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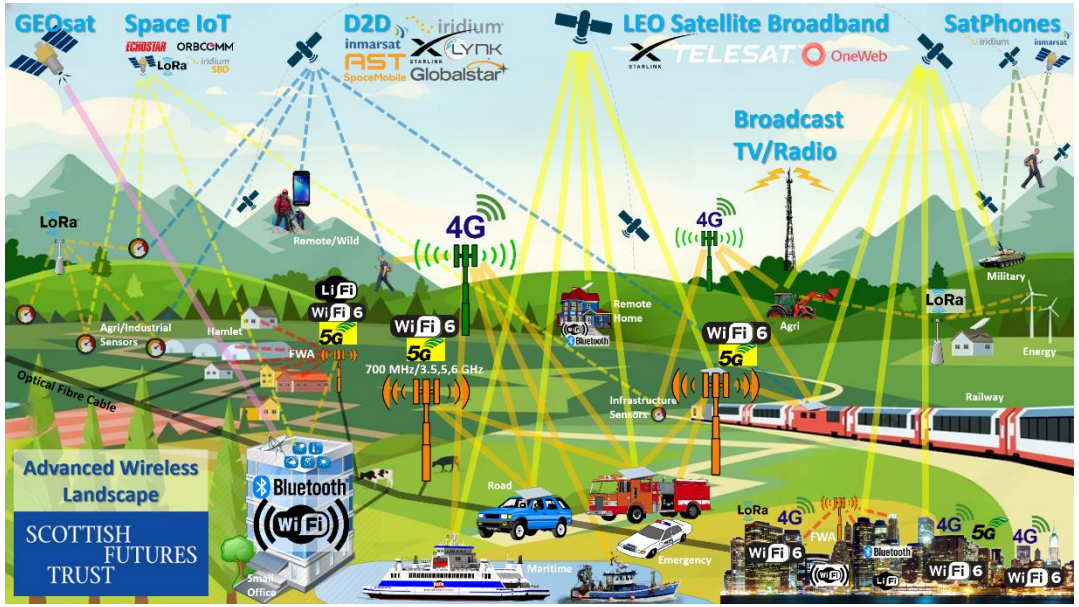
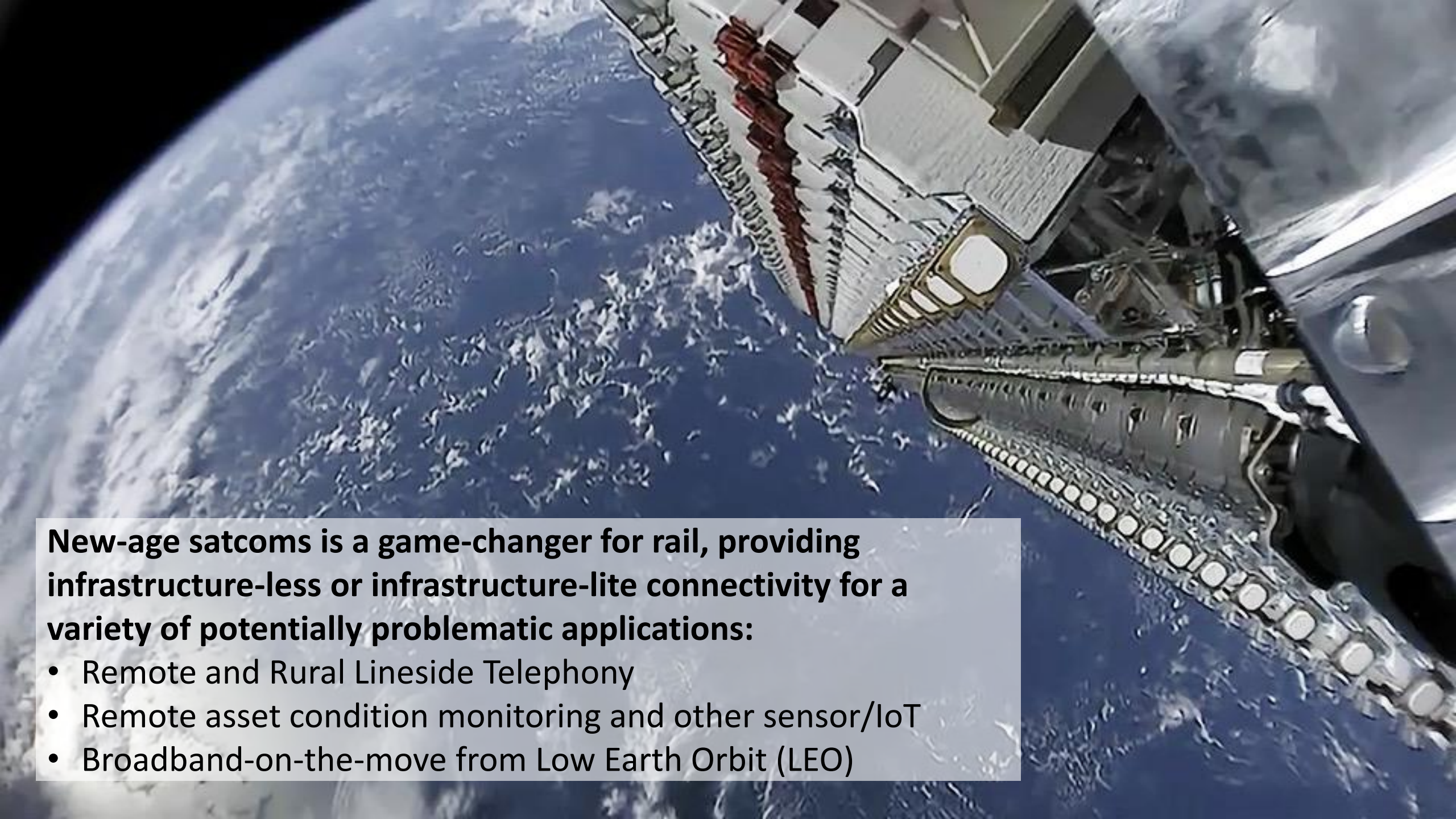
5G, 6G, 7G...

