



# DIGIRAIL Radio Measurements

**Final Report**  
**21 September 2022**

Fintraffic  
Proxion  
Sweco

Overall control of the project  
Measurements & Analysis  
Measurement vehicle

# In a Nutshell

## Questions

- Are the Finnish Mobile Networks good enough in terms of capacity and coverage for ETCS traffic (up to 50 kb/s per train)?
- Do the Finnish Mobile Networks fulfil reliability requirements in terms of IP Application traffic (= IP traffic between simulated OBU and simulated RBC)?
- In general, are well planned public mobile networks able to respond FRMCS-type of requirements on adequate level (note: pre-FRMCS requirements used as Digirail reference values here)?

## Answers

- In terms of capacity and coverage: Yes, they are, when used in Packet Duplication mode
- In terms of reliability: Finnish mobile networks fulfil ERA/Subset-093 requirements as well as pre-FRMCS requirements as known today
- FRMCS Requirements (TR22.889 and TR22.989) are fulfilled concerning Legacy Apps. Future apps requirements are currently (Aug 2022) N/A
- MCX Service: Finnish mobile networks fulfil 3GPP Rel14 requirements concerning MCPTT

ETCS      European Train Control System  
RBC      Radio Block Center  
MCPTT    Mission-Critical Push-To-Talk

OBU      On-Board Unit  
FRMCS    Future Railway Mobile Communication System

# Report Sections

1. Orientation & General Information

2. Measurement Equipment

3. Measurement Arrangements

4. Measurement Result Summary

5. Analysis & Conclusions

Each arrow is a hyperlink to Report Section, just click the desired text.

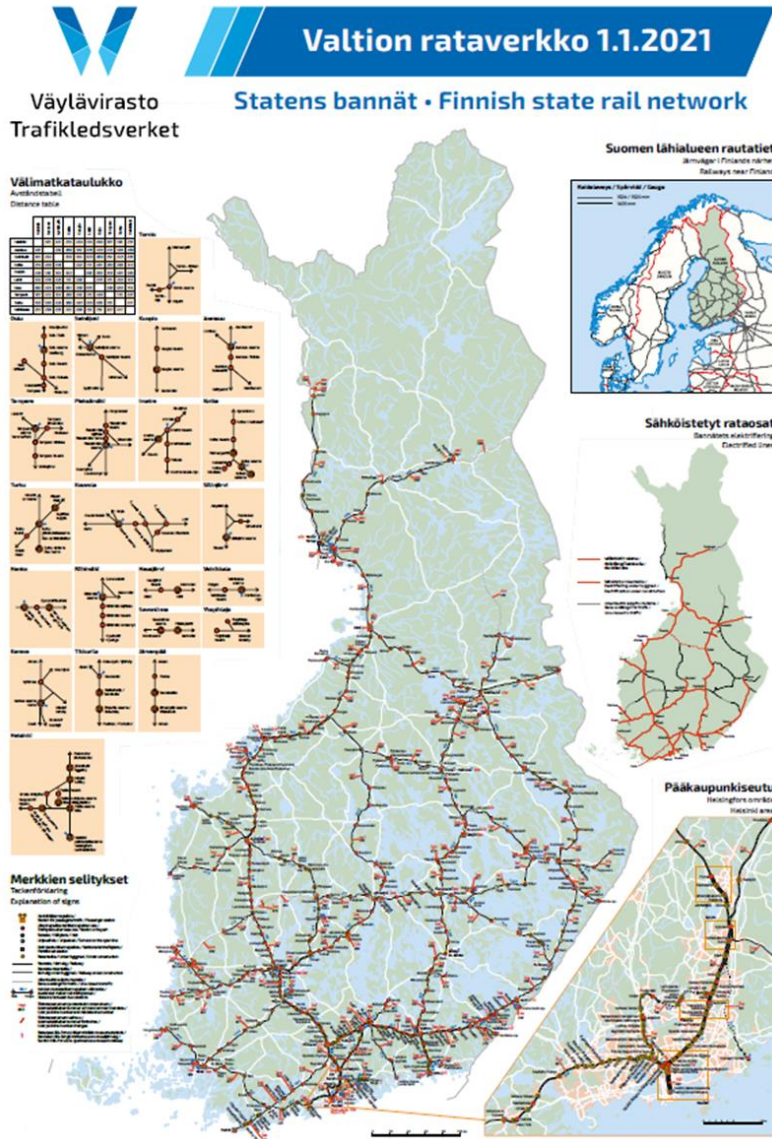
The logo consists of the words "DIGI" and "RATA" stacked vertically in a bold, green, sans-serif font, centered within a white circle. The background of the slide is a dark green color with decorative horizontal lines in a lighter green shade at the top and bottom.

