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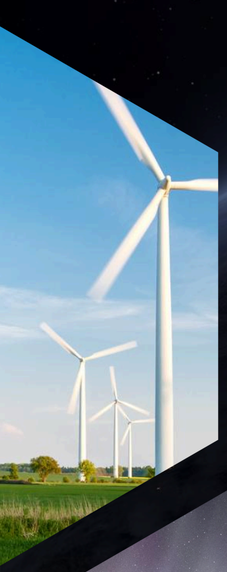

LEO Satellite Communications - Next-Gen Rail Connectivity

Authorised Starlink Reseller
The Clarus Networks Group

A BRIEF INTRO TO CLARUS

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- Formed in 2014
- Business critical communications in some of the world's most challenging environments:
  - Low Earth Orbit Satellite Communications
  - Starlink & Oneweb
  - Private 5G Networks
  - Bonded LTE Solutions
  - Cellular Coverage Technology
- Clients across Government, Energy, Maritime, Construction, Manufacturing, Utilities & Healthcare
- One of just a handful of distributors across the world to provide both Starlink & Oneweb
- The Only company to work directly with Starlink on rail certifications of the Rail Tile

LEO Connectivity

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Constellation Maturity Overview – All High Availability/Low Latency

Operational networks range from a few test satellites to 9,000+. – Game changing for rail versus GEO Constellations and other connectivity bearers

Starlink – ~9,000 satellites (growing to 15,000). Consumer & enterprise. Fully owned ground stations. Rail-certified terminal available (in-house).

OneWeb (Eutelsat) – 650 satellites. Enterprise focus. Mix of owned & user ground stations. Model under review. Rail terminal in development for Mid-2026 (3rd party).

Rivada – ~300 satellites planned. Peer-to-peer network with no ground stations. Enterprise focus. Launches starting soon. Rail terminal planned (3rd party).

Kuiper/LEO – ~3,500 satellites planned. Consumer & enterprise. Initial tests launched. Rail terminal planned (in-house).

Telesat Lightspeed – ~1,500 satellites planned. Enterprise focus. Rail Focus is Unknown

LEO Connectivity - STARLINK

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Starlink: Currently the Only Viable Rail Connectivity Network

Largest & Most Mature Constellation

- ~9,000 LEO satellites delivering global, continuous coverage.
- Supports high-bandwidth use cases: streaming, IoT, video calls.
- Clarus partnered with SpaceX to certify and adapt Starlink for rail; simplified deployment and reduced costs.

