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RomARS ML PROXY implementation on Starlink

Summary of validation campaign using commercial Observations on Starlink terminal

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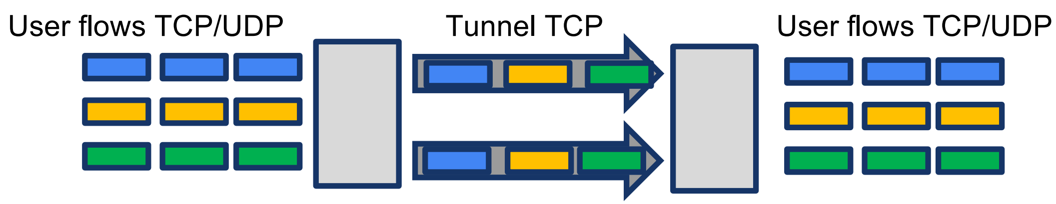
LEO and TCP Behaviours

Introduction – the “previous” scenario

- Performance of transport protocols on GEOs
  - GEO satellite, fixed link geometry, satellite visibility guaranteed for fixed services (elevation angle depending on the latitude of the ground terminal) while may be difficult for mobile services depending on the elevation angle and on the environment (rural, suburban, urban)
  - → Packet loss mainly due to congestion although in case of low availability and/or mobile services other reasons occur
  - → High but constant delay
- Multipath TCP Solutions
  - Two TCP tunnels carrying all user traffic as a payload
  - Distribution of traffic over the tunnels is done per packet. All the traffic of all applications is most likely using all tunnels



User traffic becomes payload of two TCP sessions

Starlink traffic observation

- LEO constellation architectural scenario
  - Satellites moving in a polar orbit
  - The serving satellite can be hooked when rising at the horizon and left when reaching again the horizon
  - Multi-array Antenna with electronic steering must chase the satellites (too fast for mechanical tracking system which also suffers from the dimensions and scarce practical transportability and repositioning)
  - Frequent handovers between different satellites
  - Highly variable number of available satellites
- Outcomes of observation campaign with real traffic
  - High packet loss not due to congestion
    - Isolated packet loss
    - Prolonged connection loss due to handover and low S/N
  - Very high RTT (delay) variation (jitter), partly due to dynamic geometry

