mean($MTT_{no\ seam}/MTT_{seam}$)(%)	59.38	59.35	69.79	90.71	96.78	99.97	98.55

Figure: Impact of the seam on files' transfers

⇒ Starting 500kB.

NS-2 : one flow (7/12)

- Impact of variation in delay due to sat's elevation:

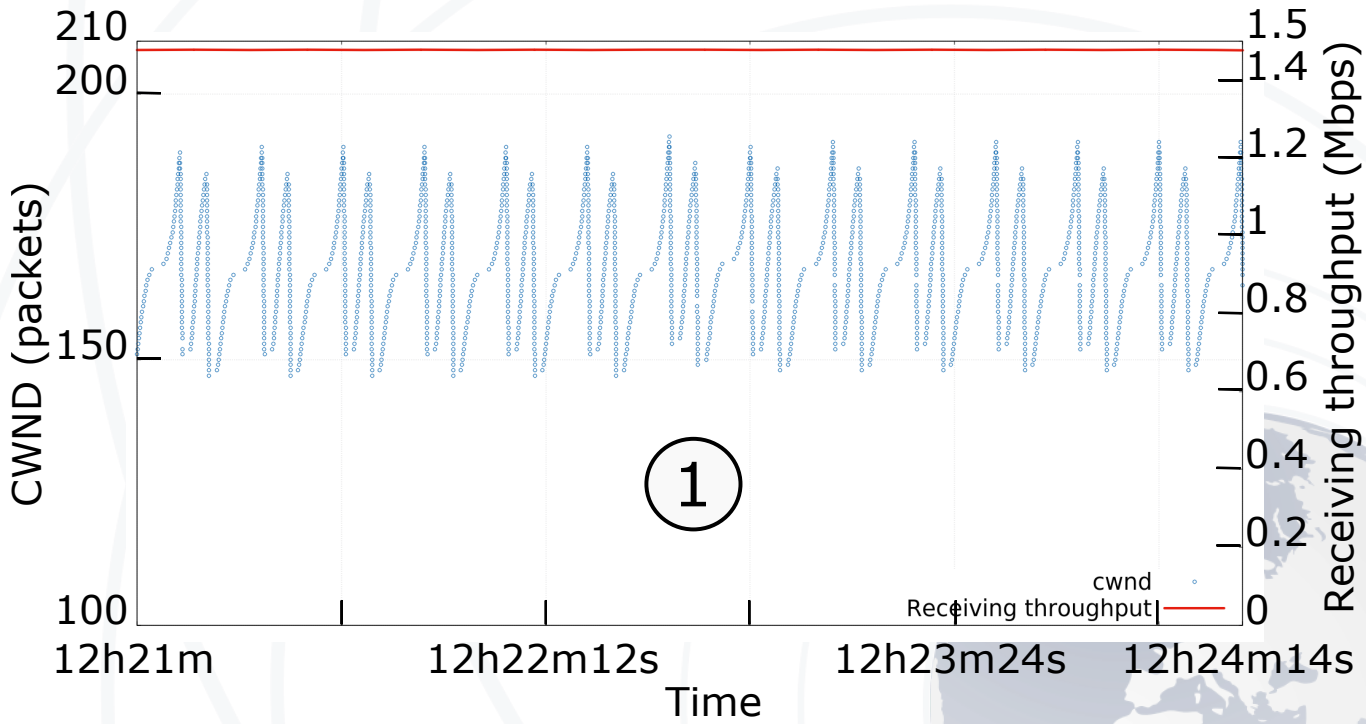
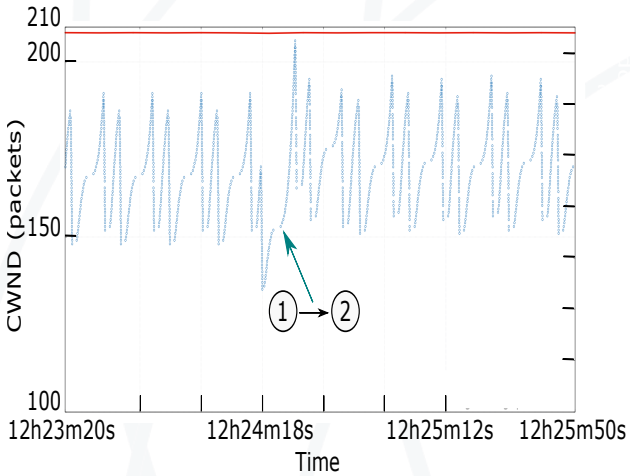


Figure: Elevation Delay Variation

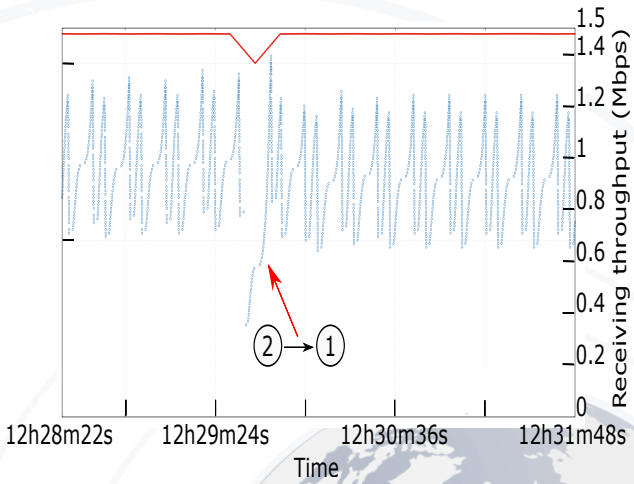
⇒ No impact (indeed the propagation delay varies smoothly within [2.6 ms ; 8.2 ms])

NS-2 : one flow (8/12)

- Impact of the delay variation due to intra-orbital handover:



(a) Elevation to intra-orbital handover



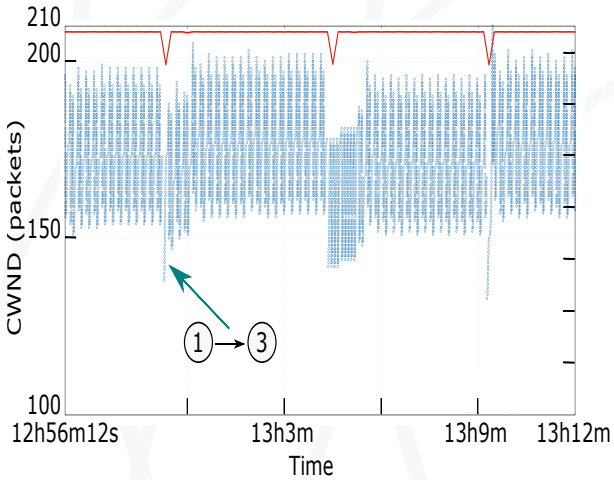
(b) Intra-orbital to elevation handover

1→2 : delay increases, so packets and ACKs sent previously are received quickly, which induces the transmitter to increase the CWND[7].
2→1 : while for the reverse handover, it's the opposite. Thus the throughput goes from 1.5 Mbps to 1.36 Mbps (decrease of 7.48%).

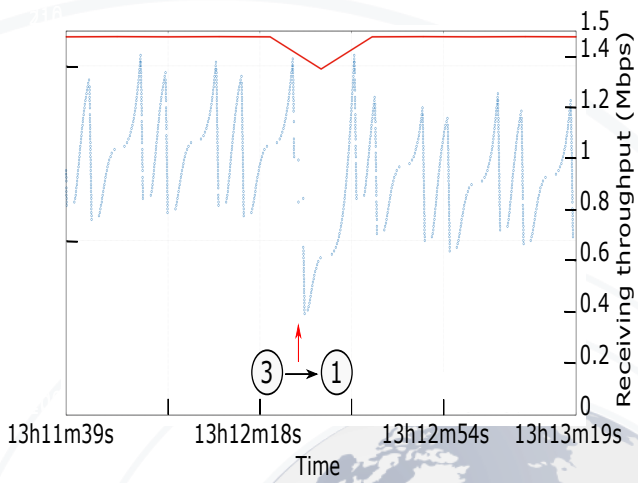
[7] Congestion WiNDow

NS-2 : one flow (9/12)

- Impact of the delay variation due to inter-orbital:



(c) Elevation to intra-orbital handover



(d) Intra-orbital to elevation handover

1→3 : same explanation as before (1→2) the throughput decreases from 1.47 Mbps to 1.35 Mbps (decrease of 8.16 %). Throughput and CWND oscillation (the two peaks) because of intra-orbital handover. (2→1) 3→1 : same explanation as before (2→1) the throughput decreases from 1.47 Mbps to 1.35 Mbps (decrease of 8.16%).

NS-2 : one flow (10/12)

Settings:

- Iridium:
  - Plane : 6.
  - Sat. per plane : 11.
  - Up/Downlink bandwidth : 120 Mbps.
  - ISL bandwidth : 2 Gbps.
  - Buffer size : BDP
- TCP:
  - CUBIC (Sender)
  - SACK (Receiver)
  - TCP IW = 10 packets
  - Size of the file sent:
    - 9kB
    - 15MB

NS-2 : one flow (11/12)

Seam VS file sizes:

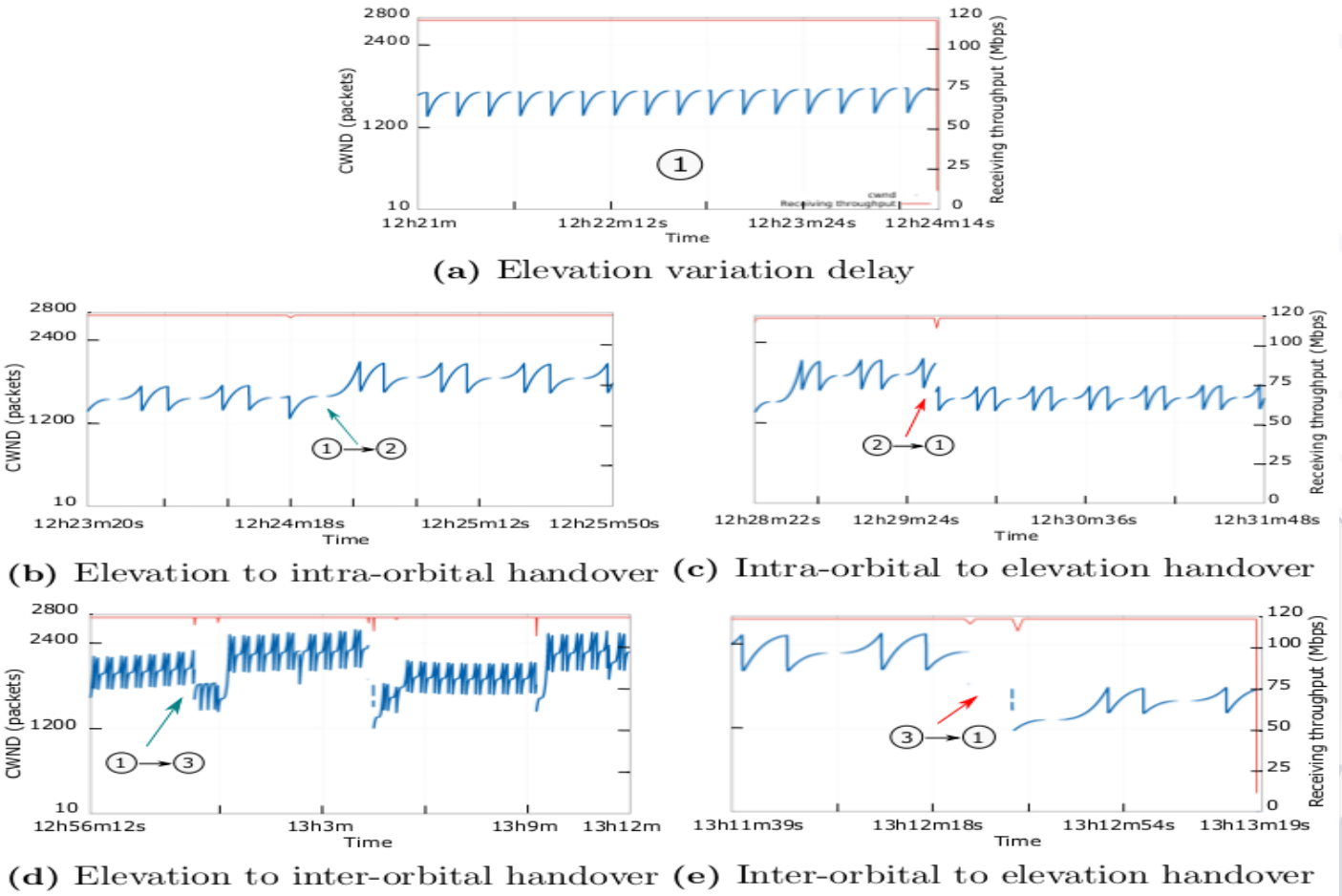
Parameter \ File size (kB)	25	50	100	500	1000	5000	10000
$\text{mean}(\text{MTT}_{no\ seam}/\text{MTT}_{seam})(\%)$	47.78	47.9	47.79	48.23	48.61	52.09	57.76