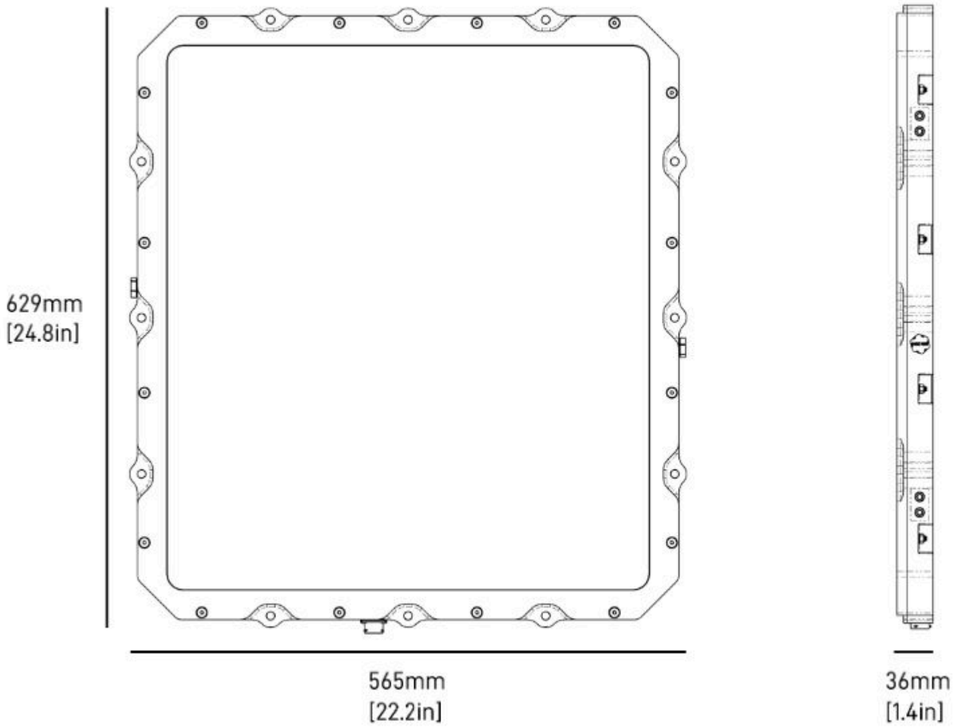
Proven Technology

- Advanced satellites and user terminals with deep operational experience.
- Designed for reliability on moving platforms – Planes, Trains, Boats and Cars

Low-Latency Performance

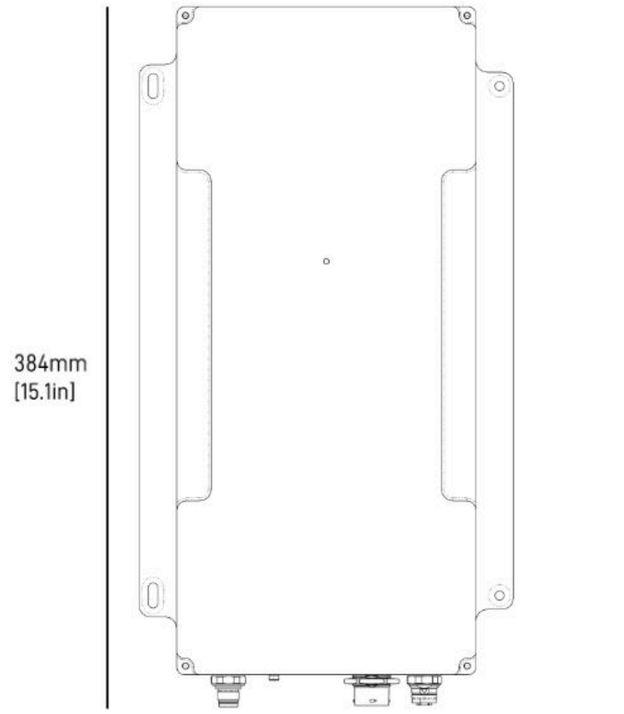
- GEO systems (~36,000 km) suffer 600+ ms latency. Limited real-time Applications
- Starlink LEO (~550 km) delivers ~20 ms, enabling real-time applications.
- Currently - Typical speeds: ~220 Mbps, increasing as new satellites launch.

STARLINK Rail Tile and PSU



Antenna	Electronic Phased Array
Performance	40-220+Mbps ↓ | 8-25+Mbps ↑ <99ms Latency
Field of View	140°
Weight	13kg [29 lbs]
Power Input	$49V_{DC}$ Power-over-Ethernet
Connector	UTO 1210 Male
Environmental Rating	EN 50155 OT 4 / IP68
Env. Salt Mist Testing	EN IEC 60068-2-11, Test Ka.
Operating Temperature	-40°C to 70°C
Flammability Rating	EN 45545-2 R7 HL1 and HL2 HL3 via Risk Assessment
Electromagnetic Comp.	EN 50121-3-2, EN 50121-4
Maximum Speed	400 mph [643 kph]
Vibration	EN 61373 Cat 1, Class A&B
High Voltage	EN 50163, $29kV_{AC}$, 5 minutes
High Current	EN 50388-1, $15kA_{AC}$/0.120s, $100kA_{DC}$/0.040s
Pressure Fatigue	>1,000,000 cycles at ±3.1kPa