# DIGI RATA

## Orientation & General Information

The scope of the Measurements and short description what was done.

# Area to Measure



- ❑ As per defined, the measured track sections consisted of so-called Operational Level 1 track sections (all tracks which are under the control of the Fintraffic Traffic Management Center)
- ❑ Due to the nature of the railway network, the total length measured was around 8000 kms.
- ❑ The whole network was measured first with router mode **Best Quality** and then a Comparison Drive was made with router mode in **Packet Duplication** with selected track sections (length approx. 2000 km)
- ❑ The only track section which was not possible to measure was between Kajaani and Ämmänsaari because of track maintenance works. The length of this track section (Kontiomäki-Pesiökylä-Ämmänsaari) is 93 km.
- ❑ During the measurement campaign RF Scanner collected radio data for both 4G and 5G. Since 5G coverage is still spot-type, all measuring modems were locked to 4G/LTE and all measurements were done over 4G/LTE connections.
- ❑ As conclusion it can be stated that all performed simulated ETCS traffic (& others) are well within the limits Digirail has set (FRMCS Draft SRS Values) as well as Subset-093 values. Closer results are presented in further slides.



# DIGI RATA

## Measurement Equipment

This section gives an overview of used equipment and vehicle.

# Proxion Measurement System Overview

## Items to Measure:

### IP and Application Measurements

Success rate, Elapsed time	Success rate, Elapsed time	Success rate, Elapsed time	Success rate, Elapsed time
<b>TCP Session Establishment</b>	<b>Simulated ETCS Test</b>	<b>DNS Query Test</b>	<b>HTTP Request Test</b>
Delay, Jitter, Packet loss	Delay, Jitter, Packet loss, Connection break		Delay, Jitter, Packet loss

### Passive Network Measurements

#### SNMP Data Collector

Operator X	Operator Y	Operator Z
PCI, RSSI, RSRP, RSRQ, SINR, Frequency, Band, Bandwidth	PCI, RSSI, RSRP, RSRQ, SINR, Frequency, Band, Bandwidth	PCI, RSSI, RSRP, RSRQ, SINR, Frequency, Band, Bandwidth