Figure: Impact of the seam on files' transfers

⇒ No impact yet, need to push even further.

NS-2 : one flow (12/12)

Delay variation sources in higher rate:



(a) Elevation variation delay

(b) Elevation to intra-orbital handover

(c) Intra-orbital to elevation handover

(d) Elevation to inter-orbital handover

(e) Inter-orbital to elevation handover

Figure: Impact of the delay variation sources

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NS-2 : Multi-flow : Test Architecture (1/7)

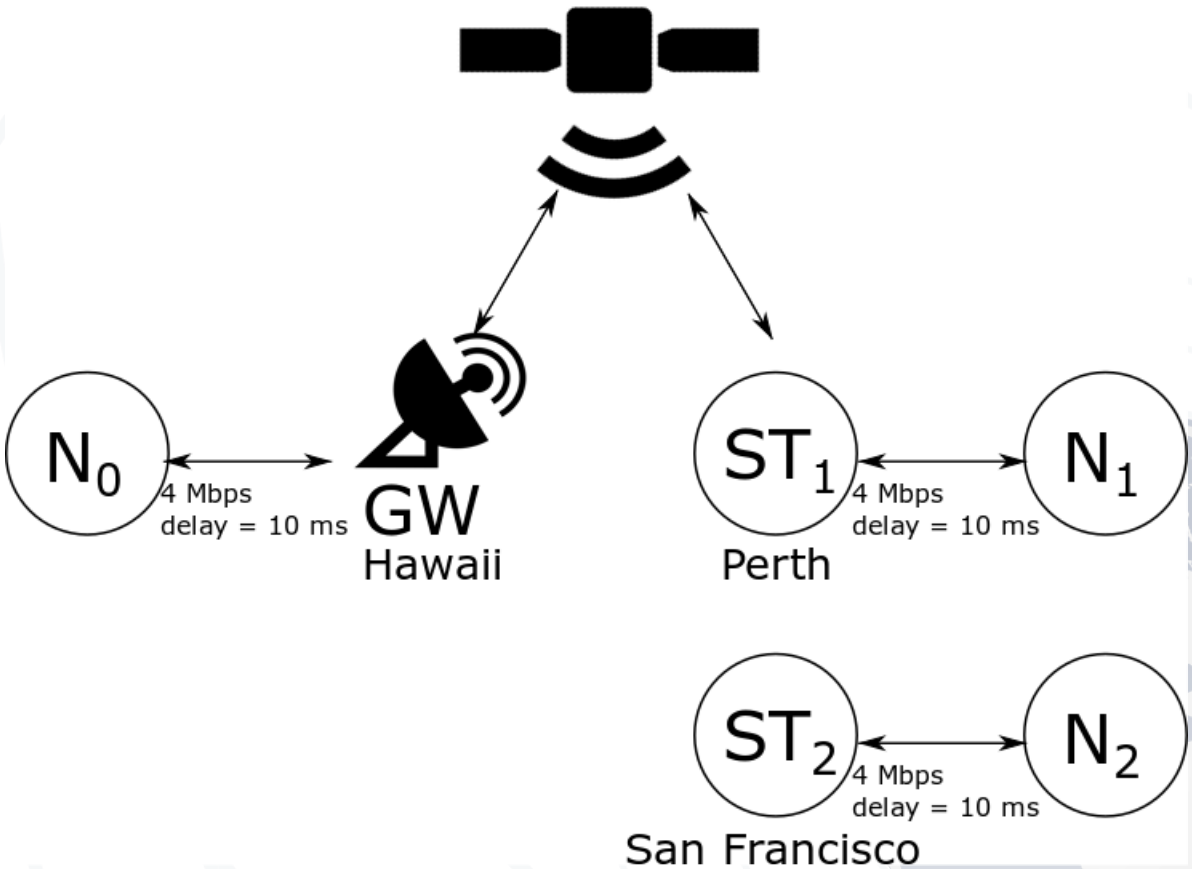


Figure: Example test Architecture for Low Throughput use case

NS-2 : Multi-flow : Settings (2/7)

- Start time of simulation : 15000.0s
- End time of the simulation : 15305.0s (outside the *seam*)
- One reference flow : at Perth (Australia)

Settings	**Low Throughput**	**High Throughput**
ISL Bandwidth	25Mbps	850Mbps
Up/Downlink Bandwidth	1.5Mbps	51Mbps
Full-duplex link Bandwidth	4Mbps	136Mbps
Full-duplex link Delay	10ms	10ms
Buffer size	BDP	BDP