STARLINK Rail Tile and PSU



Locomotive Tile to Satellite

Ku Band
RX 10.7 – 12.7 GHz
TX 14.0 – 14.5 GHz

Satellite to Earth station / Gateway

Ka Band
Up / down 26.5 – 40.0 GHz

E Band
Down 71 – 76 GHz
Up 81 – 86 GHz

https://satellitemap.space/?constellation=starlink

Weight	3.6kg [7.9 lbs]
Power Draw	110-150W Avg, 400W Peak
PSU Input	110-240V_{AC}, 6.3A, 50-60Hz
Environmental Rating	EN 50155 OT4 / IP0
Operating Temperature	-40°C to 70°C
Flammability Rating	EN 45545-2 HL3
Electromagnetic Compatibility	EN 50121-3-2, EN50121-4
Vibration	EN 61373:2010 Cat 1, Class A&B
Power Input Connector	M12 S-Code Male
Data Output Connector	M12 X-Code Female
Antenna Connector	UTO 1210 Female

Tunnels and Cuttings – Hybrid approach with Starlink

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Cuttings & Urban Canyons

- Starlink expanding constellation constantly to improve coverage.
- 140° tile viewing angle boosts availability in deep cuttings and urban canyons.
- Bandwidth may dip in obstructed areas but improves as constellation density grows.
- Best performance when combined with MNO or private trackside networks.

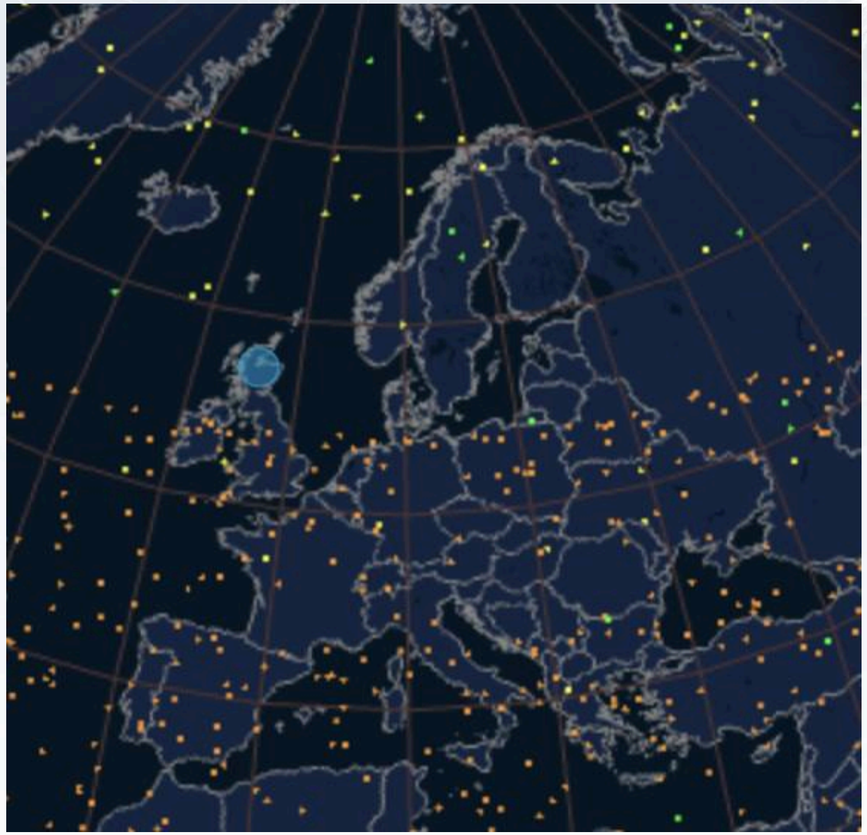
Tunnels

- Starlink cannot operate inside tunnels.
- POC to look at wayside terminals + repeaters for seamless tunnel coverage
- Onboard systems fall back to MNO or private networks, then reacquire Starlink on exit.

Hybrid Model Approach – LEO can’t do it alone

- Primarily LEO, with 5G and Trackside (mmWave etc) covering compromised areas.
- DAS in tunnels – trackside or cular
- Scotrail deployment on route shows ~96% coverage with Starlink-first hybrid deployment.

ScotRail Example – LEO Declared Benefits



ScotRail LEO Connectivity Trials – Initiative

- Funded by Scottish Futures Trust – Improve connectivity in highlands of Scotland
- Seven Class 158 trains fitted with LEO connectivity.
- Test routes: Inverness–Wick/Thurso, Inverness–Kyle, Inverness–Aberdeen.