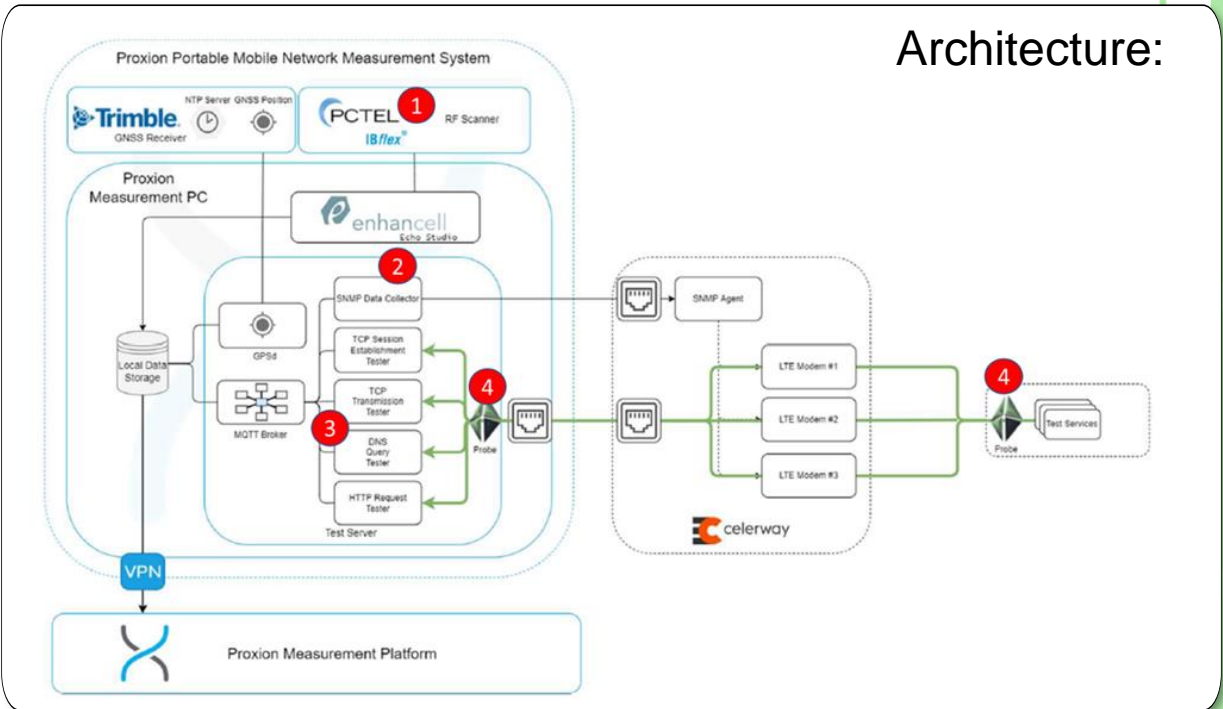
#### RF Scanner

PCI RSSI RSRP RSRQ SINR	PCI RSSI RSRP RSRQ SINR	PCI RSSI RSRP RSRQ SINR	PCI RSSI RSRP RSRQ SINR	PCI RSSI RSRP RSRQ SINR	PCI RSSI RSRP RSRQ SINR	PCI RSSI RSRP RSRQ SINR
700 MHz	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz	3500 MHz



Three public mobile networks are measured simultaneously and measurement data is collected by SNMP. RF scanning provides same information with all frequency areas. IP application measurements show how simulated ETCS traffic behaves with mobile transport.

## Architecture:



1. RF Scanner
2. SNMP Data Collector
3. Test Tools for IP Application Traffic Generation
4. Probes for Passive Network Measurements

# Proxion Measurement System Product Data

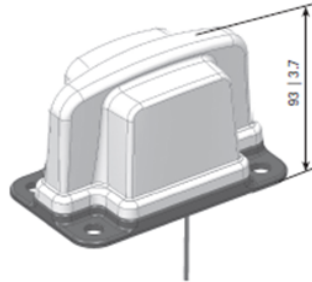
## Equipment data (sw versions and data sheet information)

- ❑ **PCTEL IBflex RF-scanner (SW: 3.8.1.0):** <https://www.pctel.com/products/test-measurement/scanning-receivers/ibflex-scanning-receiver/> ,  
Brochure: <https://d3dqzy9ky05fbv.cloudfront.net/wp-content/uploads/2020/07/IBflex-Brochure-web.pdf>
- ❑ **PC: Advantech UNO-148, Win 10 Enterprise LTSC:** [https://advdownload.advantech.com/productfile/PIS/UNO-148/file/UNO-148\\_DS\(092821\)20211111094917.pdf](https://advdownload.advantech.com/productfile/PIS/UNO-148/file/UNO-148_DS(092821)20211111094917.pdf)
- ❑ **Echo Studio sw 3.2.34 (with special feature to start and stop measurements from outside of Echo studio):**  
<https://enhancell.com/enhancell/products/echo-studio-2/>
- ❑ **Cisco RV345P router (SW: 1.0.03.15):** <https://www.cisco.com/c/en/us/products/collateral/routers/small-business-rv-series-routers/datasheet-c78-742350.pdf>
- ❑ **Teltonika RUTX11 3G/4G/LTE modem (SW: RUTX\_R\_00.02.06.1):** [https://teltonika-networks.com/downloads/en/rutx11/RUTX11\\_Datasheet-v1.1.pdf](https://teltonika-networks.com/downloads/en/rutx11/RUTX11_Datasheet-v1.1.pdf)
- ❑ **GNSS: Trimble BX992 (SW: 6.10) Accuracy 30cm:** <https://info.intech.trimble.com/bx992-datasheet>
- ❑ <https://ecatalog.hubersuhner.com/media/documents/datasheet/en/pdf/84459531>