Converged Advanced Wireless Networks

for Transport





New-age satcoms is a game-changer for rail, providing infrastructure-less or infrastructure-lite connectivity for a variety of potentially problematic applications:

- Remote and Rural Lineside Telephony
- Remote asset condition monitoring and other sensor/IoT
- Broadband-on-the-move from Low Earth Orbit (LEO)

Convergence of Advanced Wireless

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5G promises ultra-high-speed connectivity, sub millisecond latency, great reliability and more. Alongside the latest Wi-Fi (6→7), this will deliver exceptional service for urban populations[1,2].

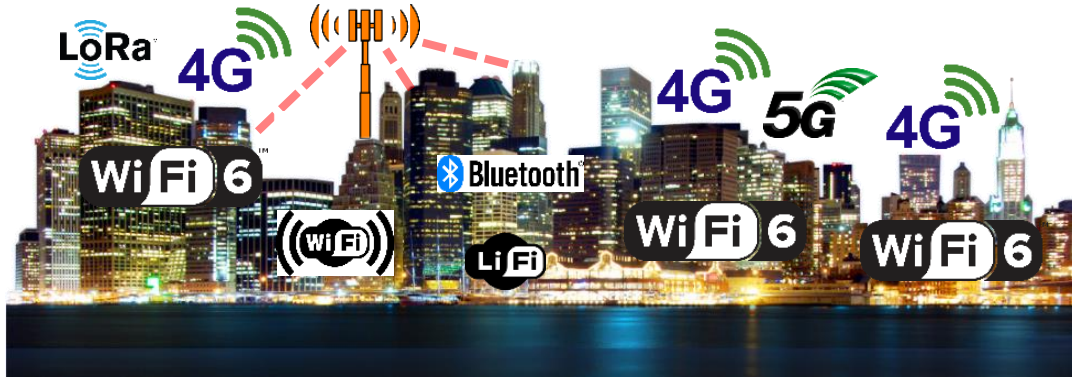
However, 5G RAN deployment raises coverage and network dimensioning issues in underserved and unserved areas, especially in low ARPU regions of emerging markets.

Furthermore, terrestrial 5G connectivity is obviously not so useful for transport such as aircraft, ships and ferries, and the infrastructure may be prohibitively expensive for non-urban rail and road transport.

Satellite systems (and possibly high-altitude platforms) are a potentially affordable means by which to address these scenarios[2], ideally as part of a converged advanced communications ecosystem.

[1] Good 4G coverage is arguably sufficient since the bulk of data (~75%) is handled by low-cost, in-building Wi-Fi. This may be why 5G roll out has been slower than many expected/hyped – see next slide.

[2] Some locations with transient demand might also be better served by satellite communications means.



Why 5G has not delivered its hype…

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This chart points out 2 crucial things that perhaps explain why 5G hasn't taken off as expected a few years ago:

- Wi-Fi 6 can cheaply provide several of the 'hyped' advantages of 5G
- For the other hyped advantages of 5G, they apparently don't matter very much at the moment (but they might in future)

…meaning that most users/ consumers don't care very much

Table: What makes 5G different and who cares? (David Green, Deloitte)

5G Feature	Does 5G have an advantage	Does that advantage matter right now?
Coverage (compared to WiFi)	Y	Y
Speed / data throughput	N - Wifi6 is comparable	n/a
Latency	Y	N
Connection density	Y	N
Device velocity	Y	N
Security	N - Wifi6 is comparable	n/a
QoS/Reliability	Y	Y
Positioning	Y	N
Handover	Y	N
Inexpensive	N - WiFi6 normally much cheaper (except where coverage area is large)	n/a

Once people transitioned from 3G (which wasn't quite good enough) to 4G (which is mostly good enough), there was little demand from 'consumers' to upgrade to 5G.

In surveys of important phone features, 5G capability is down at 12th position (cameras & battery life top the list)

By the way, this was predicted in William Webb's *"The 5G Myth: When vision decoupled from reality"*, Nov. 2016, which said of then 5G vision that users weren't fussed, the technology advanced were insufficient, and the telcos can't profit.

Terrestrial/SatComs Convergence

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But satellite and terrestrial communications are at last slowly converging.

Some evidence and predictions based on announcements:

- All Smartphones support 3GPP mobile cellular and IEEE WLAN Wi-Fi; each iteration of both technologies arguably pushes them closer to each other in terms of coverage, throughput and reliability.
- iOS11 supports Multipath TCP to aggregate the bandwidth of mobile cellular and Wi-Fi networks.
- 3GPP/BBF ATSSS (Access Traffic Selection, Switching, Splitting) applies Multipath TCP both in the User Equipment (UE) or Residential Gateway (RG) and on the network side to integrate 3GPP and non-3GPP wireless (or wired) access, enabling best network selection, handover and capacity aggregation.
- 2022 – 3GPP Release 17 – introduces non-terrestrial network (NTN) topologies based on HAPS, LEO and GEO satellites aimed at complementing terrestrial networks for coverage in remoter areas and at sea.
- 2023 – Direct-to-Device (D2D) SOS messaging becomes available on **Apple** iPhone 14 via **Globalstar** satellite, and for Android phones with **Qualcomm**'s new Snapdragon chipset that talks to **Iridium**, with **Garmin** SOS.
- 2024 – Native IoT D2D via Sateliot's 5G NB-IoT-based wholesale service capabilities.
- 2024 – SpaceX's Starlink LEO constellation provides D2D (max ~3 Mbps) via T-Mobile's PCS G-block spectrum.
- 2025 – 4G-capable D2D for voice, data & messaging becomes available using AST SpaceMobile's constellation.
- 2028 – 3GPP Release 21 – "6G Basic Features + Advanced 5G"
- 2030 – 6G delivers seamless, converged advanced wireless connectivity from a combination of satellite, terrestrial and in-building communications systems.
- 2035 – Real-time performance-tailored, low-cost wireless connectivity available with ubiquitous global coverage.