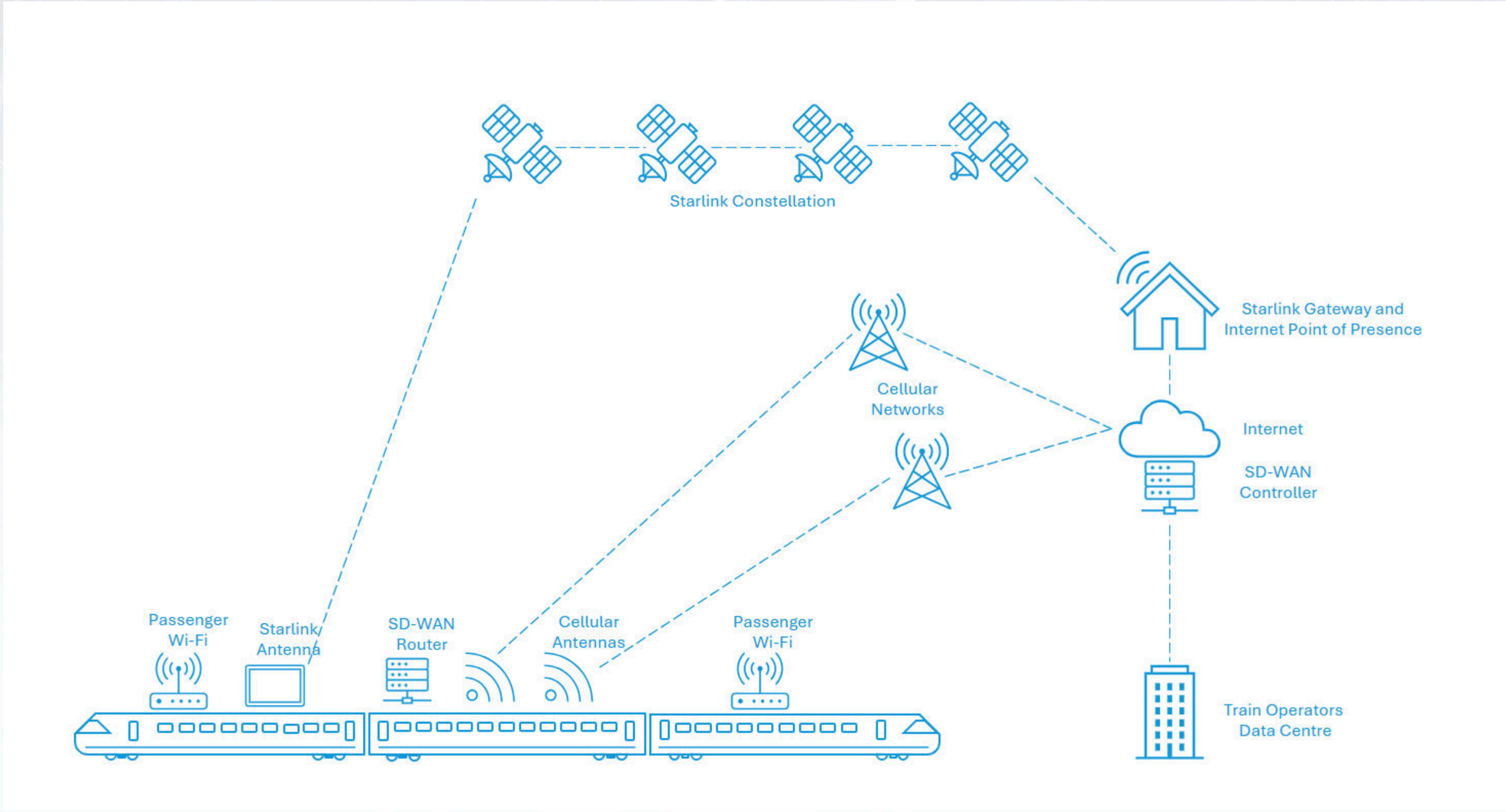
Benefits for Public Transport Operators

- Enhanced passenger connectivity and Wi-Fi calling.
- Real-time GPS tracking.
- Support for card payment systems.
- Live onboard status data: toilets, seats, bike spaces.
- Improved incident response: CCTV access, passenger welfare, technical diagnostics.