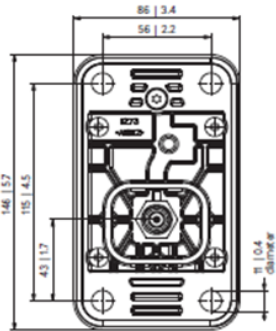
# Antenna & Low-noise Amplifier Solution

- Multi-band antenna: 700/800/900/1800/1900/UMTS/2600/3500/5000/ LTE/W-LAN and GNSS.
- The antenna can be operated in all frequency ranges simultaneously.
- Low profile antenna in fiberglass radome.
- The antenna fulfils the requirements according to EN 50155.

Type No.	87010032	
<b>Antenna multi-band</b>		
Input	N female	
Frequency range	MHz 694 – 6000	
VSWR	694 – 960 MHz: < 1.5 1350 – 4920 MHz: < 1.8 4920 – 6000 MHz: < 2.0	
Gain	dB	0 (ref. to the quarter-wave antenna)
Impedance	Ω	50
Polarization	Vertical	
Max. power	W	40 (at 50° C ambient temperature)
Operating temperature	°C	-40 – +85
Inner conductor	DC grounded	
<b>Antenna GPS / Galileo / GLONASS / BEIDOU</b>		
Center frequency	MHz	1581 ± 5
Bandwidth in 10 dB	MHz	> 49
VSWR at Fc	< 2.0	
Polarization	Right hand circular	
Impedance	Ω	50
Input	TNC male, 110 mm   4.3 inches cable length	
Radome weight	g   lb	180   0.4
Total weight	g   lb	~ 610   ~ 1.34
Packing size	mm inches	170 x 120 x 100 6.7 x 4.7 x 3.9
Height	mm inches	93 3.7



Mounting flange:



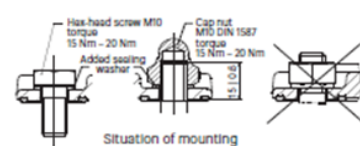
Mounting hole for the connector: 33 (max. 35) mm | 1.3 (max. 1.4) inches diameter.

Note: Keep mounting surface clear of paint for electrical contact.

Evenness of opposite surface 0.2 mm | 0.008 inches.

Surface roughness of opposite surface max. R<sub>a</sub>40.

Use a cap nut or hex-head screw plus the enclosed sealing washer.



Situation of mounting

All dimensions in mm | inches

- The low noise amplifier 86010142 is designed for the use inside vehicles with train antennas with GNSS.
- It includes a preselection filter to prevent the interference in case of simultaneous operation at the frequency range 380-960 / 1710-3800 MHz and GNSS.
- The product fulfils the requirements according to EN 50155.

## Block Diagram



Type No.	86010142	
Frequency	MHz	1559 – 1609
Gain	dB	25 ±2
Noise figure	dB	< 2.0
VSWR (input, output)	< 1.8	
Operation voltage	V	3.3 ... 5.5, ripple < 50 mV, supplied at inner conductor RF-output
Operation current	mA	≤ 30
Connector input	TNC female	
Connector output	N female	
Dimensions (w x h x l)	mm inches	70 x 22 x 50 2.8 x 0.9 x 2.0
Mounting	mm inches	4 holes, 4.5 diameter 4 holes, 0.2 diameter

## Additional features:

- The maximum input power at the input of the amplifier at the frequency range 380-960 MHz and 1710-3800 MHz is limited to +25 dBm.
- The noise level at the GNSS-frequency generated by the operation at the frequency range 380-960 MHz and 1710-3800 MHz should not exceed the thermal noise level at the input of the GPS Amplifier, otherwise the noise figure will be increased.