Converged Advanced Wireless in the Transport Context

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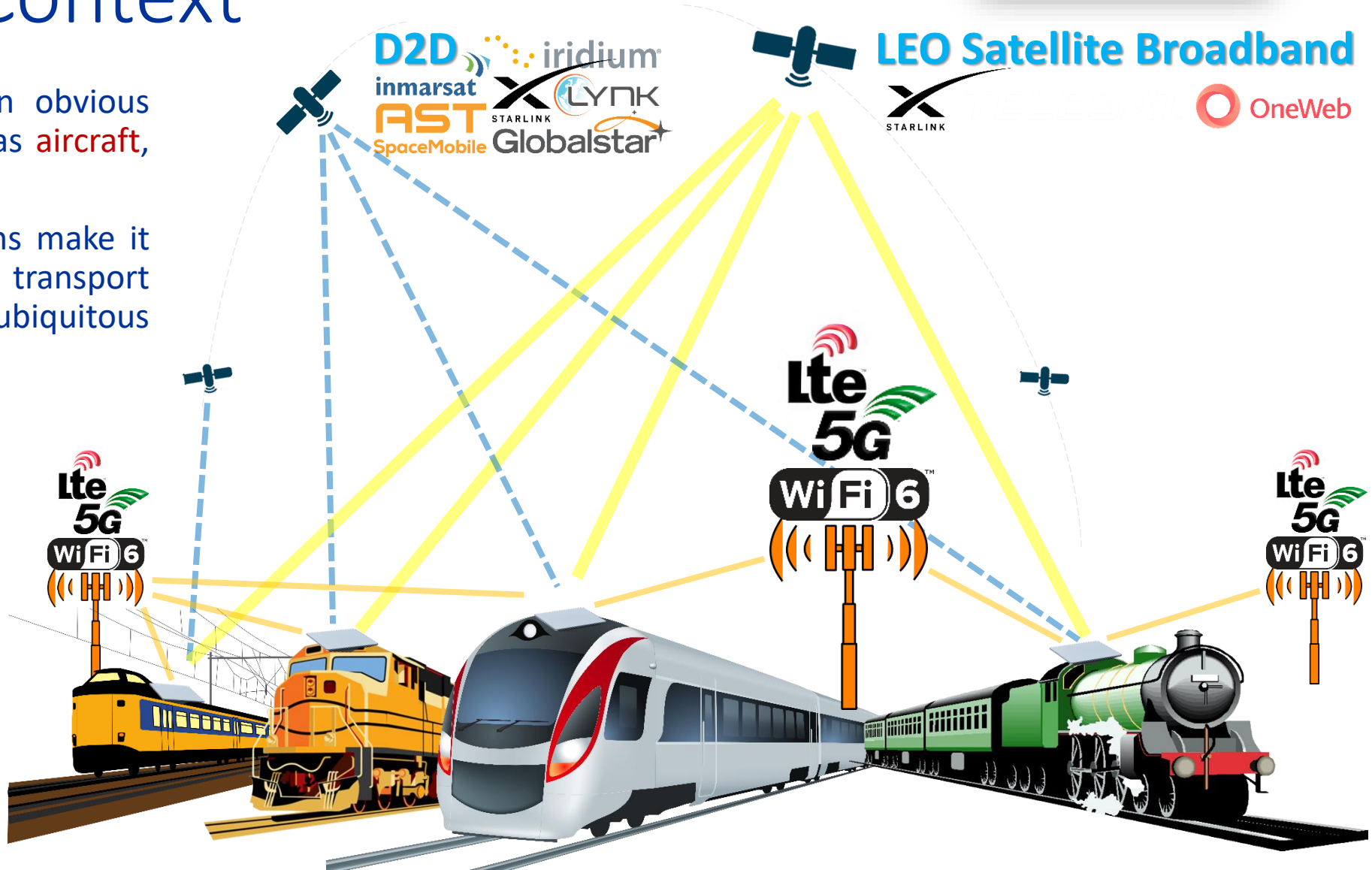
Satellite connectivity is an obvious choice for transport such as aircraft, ships and ferries.

But large LEO constellations make it attractive for rail and road transport because of the near ubiquitous coverage capability.

Combining multiple independent satcoms and terrestrial bearers can provide an aggregate bearer system that can be:

- Highly available
- Futureproofed
- High capacity
- Infrastructure-lite



Direct-to-Device (D2D)

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- D2D is the concept of bringing a satellite signal directly to a mobile handset, or IoT device.
- New 5G NR standard from 3GPP incorporates integration for non-terrestrial networks (NTN).
- Allows standard mobile devices to connect seamlessly with traditional cellular base stations and satellites base stations.
- Especially useful in remote, rural, very hard-to-reach places
- Likely start with messaging, then 3G-like speeds (3-5 Mbps), then 4G (~10-50 Mbps)

This has several significant implications:

1. Enables majority of 500+ million people currently not connected in the 85% of the world without coverage
2. Will extend roaming capability to remote areas without terrestrial coverage (e.g. mountainous terrain)
3. Scales the supplier ecosystem (chipset makers and handset OEMs), driving down the total cost of ownership.
4. Cost efficiencies because it reduces the amount of new terrestrial infrastructure required of telcos.