Table: Simulation settings

NS-2 : Multi-flow : Low Throughput (3/7)

- Same start time
  - Same RTT[8]

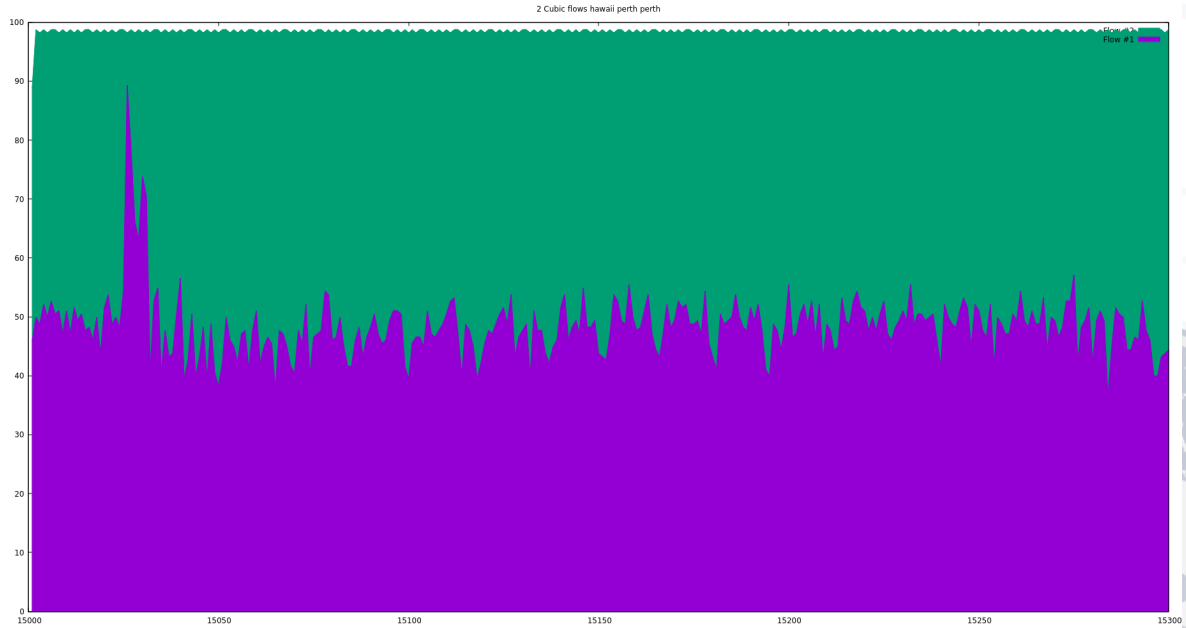
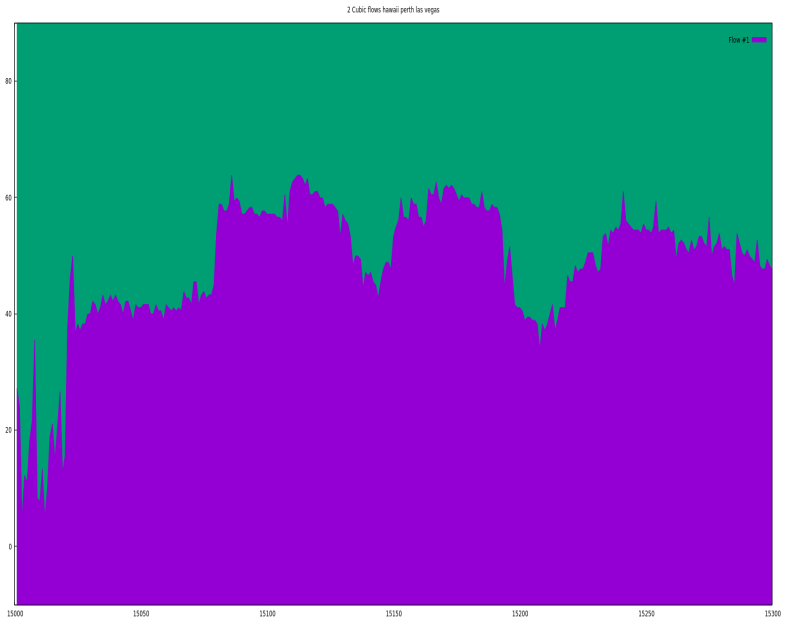


Figure: Same RTT multiflows

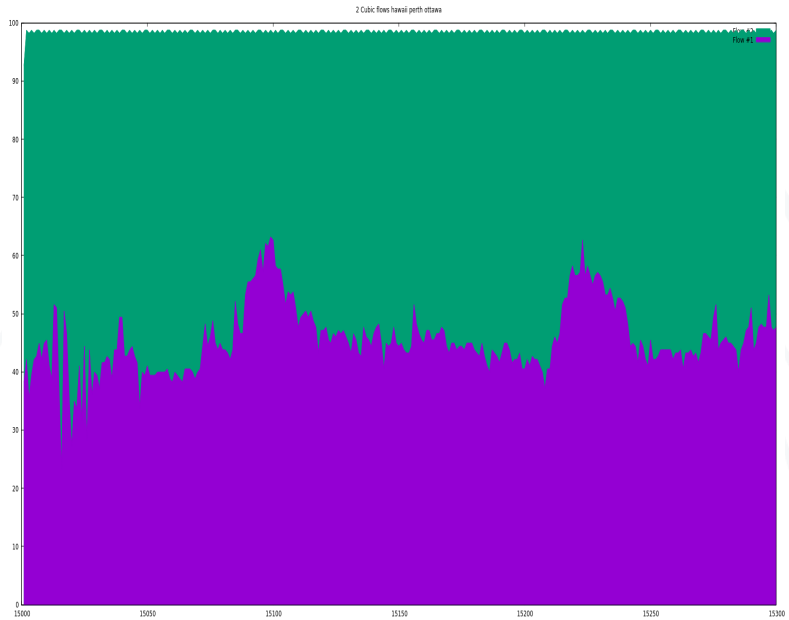
[8]Round Trip Time (roughly = 2 x One-Way Delay)