## Environmental conditions:

Temperature range: -25 °C ... +55 °C (data as specified)  
-40 °C ... +85 °C (extended range \*)

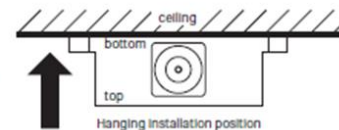
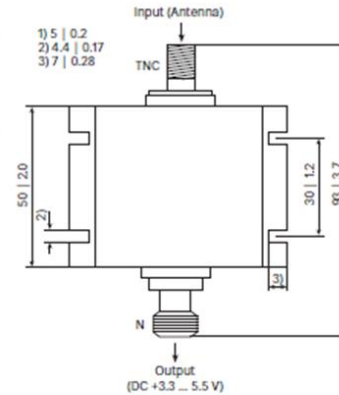
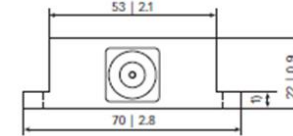
## Please note:

It is necessary to use four fixing screws to mount the LNA in case the installation height is more than 2 m.  
The system operator (receiver) needs to secure a current limit of < 1000 mA.

## EU-RED:

Hereby, KATHREIN SE declares that the radio equipment type 86010142 is in compliance with Directive 2014/53/EU.  
The full text of the EU declaration of conformity is available at the following internet address: <http://www.kathrein.com>

\*) Extended range of operation:  
Within an extended temperature range of -40 °C ... +85 °C and an extended supplied voltage range of 3.0 V ... 6.0 V operation is possible with the following restrictions:  
Noise figure: < 2.5 dB  
Gain: > 20 dB



All dimensions in mm | inches

# GNSS and RF Scanner Antenna Solutions

## Zephyr 3 Rover

The Trimble Zephyr 3 Rover is a high-performance lightweight GNSS rover antenna optimized for precision RTK applications. The Zephyr 3 Rover GNSS antenna is typically used in roving applications. It minimizes multipath and offers robust low elevation tracking and sub-millimeter phase center repeatability.



<https://geospatial.trimble.com/sites/geospatial.trimble.com/files/2019-03/Datasheet%20-%20Trimble%20Zephyr%203%20GNSS%20Antennas%20-%20English%20USL%20-%20Screen.pdf>

## SUB-6 GHz MOBILE OUTDOOR ANTENNAS

### Vertically Polarized – for All Networks

PCTEL's vertically polarized sub-6 GHz high-performance magnetic and permanent mount outdoor antennas are designed to provide wide band coverage of full spectrum VHF, TETRA/UHF and 450 to 6000 MHz frequencies.

