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

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Scope

- Increasing need for worldwide high-speed internet coverage
- Terrestrial solutions fail to deliver
⇒ Reemergence of satellite constellations

Currently several constellation aim at increasing the throughput provided to the end user (*e.g.* for collective terminal services), two families :
- Without ISLs (*e.g.* OneWeb, O3Bm or Boeing)
- With ISLs (*e.g.* Iridium, Telesat or Starlink) :

\+ Enhancement of the coverage, reduction latency and limiting the size of the ground segment

\- Delay variation

⇒ To which extent delay variations caused by the intrinsic characteristics of the satellite constellation topology would affect the performances of the transport layer protocol.

Study use case : Iridium constellation

* LEO (780 km)
* Near-polar ⇒ orbital *seam*
* 4 ISLs : 2 intra-plane & 2 inter-plane except for the poles and on the *seam*
* No cross-*seam* ISLs
* 6 Orbital planes
* 11 satellites / plane

Causes of delay variation :

1. Elevation variation : movement of satellite with respect to the ground terminal

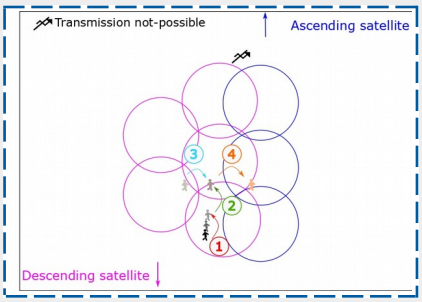
2. Intra-orbital handover delay : satellite drops below the elevation mask of the terminal (every ~ 10 mins)

3. Inter-orbital handover delay : rotation of the earth on its axis or the movement of the ground terminal along the longitude (every ~ 2 hours)

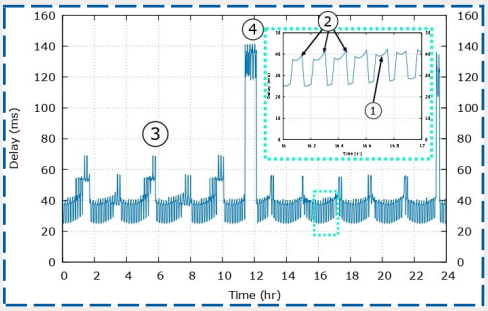
4. *Seam* handover delay : when satellites on the 1st and last planes are sought (happens at least twice at most 3 times during 24 hrs, duration depends on the longitudinal separation)

5. ISLs changes delay : deactivated at the poles becauseof high-speed rotating satellites that cross one another

Delay variation transitions



One-way delay evolution in Iridium (main factors of delay variation are numbered)



Impact evaluation

- TCP CUBIC (with SACK receiver)
- TCP IW: 10 packets
- Queue size: BDP
- Up/Downlink bandiwdth: 1.5 Mbps
- ISLs bandiwdth: 25 Mbps
- FTP
- Mouse file: 9 kB
- Elephant file: 15 MB
- 7 Iridium Gws & terminals in 17 different cities

*** Impact of the *seam* :**

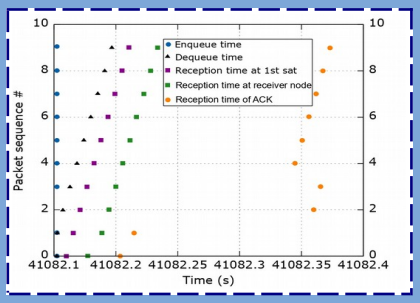
Mean Transfer Time (MTT)

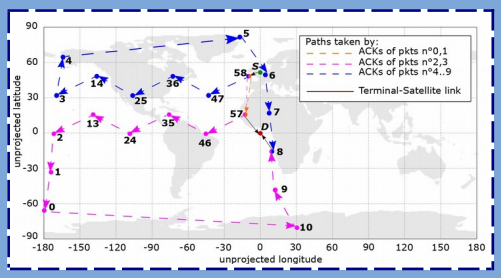
Parameter \ File size	9 kB file	15 MB file
$MTT_{no\ seam}$	90.35 ms	89.67 s
MTT_{seam}	179.43 ms	91.02 s
$MTT_{no\ seam}/MTT_{seam}$ (%)	50.35	98.52

⇒ path changes ⇒ delay changes. **Seam** impactful on the 9 kB file

9kB file during *seam* handover

⇒ out-of-order Packets





Starting which file size is the *seam* detrimental ?

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

*** Impact of the elevation delay :** It has no impact

*** Impact of the intra-orbital handover :** 7.48% decrease in throughput

*** Impact of the inter-orbital handover :** 8.16% decrease

Conclusion & perspectives

- ***Seam*** least frequent most detrimental
- All of the results could be extended to satellite constellations with similar characteristics

⇒ Preliminary tests for higher bandwidths have shown similar results
⇒ Study of the fairness between multiple competitor flows & with different transport protocols
⇒ Emulation + test bed