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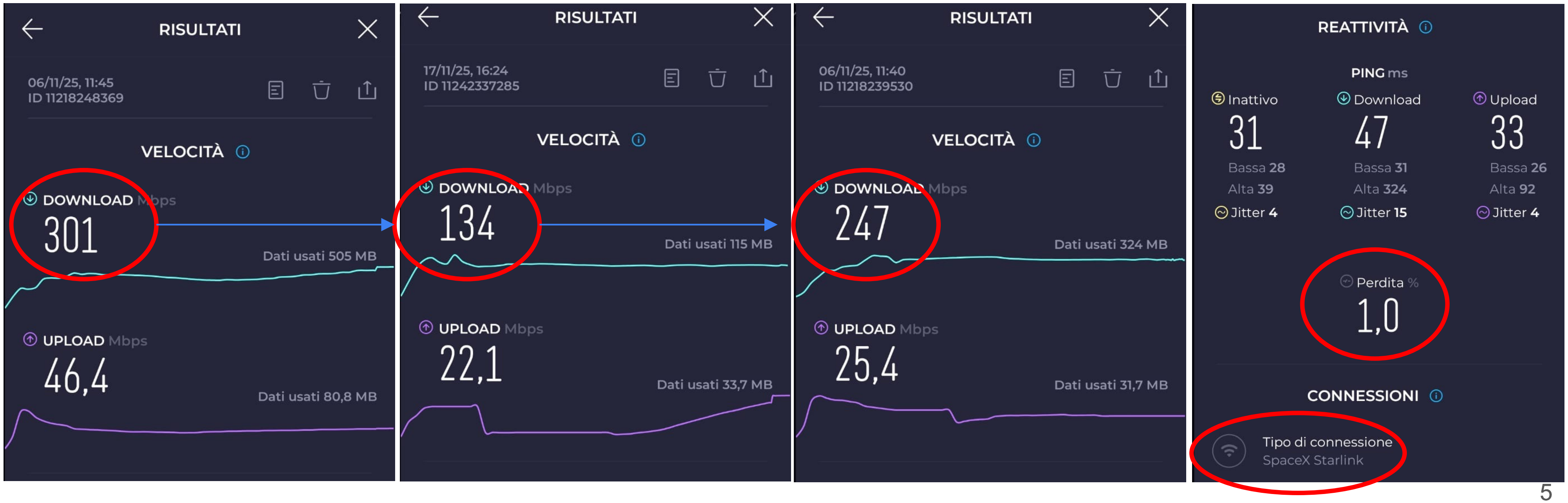
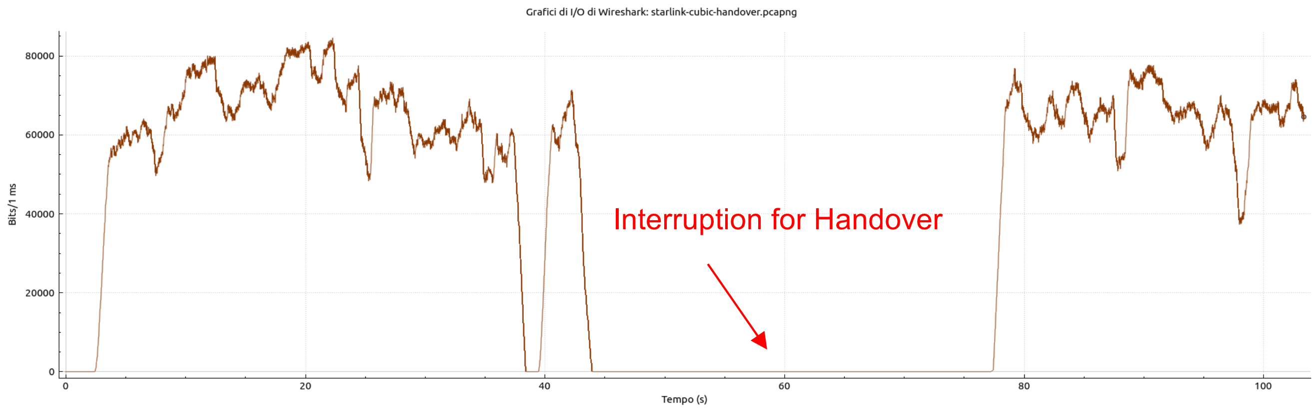
Starlink Channel characterization

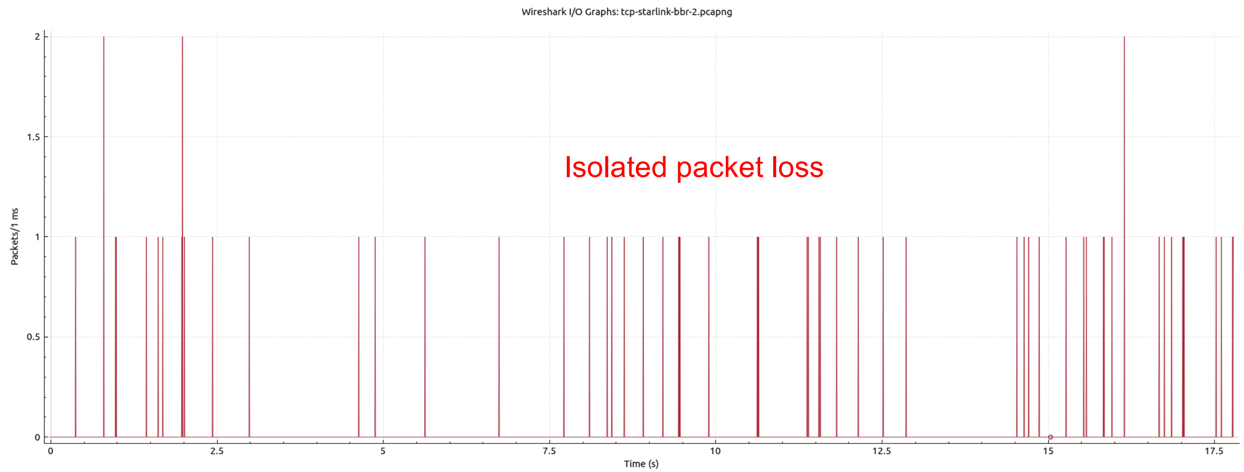
- Assessment of the available bandwidth and RTT (Ookla SpeedTest Results)
  - Bandwidth fluctuation depending on: Satellite Position, Number of users connected, etc.