#### OP278H

698 – 3800 MHz  
Magnetic Mount



#### OP286H

698 – 3800 MHz  
Permanent Mount



#### OP451

450 MHz – 6 GHz  
Magnetic Mount



#### OP697

136 – 175 MHz  
380 – 960 MHz  
Extra Strength  
Magnetic Mount<sup>3</sup>

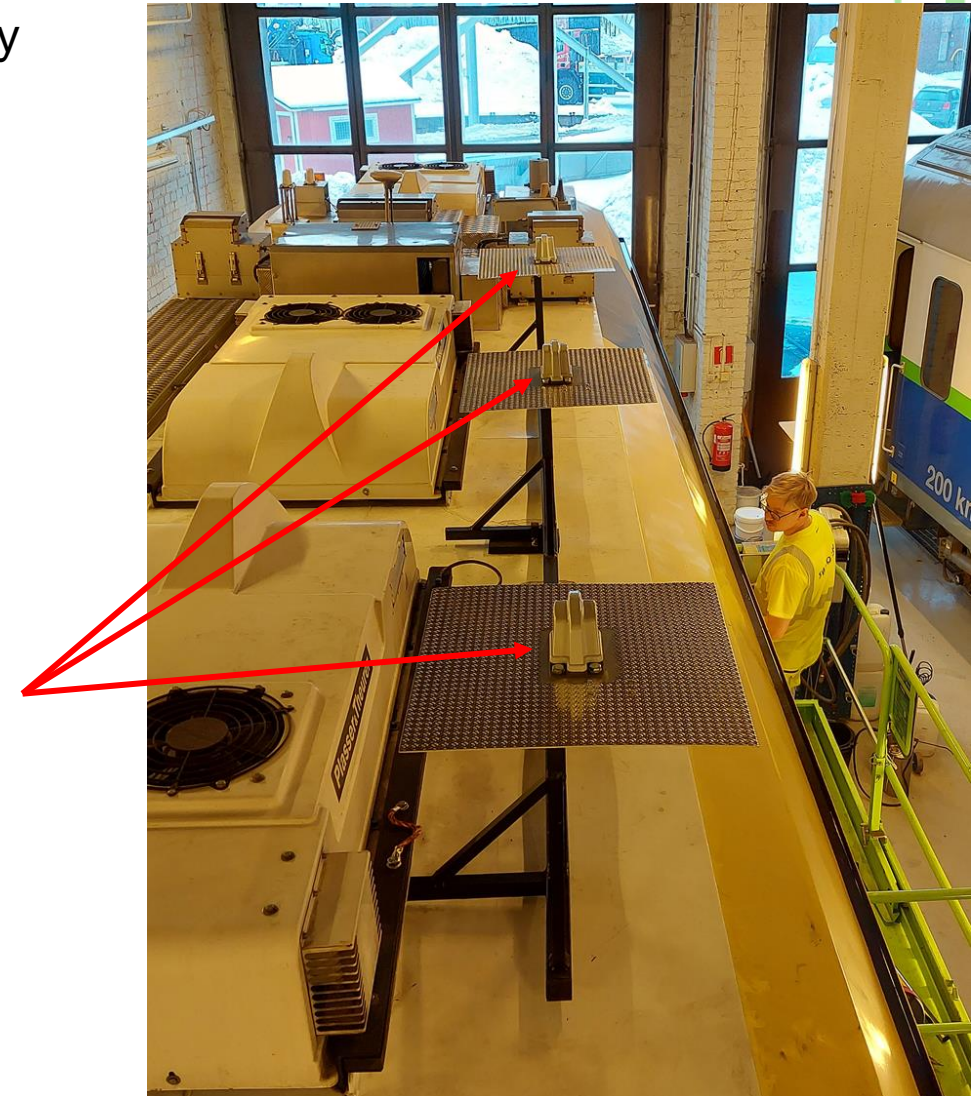


2 x OP278H Antenna for RF scanning. Details for the antenna:

[https://s3-eu-west-1.amazonaws.com/cdn.webfactore.co.uk/5183\\_pctel-antennas-for-scanning-receivers-brochure-revc-june2021-web.pdf](https://s3-eu-west-1.amazonaws.com/cdn.webfactore.co.uk/5183_pctel-antennas-for-scanning-receivers-brochure-revc-june2021-web.pdf)

# Antenna Installation

- ❑ Antenna to be used in the testing is especially designed for railway use: Kathrein Train Antenna 694–6000 MHz and GNSS (GPS, GLONASS, BEIDOU, GALILEO) 87010032.
- ❑ In addition to the antenna, Low Noise Amplifier GNSS (GPS, GLONASS, BEIDOU, GALILEO) 86010142 were used.
- ❑ 3 pcs of Kathrein antennas were located on the rooftop of the measurement vehicle having 1 – 1.5 m mutual distance to each other. Each antenna was provided with low-noise amplifier and cabling is done to the personnel premises located in the middle part of the measurement vehicle. Also, the Arcus multi-channel router is installed in the personnel premises of the vehicle.
- ❑ Antenna cabling:
  - Ant01, on rear of Emma
  - Ant02, on middle of Emma
  - Ant03, closest to measurement rack



# Antenna Installation

## ☐ RF –scanner antenna cabling:

Connector 1 – right antenna cable: Ant04

Connector 2 – left antenna cable: Ant05

## ☐ Antenna heights from track level.

Trimble Zephyr: 4259 mm.

Kathrein Huber+Suhner: 4472 mm.

PCTEL: 4459 mm.

## ☐ Antenna cables & length.

Trimble Zephyr: 1x RG58 10 m.

Kathrein Huber+Suhner: 3x RG213 20 m.

PCTEL: 2x RG58 10+5 m.

# Celerway Arcus Multi-channel Router



PRODUCT SPECIFICATION



## ARCUS

Our flagship router, Arcus is powerful, ruggedized, 5G-ready and enables up to 7 simultaneous WAN connections (3 cellular).

Turn to Arcus when you need high-capacity connectivity on the move or outdoors, and application performance for latency-sensitive applications.