NS-2 : Multi-flow : Low Throughput (4/7)

- Same start time
  - Different RTT (Las Vegas $<$ Ottawa $<$ Perth)



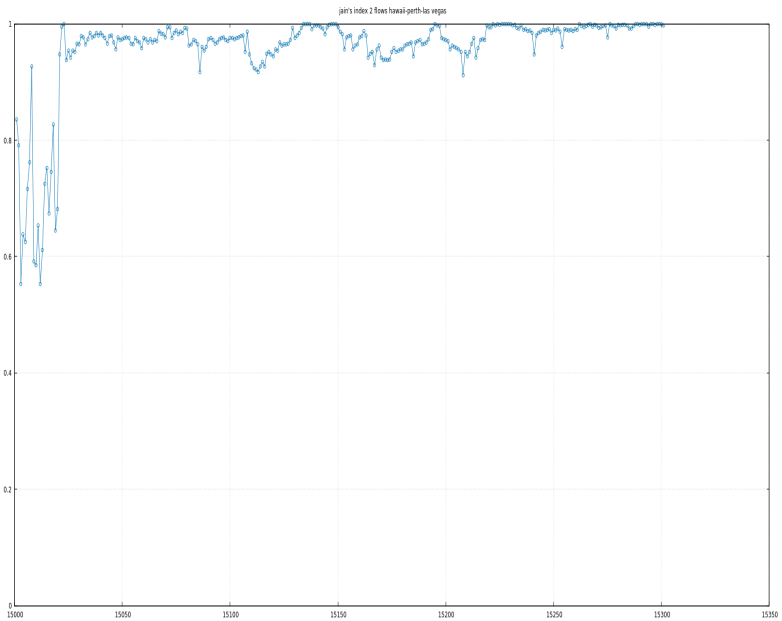
(a) 2 flows share Perth VS Las Vegas



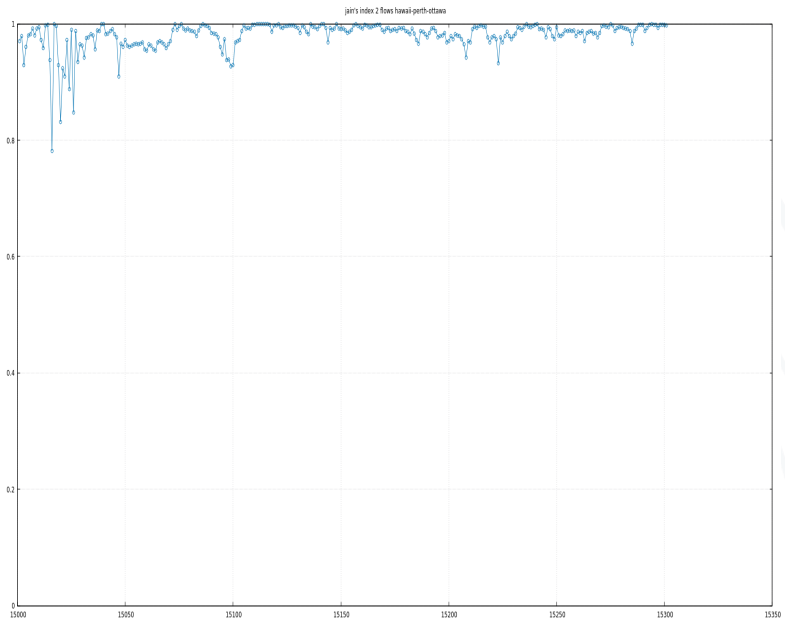
(b) 2 flows share Perth VS Ottawa

NS-2 : Multi-flow : Low Throughput (5/7)

- Same start time
  - Different RTT : Jain's Fairness index



(c) 2 flows jain's index Perth VS Las Vegas handover



(d) 2 flows jain's index Perth VS Ottawa handover

NS-2 : Multi-flow : Low Throughput (6/7)

- Different start time : Second flow is differed with 50s (after the non-permanent phase : *Slow Start*)
  - Same RTT