Starlink Channel characterization (II)

- Analysis of losses
  - Handover (Timeout)
  - Spurious

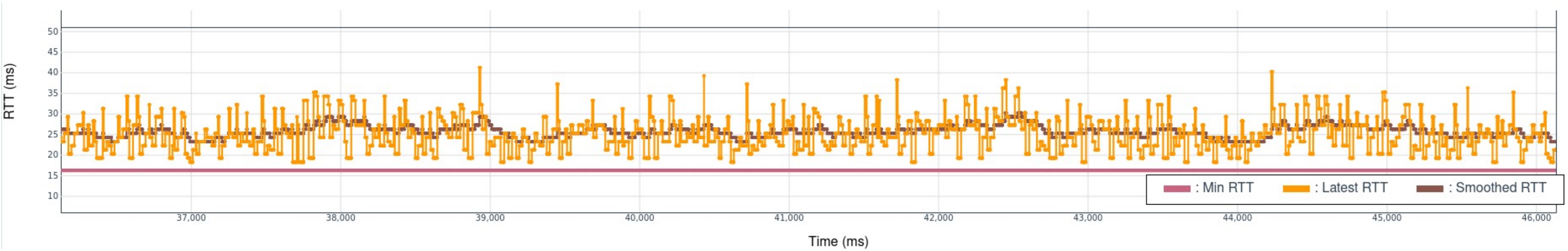




Starlink Channel characterization (III)

- Analysis of Physical Latency and RTT
  - High Jitter/Variance in latency

RTT ranges from 20ms to 35ms, 75% more



Confirmation from other international studies

A Global Perspective on the Past, Present, and Future of Video Streaming over Starlink

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REESE ENGHARDT, Netflix, USA
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This study presents the first global analysis of on-demand video streaming over Low Earth Orbit (LEO) satellite networks, using data from over one million households across 85 countries. We highlight Starlink's role as a major LEO provider, enhancing connectivity in underserved regions. Our findings reveal that while overall video quality on Starlink matches that of traditional networks, the inherent variability in LEO conditions—such as throughput fluctuations and packet loss—leads to an increase in bitrate switches and rebuffers. To further improve the quality of experience for the LEO community, we manipulate existing congestion control and adaptive bitrate streaming algorithms using simulation and real A/B tests deployed on over one million households. Our results underscore the need for video streaming and congestion control algorithms to adapt to rapidly evolving network landscapes, ensuring high-quality service across diverse and dynamic network types.

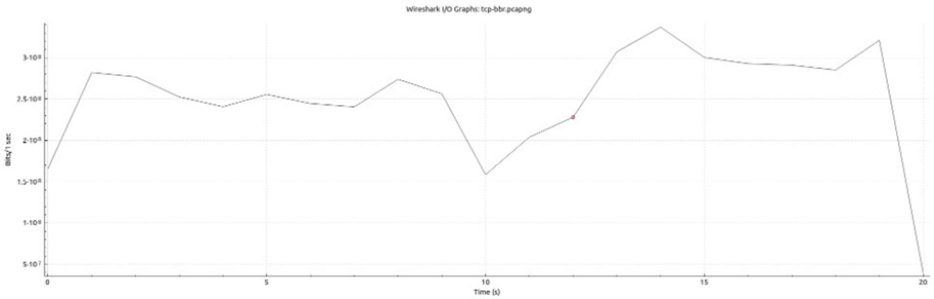
CCS Concepts: • **Networks** → *Network services*; **Network measurement**; **Network performance analysis**;