Public Sector & Community Benefits

- Low-cost way to gather real-world data without trackside infrastructure.
- Positions Inverness as a hub for digital rail innovation.
- Enables easier integration across transport modes.

ScotRail - Class 158



Starlink Tile & Shroud – Class 158

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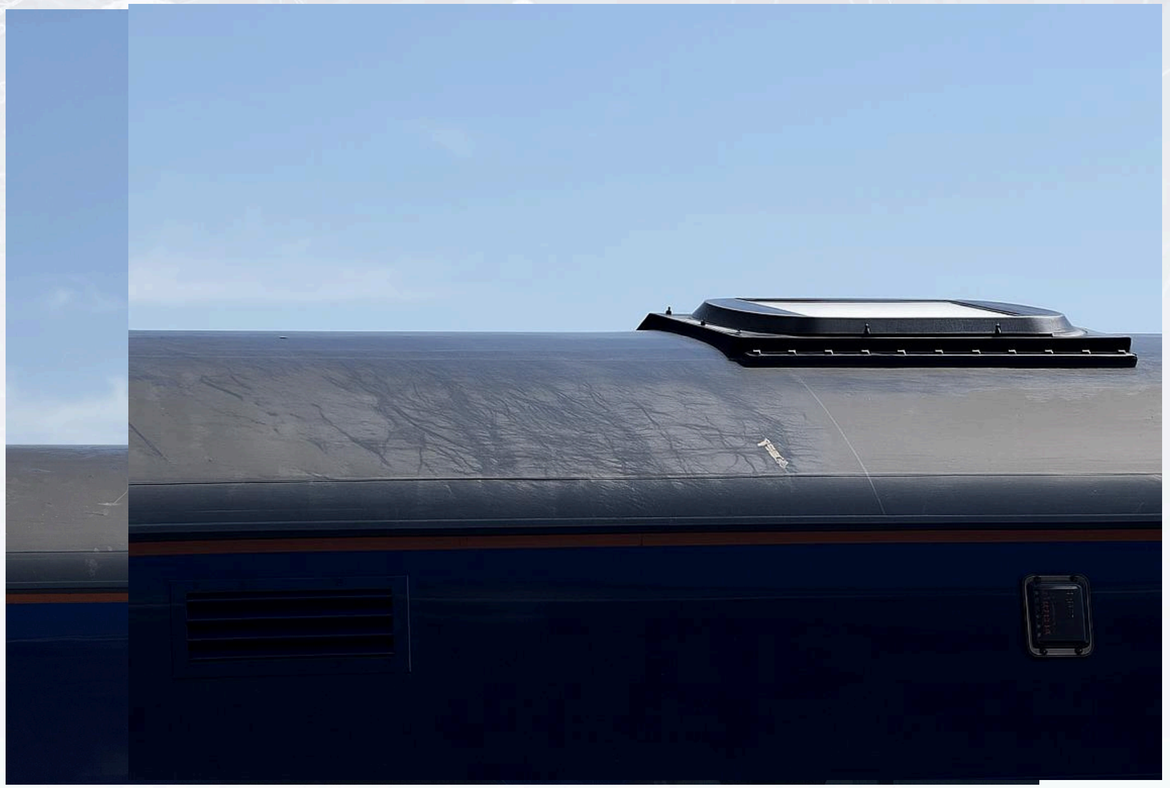
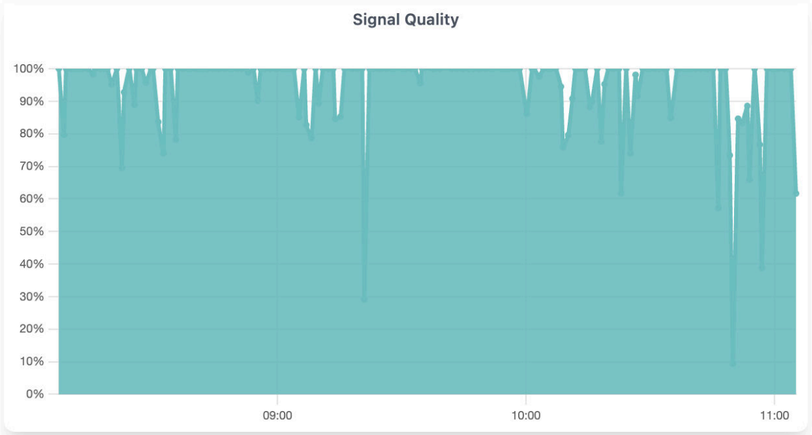
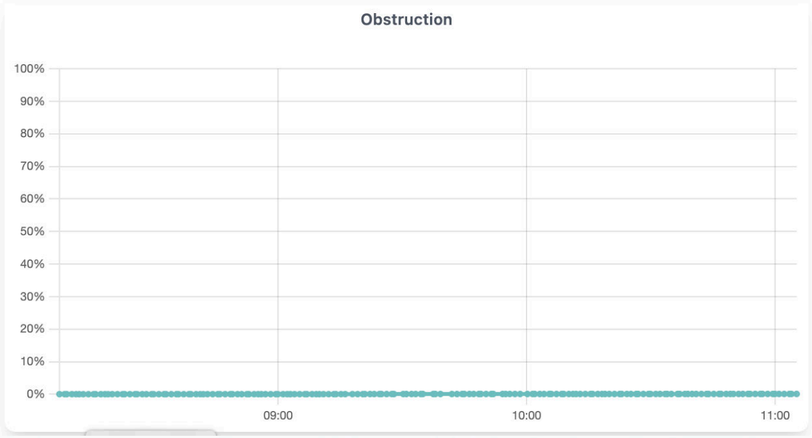