Future Rail Mobile Communications System (Train)

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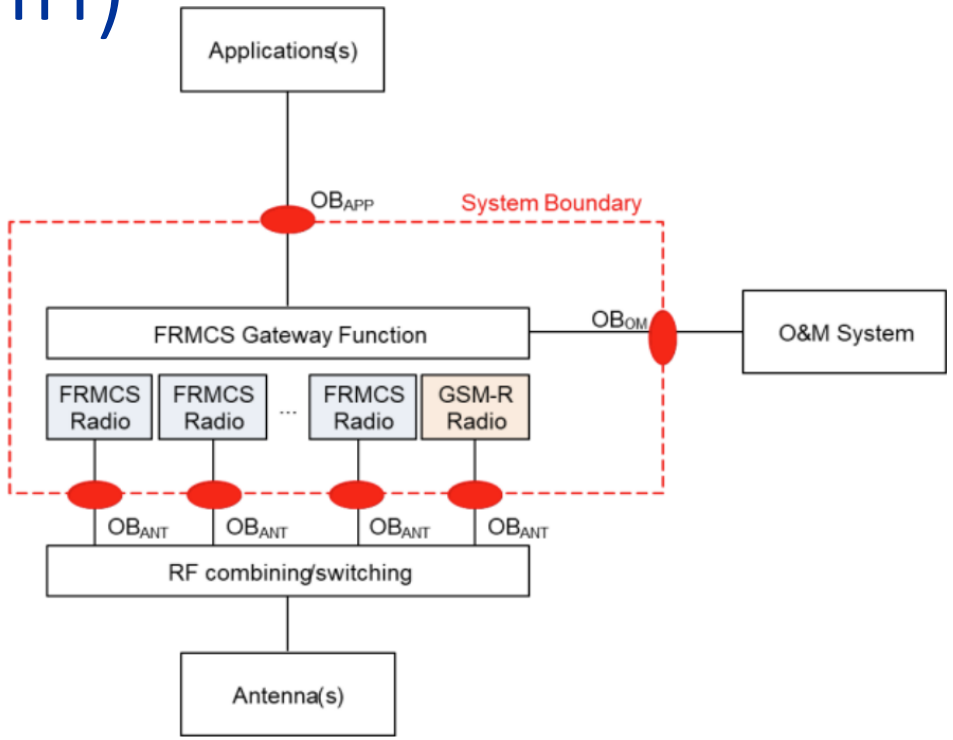
Future Rail Mobile Communications System (FRMCS) is the UIC's successor to GSM-R.

Key Design Paradigms:

- **Decoupling of Applications and Transport** – (GSM-R involved the integration of applications with the GSM transport)
- **Bearer Flexibility** - capable of providing transport services using a variety of radio access bearers (railway dedicated or public) sequentially or simultaneously using different transport technologies (e.g. 4G, 5G, Wi-Fi, Satellite, etc.)
- **Resource Sharing** - QoS-aware transport services for multiple FRMCS applications of any category, including prioritisation among applications.

The FRMCS Gateway Function is not a million miles away from a Multi-WAN router, or even an iPhone.



Functional Architecture of FRMCS On-board System (Ref: TOBA-7540)

FRMCS Gateway Function: Manages the data flows, has a control plane interface for the applications, distributes the user plane data from data applications over the various radio units depending on the application's QoS requirements and possibly priorities among applications.

FRMCS Radio: Modem with any 3GPP or non-3GPP radio access technology supported by the FRMCS system. An FRMCS on-board system contains 1..n FRMCS radios.

Future Rail Mobile Communications System (E-2-E)

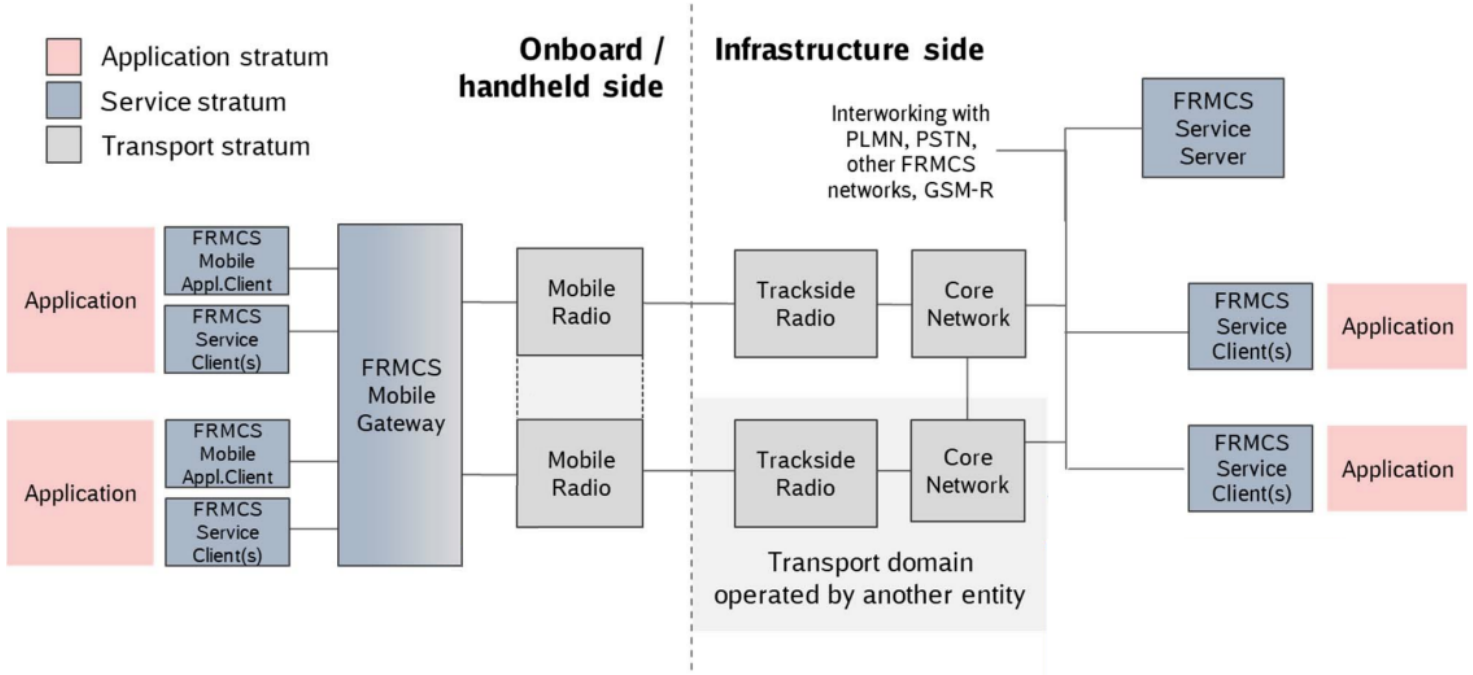
Proposed technical realisations of FRMCS, especially on the infrastructure side, uses building blocks from 3GPP and other standards bodies.