Characterization of the LEO channel

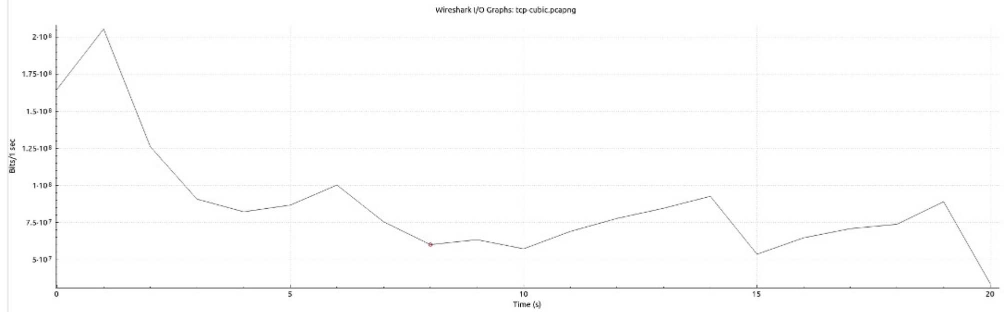
- Throughput variation
  - The number of visible satellites and the total available bandwidth changes frequently
- Transport layer congestion control (traditional) works poorly
  - Congestion control tries to saturate the channel to use all the resources
  - However, when it realises the occurrence of lost packets, it slows down because it assumes there is congestion
  - Instead, in most cases packets are lost in the handover phase or simply due to poor channel quality, but not necessarily due to lack of resources
- In case of Streaming, high buffering is introduced
- In summary
  - The available bandwidth is not fully used
  - Lower speeds: It slows down the speed and/or accelerate slowly
  - It takes up more bandwidth for retransmissions and buffering
- NOTE:
  - The Ookla speed test **does not use** congestion control.
  - It simply shoots all possible packages and measures how many arrive.
  - It's a real test of the overall bandwidth available at that time (upper bound) but not of the real experienced one by real processes.
  - In fact, real traffic makes use of the **congestion control** and therefore suffers the problems described above.

Comparing Congestion Control in TCP

- Single connection performance with a long transfer
  - TCP (BBR)



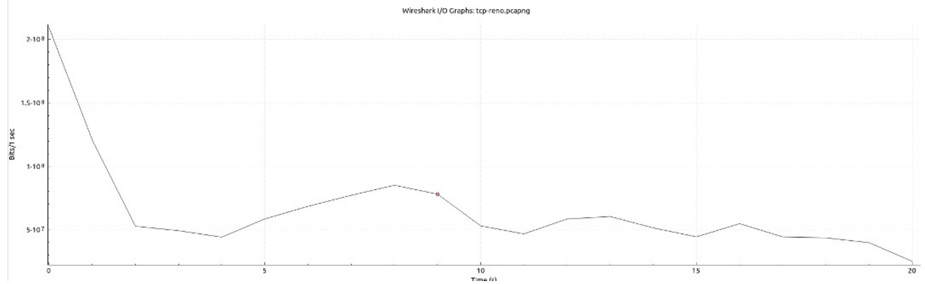
- Single connection performance with a long transfer
  - TCP (Cubic)



Cubic slow and decreasing

BBRv3 is relatively fast and introduce the benefits of Wave CC

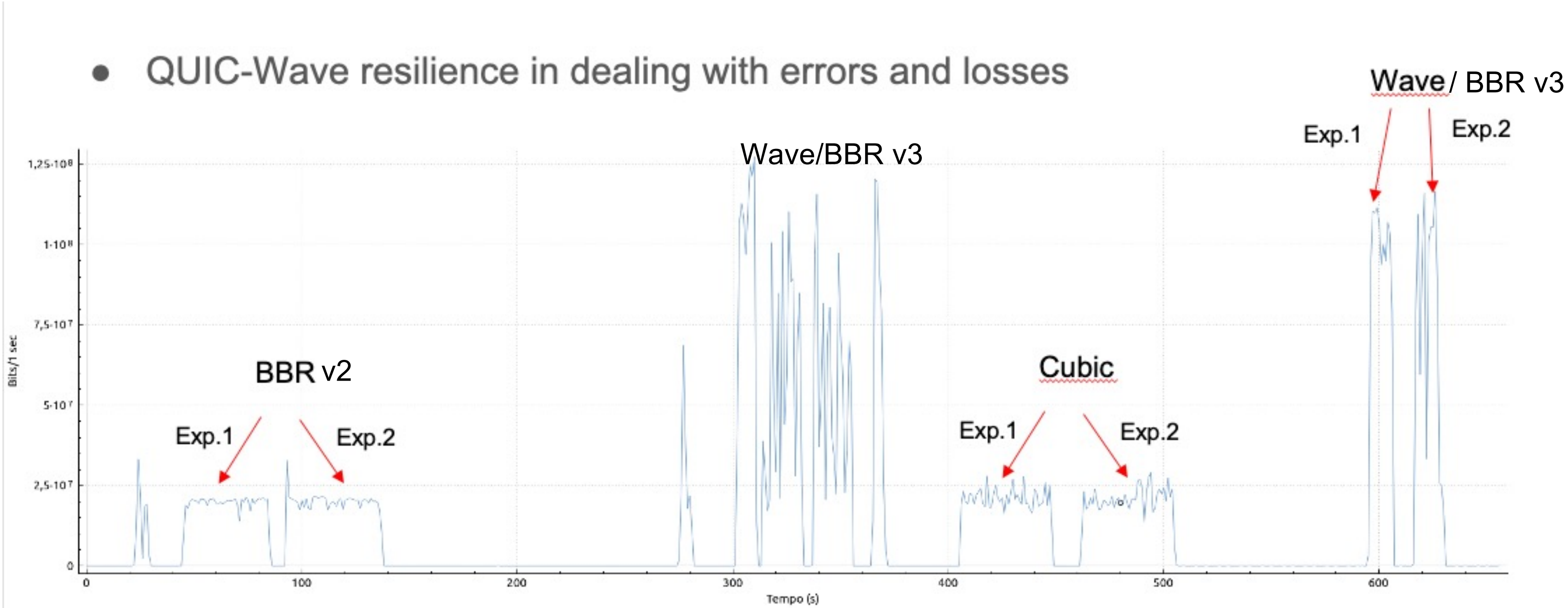
- Single connection performance with a long transfer
  - TCP (Reno)