Maximum load balancing capacity	1 Gbps
Phantom VPN encryption	1 Gbps
IPSec VPN encryption	1 Gbps
Maximum number of simultaneous WANs	7
Dimensions w x h x d	200 mm x 55 mm x 280 mm
Weight	2.20 kg
Operating temperature	-20 °C to 70 °C
Humidity	5% to 95%
Power supply	3-pin terminal block (+, ignition), +9~36VDC ATX mode support ignition delay on/off control
Integrated cellular	3 x cellular (5G/4G/3G/2G)
SIM card slot	6 x nano
Ethernet (WAN and/or LAN)	3 x M12 X-coded GBE
Wi-Fi (WAN and/or LAN)	5GHz/2.4GHz dual-band (optional)
USB	2 x USB 2.0
Mini-PCIe	1 x WiFi, 1 x cellular (LM940 or EG25)
M.2	2 x cellular (RM500Q or EM12)
Antenna connectors cellular	10 x SMA female
Antenna connectors WiFi	3 x RP-SMA female
Antenna connectors GPS	1 x SMA female
PoE	M12 X-coded PoE 802.3af OUT
Rating	MIL-STD-810G vibration/shock resistance & E-Mark

Radio Unit #0 (RM500Q-GL): Connected to Operator Z Nw  
Radio Unit #1 (RM500Q-GL): Connected to Operator Y Nw  
Radio Unit #2 (LM940): Connected to Operator X Nw

CelerwayOS Software version: measurements started with version 2.7.0. This was upgraded 29.4.2022 to 2.7.1 since it improved the behavior of the radio unit #2.

Celerway Phantom is proprietary technology and a key component of CelerwayOS that includes combination of dynamic VPN load balancing and seamless switching between multiple networks.

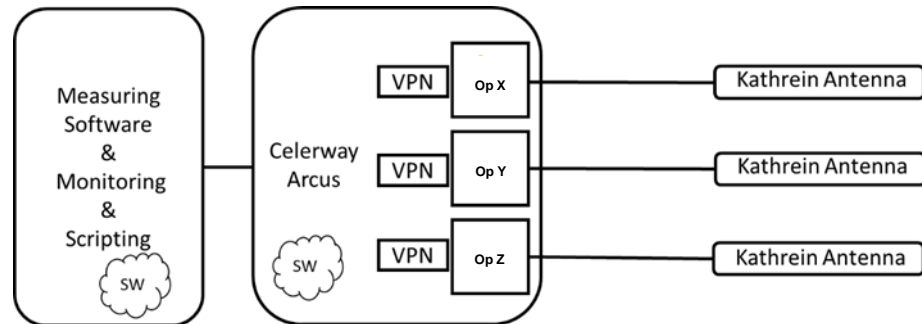
<https://www.celerway.com/celerwayos>

[https://creatorapp.zohopublic.eu/file/crm\\_stamp/cw-partner/Product\\_Specification/101006000000298021/File\\_upload/download/gbN5Q5Hdd5vyZpN2umb1wOtZvHrWdC4bhg83ze7FVUP5gTE7Mvkrf8jxkg0kSeVgkYOk2g4rGbUCKB u6xtbVMTRnuxrYe3P2S9Dg?filepath=/1657777581774\\_ARCUS.pdf](https://creatorapp.zohopublic.eu/file/crm_stamp/cw-partner/Product_Specification/101006000000298021/File_upload/download/gbN5Q5Hdd5vyZpN2umb1wOtZvHrWdC4bhg83ze7FVUP5gTE7Mvkrf8jxkg0kSeVgkYOk2g4rGbUCKB u6xtbVMTRnuxrYe3P2S9Dg?filepath=/1657777581774_ARCUS.pdf)  
[https://creatorapp.zohopublic.eu/export/crm\\_stamp/cw-partner/pdf/Components\\_ARCUS/TG9z8Cq8a1sSjt7dqxVHmssXvHyRmTVfK70gtSjNmft0PKA6gkF2DD9jhfRtrKuGKp8PPVTv75Td6fnw6k2gdwxw9CBCon9HrVSH](https://creatorapp.zohopublic.eu/export/crm_stamp/cw-partner/pdf/Components_ARCUS/TG9z8Cq8a1sSjt7dqxVHmssXvHyRmTVfK70gtSjNmft0PKA6gkF2DD9jhfRtrKuGKp8PPVTv75Td6fnw6k2gdwxw9CBCon9HrVSH)

[← Back to Report Section Slide](#)

# Celerway Arcus Multi-channel Router

Measurement System – Router – Antenna Connection:



Note concerning routing arrangements:

Celerway Arcus Multi-channel router uses PhantomVPN being vendor-specific routing solution where IP packets are duplicated/triplicated when the system is running in Packet Duplication Mode. This is why in this document this mode is marked as Packet Duplication.