Mobile radios include 3GPP or non-3GPP (e.g. 4G, 5G, Wi-Fi, satellite)

An FRMCS deployment scenario:

Scenario 2: Interconnected Trackside Transport domains with separate core networks (other are available – see Chapter 7, ETSI TR 103459)

ETSI TR 103 459 V1.2.1 (2020-08)



Future Rail Mobile Communications System (E-2-E)

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3GPP TR 22.889 Requirement [R-12.9-008]

"The FRMCS System shall be able to make use of one or more of the following:

- 3GPP radio access (i.e. 4G and/or 5G) through railway-dedicated licensed spectrum
- 3GPP radio access (i.e. 4G and/or 5G) provided by public providers
- 3GPP radio access (e.g. LTE-U) through unlicensed spectrum
- Non-3GPP radio access (e.g. IEEE 802.11 [i.24] based and/or satellite based)
- Wireline access

NOTE 1: GSM-R, TETRA, and P25 are not considered as a radio access technology of FRMCS.

NOTE 2: Not all of the radio access technologies may support all of the FRMCS requirements."

Future Rail Mobile Communications System (E-2-E)

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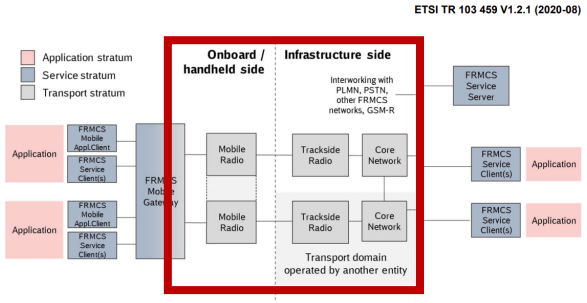
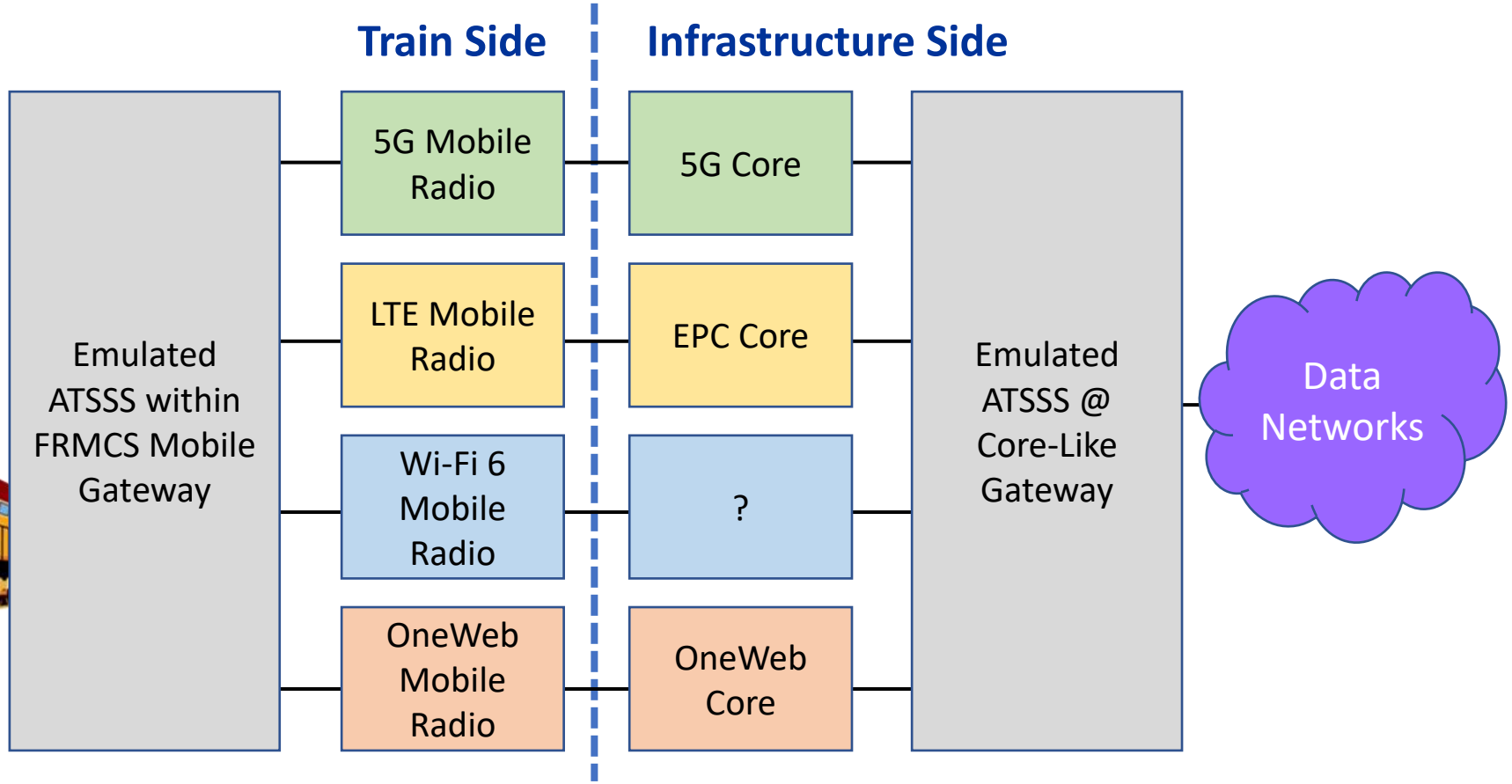
Potential technical realization of FRMCS system are based on convergence under a 5G core network, others are core agnostic. Use of ATSSS would require a 5G-core, but Emulated-ATSSS could be core agnostic:





Satellite Communications on the Railways:
Broadband Connectivity to Trains

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- With Tactical Wireless Ltd (TWL) and LNER, Network Rail is testing StarLink on-the-move.
- The Starlink high-performance aero terminal is being used.
- A specialized high throughput mobile unit is to be mounted on an IC225 LNER train.

Starlink Flat High Performance Terminal

LNER LONDON NORTH EASTERN RAILWAY

TACTICAL SPACE SYSTEMS

NetworkRail

Satellite Communications on the Railways:
Broadband Connectivity to Trains

Implementation (roll-out) has the potential to be very rapid because no terrestrial infrastructure is needed – full service is enabled by installing one or more flat panel antennas to be installed on the roof and connected into the existing WiFi infrastructure (or a new WiFi access point can be provided).

For older rail vehicles, roof modifications may be necessary to provide loading gauge clearance through tunnels and bridges.

Opex is currently on an 'all-you-can-eat' tariff, but this could change.

(US's) Starlink is the only provider today, but new entrant (UK's) OneWeb begins service later in 2023.

High-level business case comparisons indicate that the opex costs are in line with existing 4G costs.

Satellite Communications on the Railways:

Broadband Connectivity to Trains

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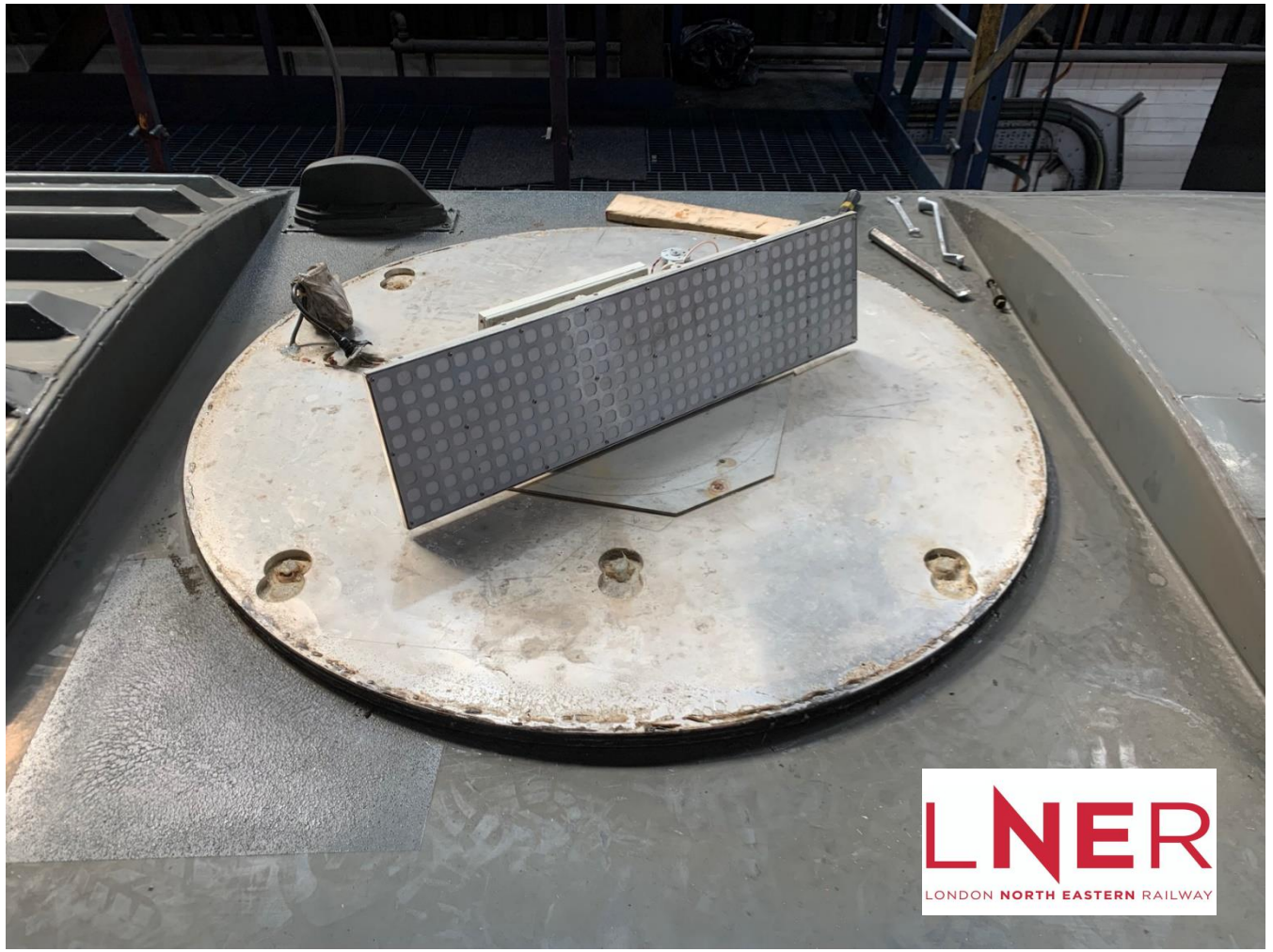