Reno very slow and decreasing

Wave: Congestion control optimized for highly variable channels

Congestion control of Wave protocol was created for high packet loss environments.
Wave does not slow down immediately in the event of a packet loss → It tries to saturate the channel anyway.



Summary on main issues with LEO

- LEO satellites move quickly relative to Earth
- A connection lasts a few minutes before frequent and unpredictable handover:
  - satellite
  - beam
  - Ground Gateway
  - IP Path
- Effects
  - Micro-interruptions
  - Jitter; sudden fluctuations in RTT
  - Latency variation
  - resetting TCP sessions
  - Packet out of order

It's not a bug: it's the nature of LEO

Most affected applications:

- Traditional VPNs
- TCP not optimized
- VoIP without buffering
- IT Applications (database, ERP, etc)

Above all: Packet loss not due to congestion

- TCP interprets loss as congestion
- Drastically reduces the window
- Throughput decrease
- This is one of the main killers of LEO performance

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QUIC for improved LEO communication

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Proposed solution

- Step One: Move to QUIC and create multiple tunnels
  - It has been demonstrated that many “small” pipes are faster than a single large tube.
  - Each tunnels relay on a single link.
  - Multiple tunnels can be associated to a single link or multiple links
- Step Two: Distribute traffic over the different tunnels per application and not per packet.
  - Loss in one satellite link impact only one or few applications while the other applications remans immunes.
  - Each pipe (ie application) is independent and does not suffer the packet loss of the others
  - Each tunnel is associated to a homogeneous type of traffic and application (eg same QoS Requirements)
- Step Three: Benefit of the BBRv3 (and in future Wave) congestion control
  - Each pipe is accelerated by appropriate congestion control
- Step Four: transfer to the customer the benefits of the new solution
  - New services: Bonding, Back Up , Duplications;
  - Segmentation and prioritization of different traffics
  - Improved user Experience, More Stability, Application Reliability
- Step Five: AI - Ready
  - The characteristics of the tunnel can be adapted based on decision coming from a AI/ML layer (Quality on Demand)