Performance Result – based on usage/demand





Coverage	96.24%
Latency Average	29.96
Latency Max	81.00

Data-usage – 646GB (July) – Per Train – Per Month

Previously Max 50GB – Per Train - Per month

The use cases in Rail that Clarus is currently using LEO Connectivity to fix – who we are working with:

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- Passenger Experience - Clarus Networks, Unwired Networks, Motion Applied, Nomad Digital, Passengera
- Operations Communications - Unwired Networks
- Train Location - Incremental Solutions
- Live CCTV and Collision detection - ADComms
- Control, Command and Signalling (CCS) bearer - Universal Signalling, Comms Design
- Remote Condition Monitoring (CBM) and Telemetry - Train Builder
- Infill on routes with partial Private Trackside Networks - Clarus Networks – Angel Trains/DfT
- High Speed Comms to complement existing Cellular networks - Motion Applied
- Infrastructure Monitoring – Fixed and Mobile – Global Rail Tech Provider

FRMCS – LEO connectivity is an option - Future iterations could utilise LEO in remote areas to support CCS systems

Security - USER Cases – Quantum Key Distribution (QKD) – LEO with Optical

Providing enhanced security for CCS systems – High availability and low latency enables this – adding enhanced security to the communication chain.

- LEO Provides mechanism to effectively distribute keys to Optical transmission devices on the trackside – provides added layer of security to communication
- Quantum Key Distribution (QKD) provides the means of guaranteeing that the encryption keys for securing data are un-hackable.
- QKD will enable secure communication of data required by trains for safety-related systems and operations.
- QKD from satellite overcomes inherent distance-limitations of terrestrial systems – but is impractical direct to moving trains.
- R&D by the University of York and Clarus Networks to facilitate QKD to Trains when stationary via Optical transmission.
- Initial testing at facilities at University of York and Network Rail .

Digital Signalling – Universal Signalling

- A cost effective bearer for Signalling in areas where budgets do not warrant ETCS
  - Comms is always the limiting factor
  - Hybrid LEO provides a solution – either as Primary and Secondary Bearer – Low Latency and High Availability with out foxed infrastructure
- Delivering signalling functionality in compressed timeframes, at reduced costs.
- Leveraging space positioning, and (soon) LEO Comms:
  - Keeps costs low
  - Enables faster market entry and deployment
  - Same product can be deployed worldwide without adaptation
  - Products can be overlaid on all other signalling systems
  - Open architecture = easy interfacing with 3rd party systems


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