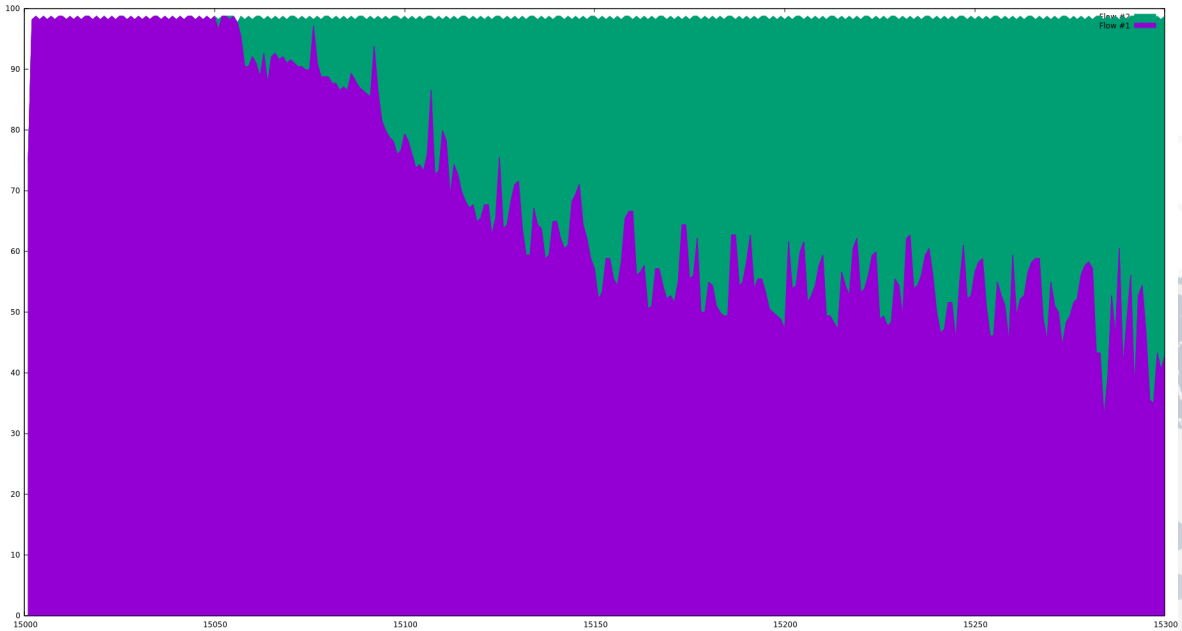
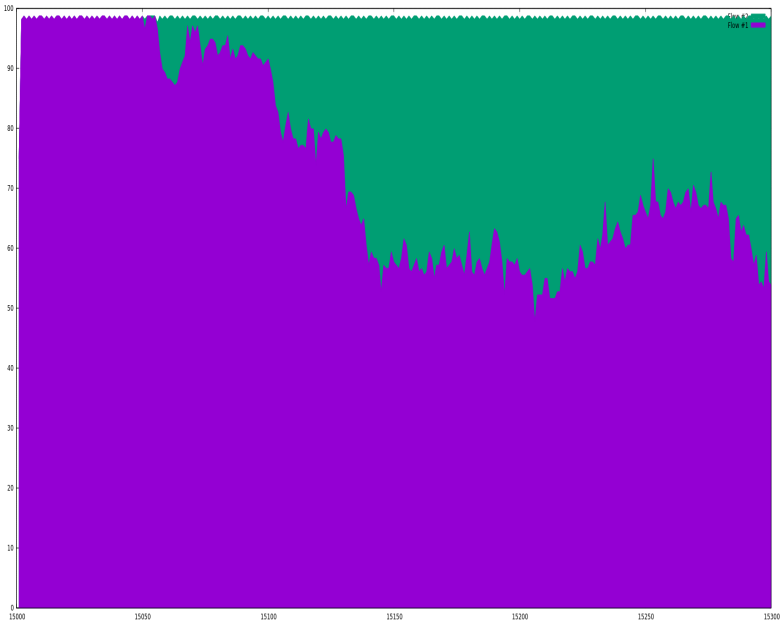


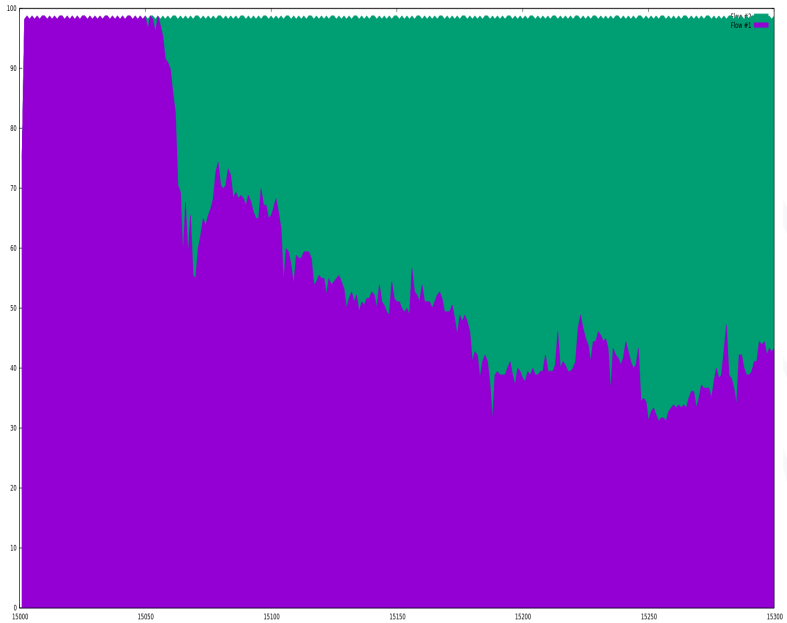
Figure: Same RTT multiflows different start time

NS-2 : Multi-flow : Low Throughput (7/7)

- Different start time
  - Different RTT



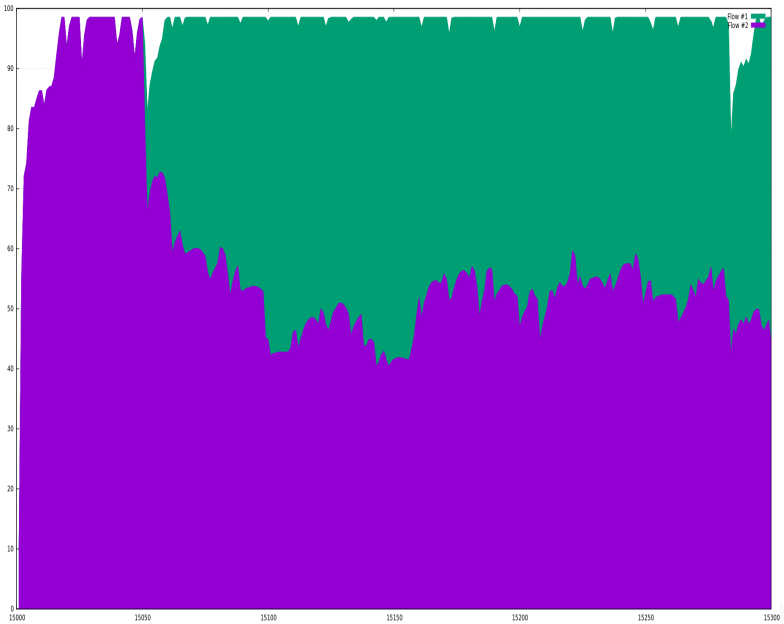
(a) 2 flows share Perth VS Las Vegas 50 s differed