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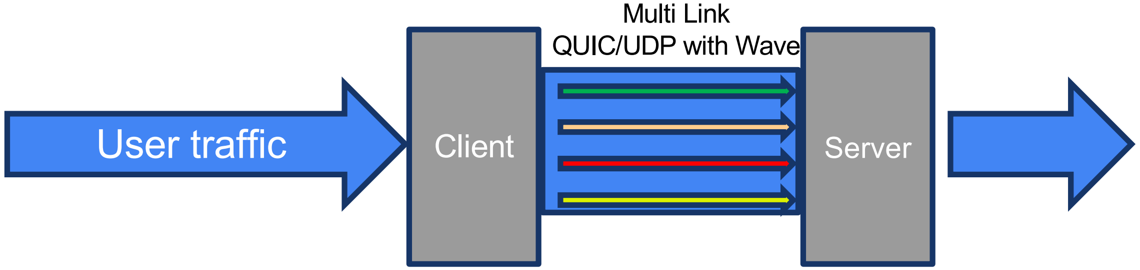
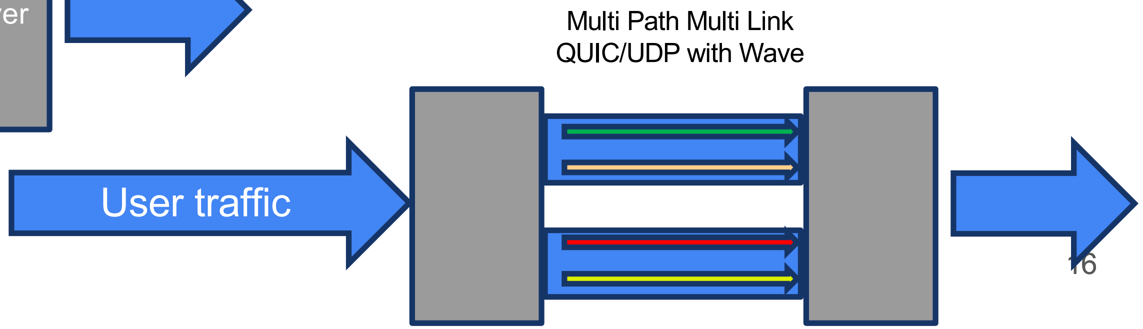
Benefits to Telespazio, Customers, Users

Benefit #1

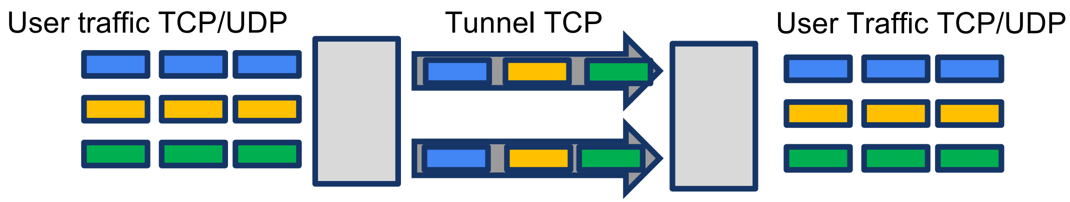
- Even the single antenna benefits from Multi Tunnel QUIC
- A Multi Tunnel QUIC solution can work with just one antenna and thus enables the advantages of QUIC/UDP right from the start
- Fully MultiPath compliant
  - Multi Link can also be used in a Multi Antenna scenario
  - The different pipes can be distributed on several antennas





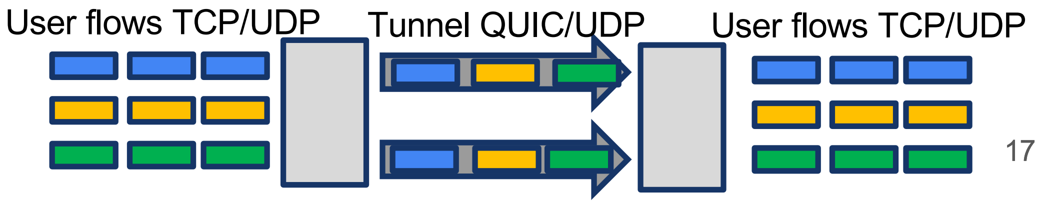
Benefit #2

- A QUIC/UDP tunnel is easier to move from one antenna to another
  - faster and more robust path handover
- Using UDP as a tunnel transport instead of TCP has two advantages
  - UDP is faster in case of failover and session rebuild
  - The underlying TCP would do the correction of lost packets even when the payload does not require it (eg streaming/voip)
- QUIC has embedded encryption based on DTLS1.3