Satellite Communications on the Railways:
PSTN Switch Off

- The Public Switched Telephone Network (PSTN) is progressively being switched off across the UK.
- In rural and remote locations, Network Rail uses PTO lines for some classes of operational phones, such as
    - RETP Token Exchange Point (TEP) Telephone
    - User-Worked Crossings
    - Level Crossings (not many of these are PSTN)

Satellite Communications on the Railways:
Infrastructure Monitoring

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For example:

- Increasing frequency and severity of flooding represents the most significant climate change risk to rail infrastructure
- Results in damage to structures, earthworks movement, landslips etc.
- But many locations where flooding may occur are remote and rural locations.
- Seldom any electrical power
- Often no cellular coverage…

Effects of Bridge Scour, Lamington Viaduct – 31 Dec 2015

Satellite Communications on the Railways:

Infrastructure Monitoring via Iridium SBD (with RDN Ltd)

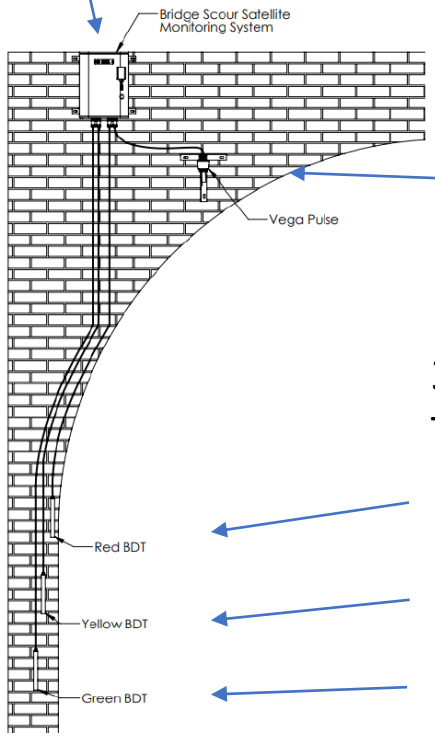
Ultra-low-power unit with LiFePO4 battery life measure in years

Up-Link

Cross-Link

Down-Link

Ground Station



1 x Water Level Measurement Sensor

3 x Water Level Trigger Sensors

Trial customers in W&W, Southern and Scotland's Railway

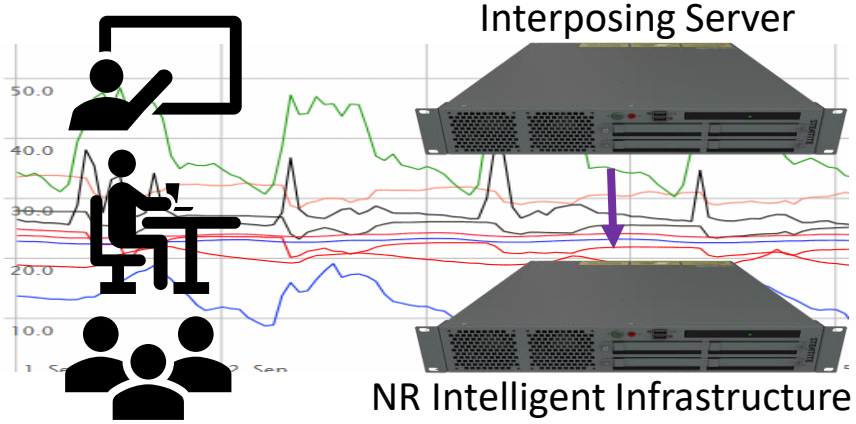
INITIAL TRIAL SITE:

Underbridge 310/184A

West Highland Line WHL 55m+0270yds

Railway Ops, Maintenance, Asset Mgmt personnel etc.

Interposing Server

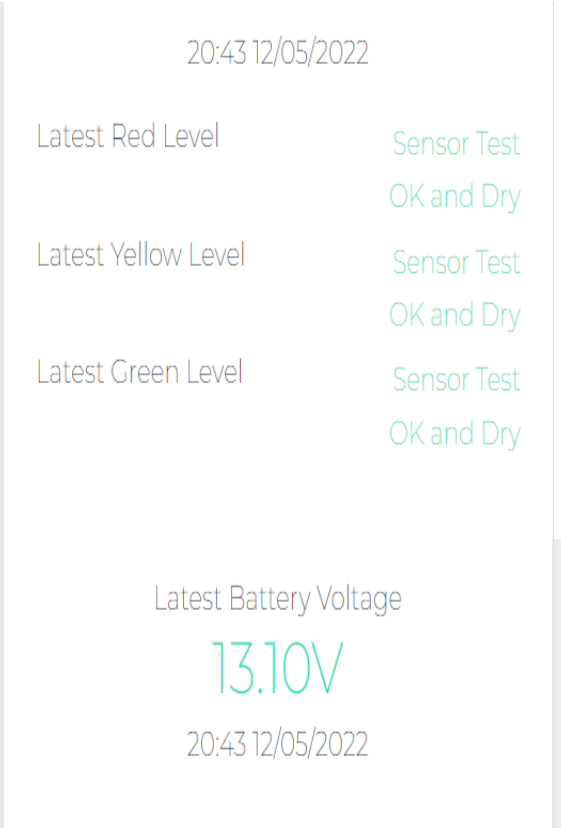


NR Intelligent Infrastructure

Satellite Communications on the Railways:

Infrastructure Monitoring via Iridium SBD (with RDN Ltd)

Example: Deployment in remote location (Bridge of Orchy in Scotland) to monitor bridge scouring.