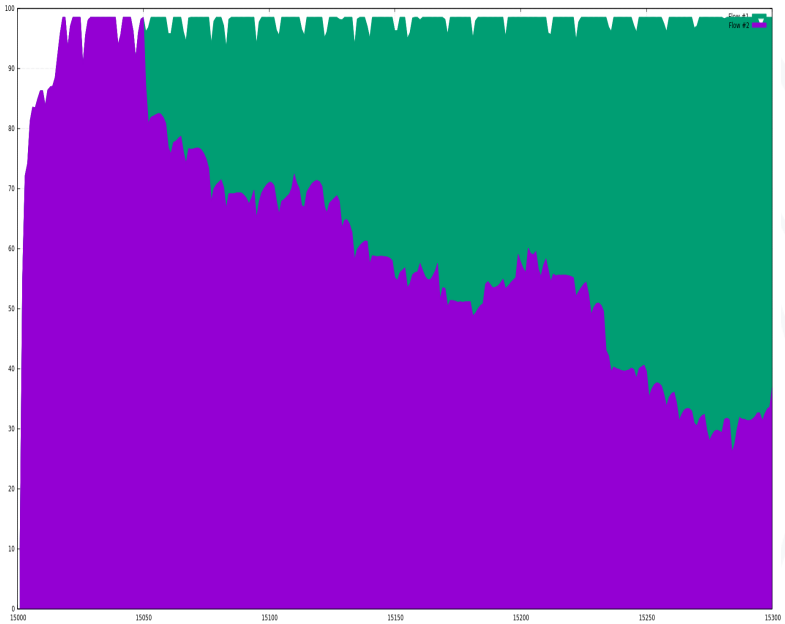
(b) 2 flows share Perth VS Ottawa 50 s differed

NS-2 : Multi-flow : High Throughput

- Same start time
  - Same RTT : Same behavior
  - Different RTT : Same behavior
- Different start time
  - Same RTT : Same behavior
  - Different RTT : Different behavior



(c) 2 flows share Perth VS Las Vegas 50 s differed



(d) 2 flows share Perth VS Ottawa 50 s differed

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OpenSAND (1/4)

What is Amal up to now ?

Open Satellite Network Demonstrator is a satellite testbed emulating the main features of a SATCOM system maintained by the collaboration work of Viveris Technologies, Thales Alenia Space and CNES.

OpenSAND (2/4)

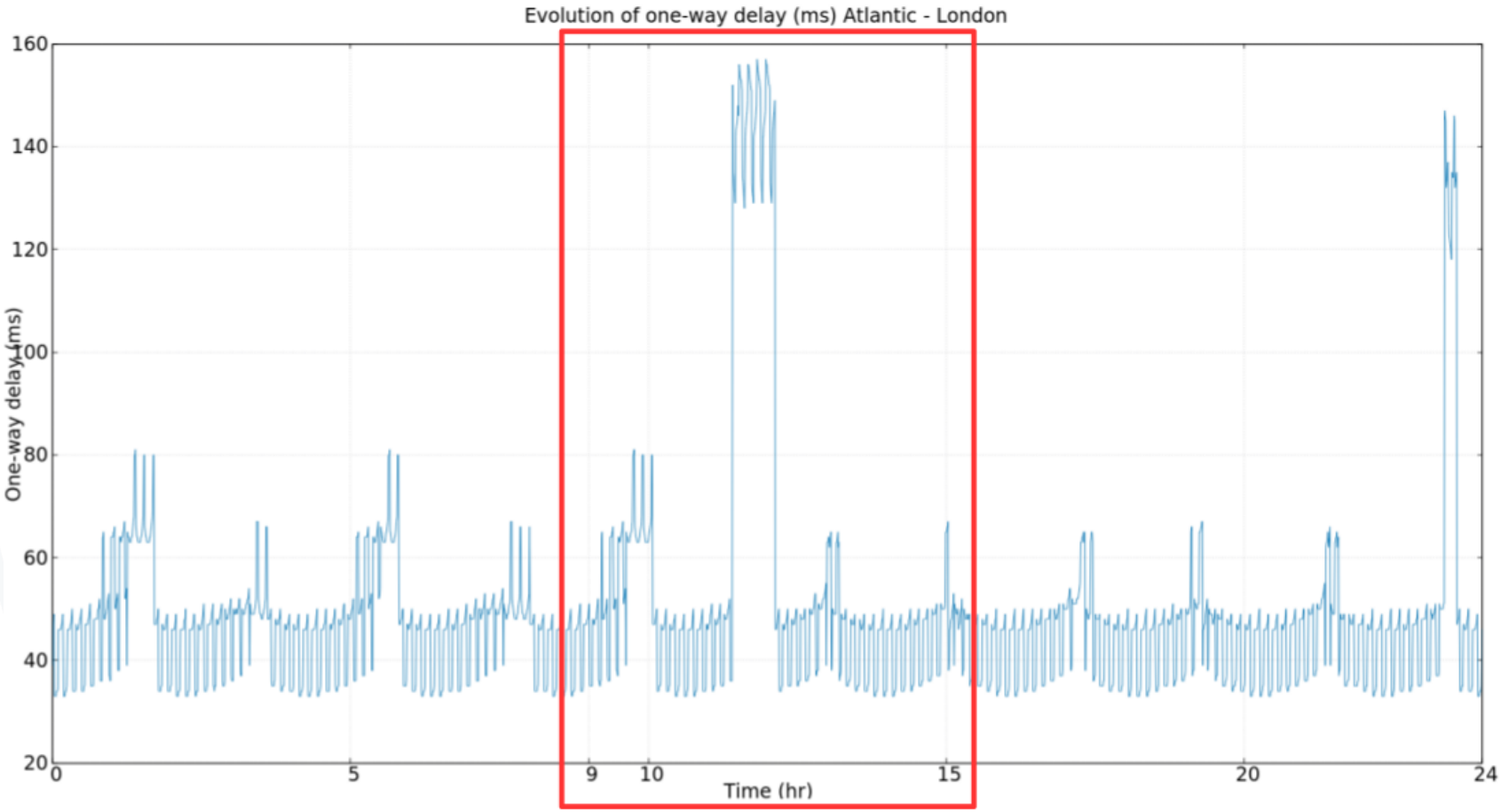

Figure: One-Way Delay

OpenSAND (3/4)