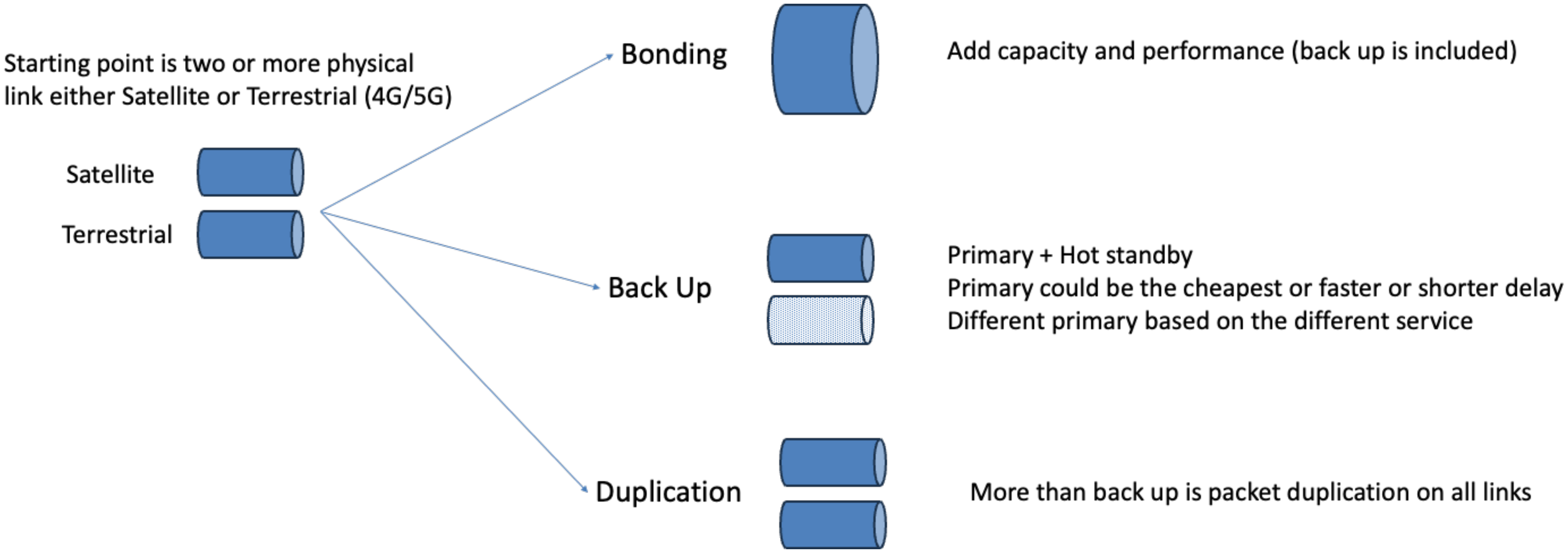
These TCP tunnels correct errors even when not needed

Error correction only when needed. The control is left to the end points and above layers. Proxies do not introduce additional delay.