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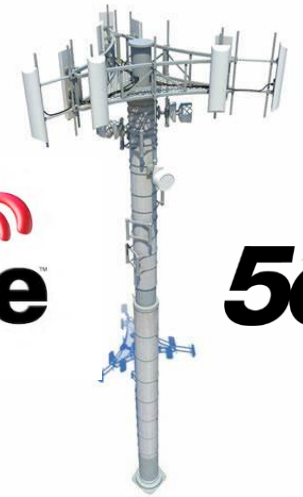
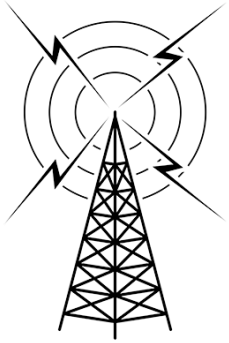
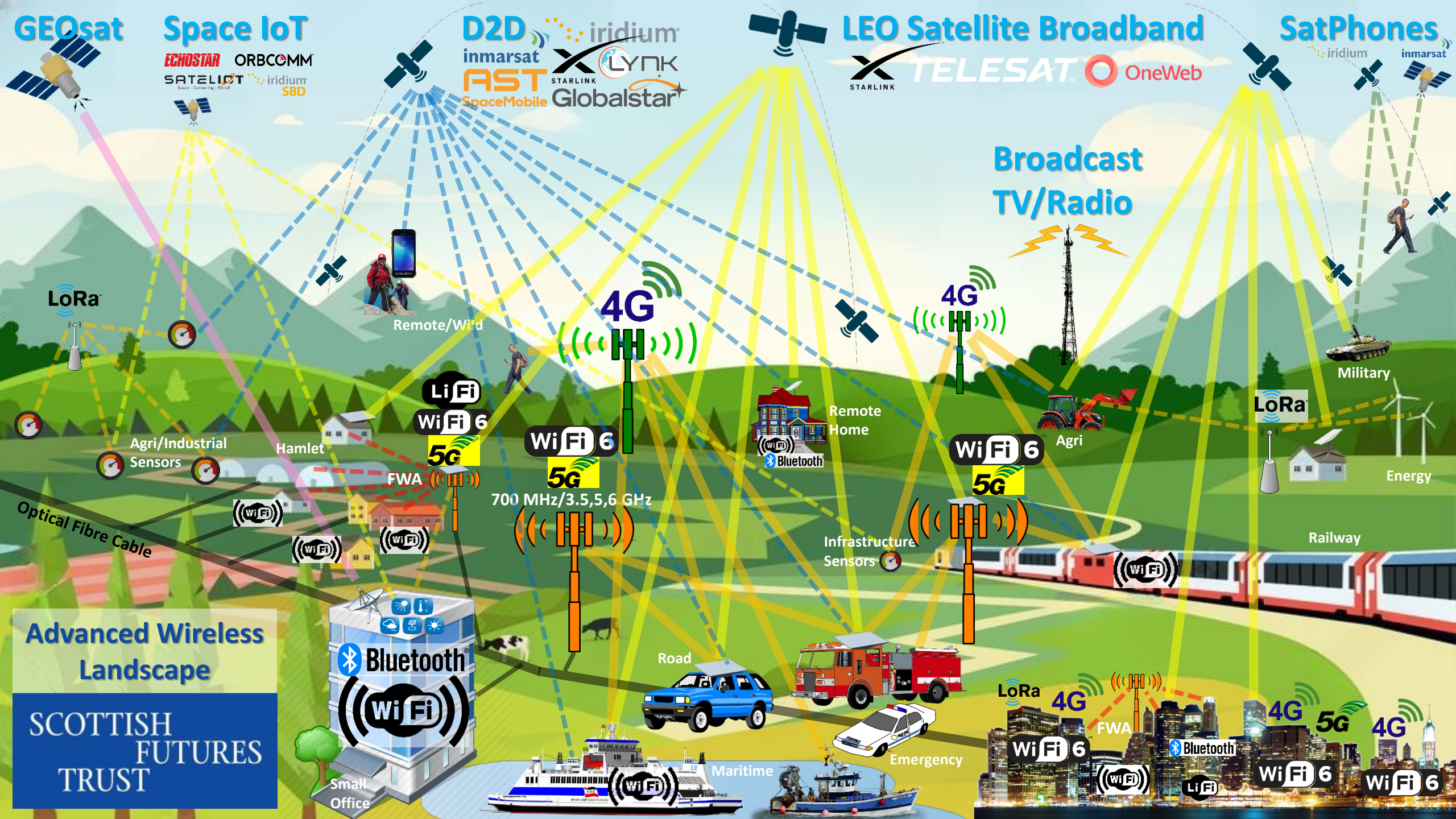


FRMCS is only one small part of the evolving “advanced wireless landscape.”

So I’ll finish with a colourful picture…




GEOsat
Space IoT
ECHOSTAR
ORBCOMM
SATELIOT
iridium SBD
D2D
inmarsat
AST SpaceMobile
iridium
STARLINK
Globalstar
LEO Satellite Broadband
STARLINK
TELESAT
OneWeb
SatPhones
iridium
inmarsat
Broadcast TV/Radio
LoRa
Remote/Wild
4G
Li Fi
Wi Fi 6
5G
FWA
700 MHz/3.5,5,6 GHz
Agri/Industrial Sensors
Hamlet
Optical Fibre Cable
Remote Home
Bluetooth
Infrastructure Sensors
Agri
Military
Energy
Railway
Road
Emergency
Maritime
Small Office
Advanced Wireless Landscape
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