One Flow :

- Low Throughput :
  - Up/Downlink bandwidth : 1.5 Mbps
  - ISL bandwidth : 25 Mbps
  - Buffer size : BDP

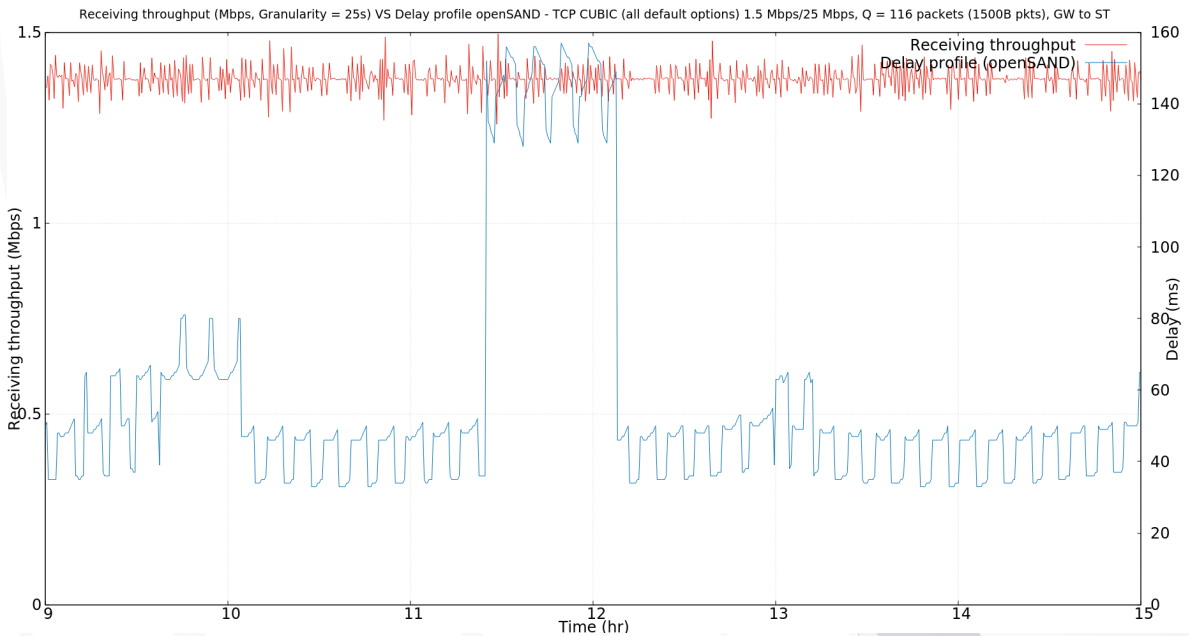

Figure: Received throughput VS OWD

⇒ Currently under investigation ..

OpenSAND (4/4)

One Flow :

- High Throughput :
  - Up/Downlink bandwidth : 49.5 Mbps
  - ISL bandwidth : 825 Mbps
  - Buffer size : BDP

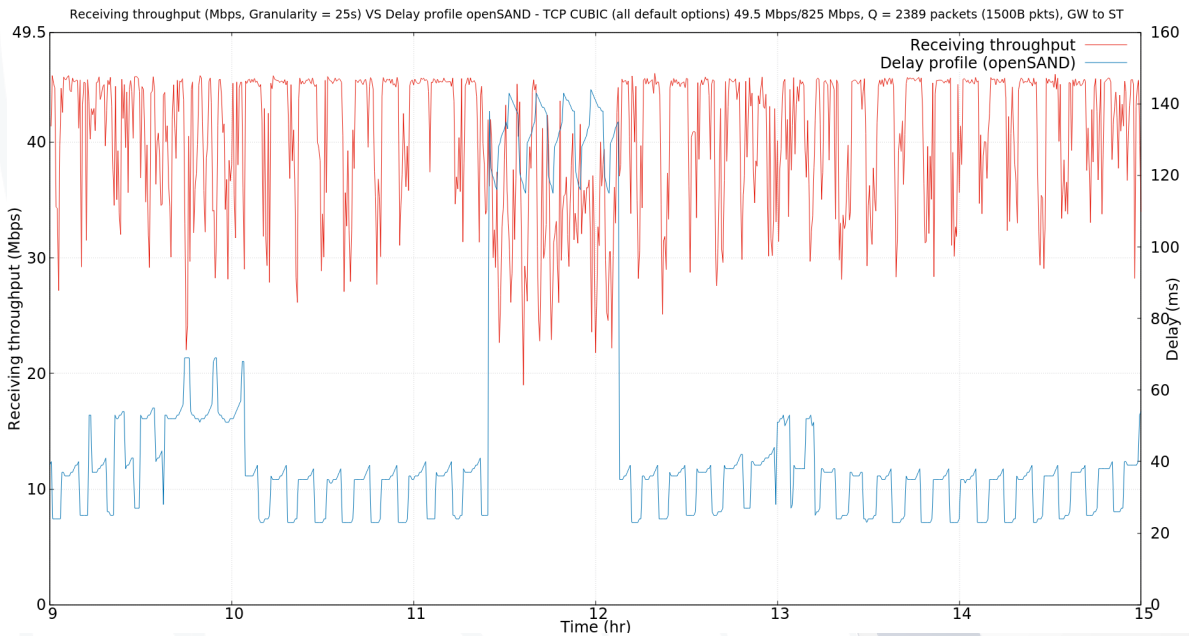

Figure: Received throughput VS OWD

⇒ Currently under investigation ..


Thank You