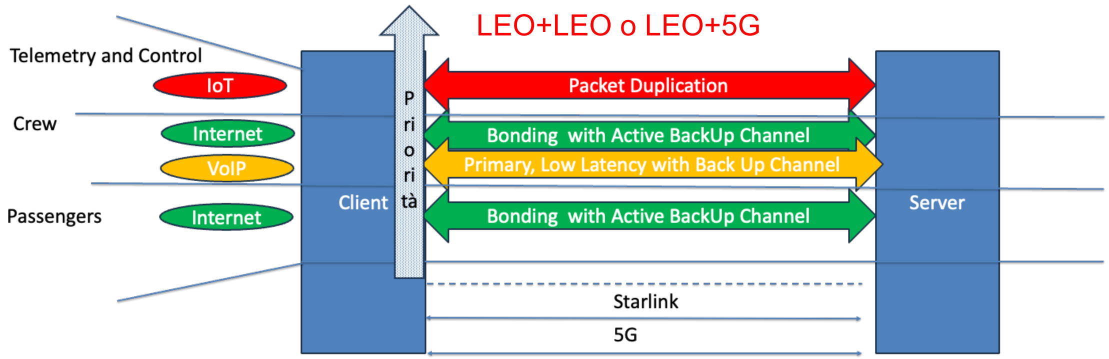
Benefit #3

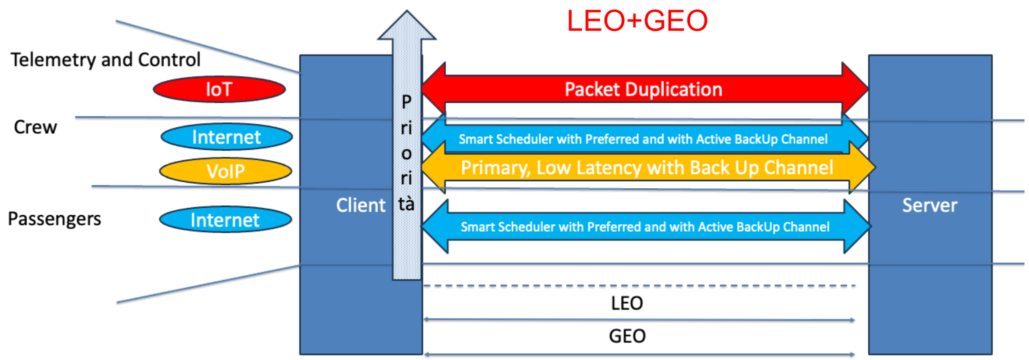
- It is possible to enable different services, traffic classes, and tunnels
  - Bonding
  - Low Latency with Active Back Up
  - Packet Duplication



Benefit #4

- Each tunnel with different priorities
- Possibility to manage different type of technologies





Benefits for Telespazio

- Client can be installed in the TSP T-BOX
- Server can be installed at Fucino Teleport
- Tailor-made customizations for customer
  - Implement new and different services (to be included in the commercial offer)
    - Bonding, back up, Packet duplication
    - Different priorities between different links
- Improve the User Experience
  - Impact on the real user traffic (and not at speed test only)
  - Stability and smooth operation
- Possibility to implement multi satellite – multi orbit architecture with the best performances
  - Same delays: LEO + LEO ; LEO + Terrestrial
  - Different delays: LEO + GEO + Terrestrial
- O&M with more visibility and control:
  - More KPIs
  - Improvements for both TSPZ and the customer portal
  - Improve the Remote support on the TBOX with help desk team

Benefits TCP vs QUIC

- TCP is performing poorly on LEO
- QUIC allows a more stable connetion since not impacted by sporadic loss of packet
  - Stable throughput
  - More efficiency that turns into more capacity
  - Reduced freeze/interruptions
- Result for the customer:
  - Better user experience for execution of applications
  - X% more of throughput per user
  - Feel always online, with less interruption
  - Less jitter allows video and web more fluid
  - It's not just "faster", it's "more usable"
  - QUIC doesn't make LEO just faster, it makes LEO more stable, continuous, and predictable
    - stability = perceived performance
    - Continuity = reliability
  - On LEO, QUIC improves perceived performance and keeps sessions alive during handovers.

	TCP	QUIC
Sessions	Reset	Persistant
Throughput	Up/Down	Stable
Video	freeze	fluid
Web	reload	fluid

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- QUIC does not reduce the €/Mbps cost, but it reduces the operating cost and increases the value of the bandwidth already paid
  - less inefficiencies
  - less downtime
  - less "wasted" bandwidth
  - fewer operational interventions
  - Better productivity / service
- GAIN in Bandwidth (Practical exercise to be done with the customer)
  - X€/month price of the bandwidth for N Mbps Nominal
  - TCP is only able to exploit T% of the Nominal bandwidth
  - QUIC is able to deliver Q% of the Nominal bandwidth where Q>T
  - Q-T=G, Gain from TCP to QUIC.
  - G% is a gain in Mbps and also in €/month
  - If there is a fleet of Ships the gain is Number of Ship * G → N*G can be in the order to thousand of € per month
- SAVINGS in Runtime
  - QUIC allows better Session-continuity while working with IT applications
  - At application level with TCP there could be N interruption for M minutes for a total time of N*M
  - Avoiding N*M minute of downtime during the day (* month) allows in saving in manpower and efficiency
- Other savings
  - Less costs of help desk /support (cost of support)
  - Improved Crew Welfare (cost of replacement)

Problem on LEO	Benefit with QUIC	Type of App impacted
Packet loss non congestion driven	Stable bandwidth, quick recovery	SaaS
Handover / IP change	session continuity	web, API
RTT / jitter variable	pacing	video, VoIP
Throughput instable	More bandwidth	upload/download
Handshake slow	0-RTT	web

For each customer, based on the type of applications and number of ships, it can be quantified in € the benefit of QUIC

Final Statement

- We can build a solution designed for Telespazio requirements which is:
    - Open solution (not a black box)
    - Integrated with current TBOX / Servers
    - Integrated with current Management Systems
    - Open to evolutions, and customizations based on specific customer requirements
- Next step
    - Finalize a Requirement List
    - Agree on business model and economical offer

Demo Set Up

Demo Architecture – building blocks