There are several similar type of solutions in the market and in the future, so-called Multipath TCP is considered as an option to "multi-route" IP packets over several networks when there is a need to gain redundancy and reliability. Specification of this is Multipath TCP v1 specification in [RFC 8684](https://tools.ietf.org/html/rfc8684).

# Used Subscriptions (SIM Cards)

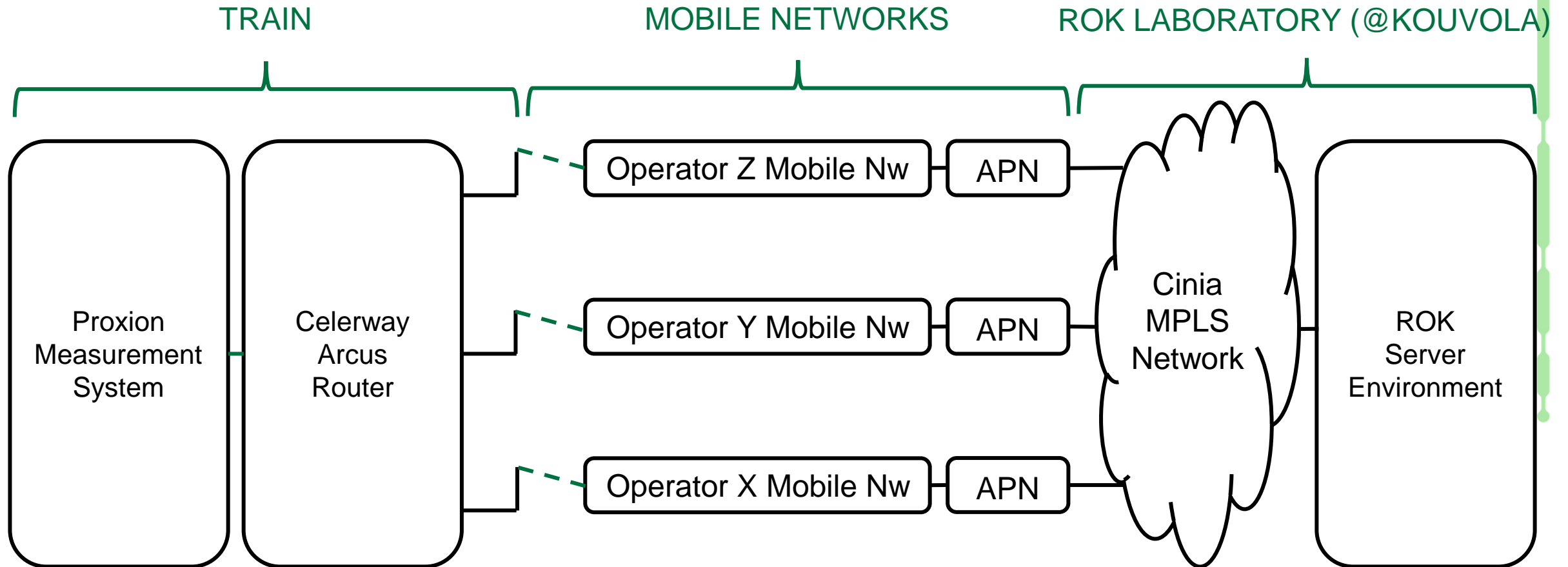
- ❑ All subscriptions used (Operator Z, Operator X, Operator Y) were priority subscriptions having network-specific prioritization methods active.

QoS Parameter	Parameter Value	Notes
GBR	50 kb/s	Operator defines this value in subscription data.
Throughput	500 kb/s	Highest bandwidth allowed for the bearer. Operator defines this value in subscription data.
EPS Bearer	used	QCI65, QCI84,QCI70
ARP	In use	
ACB	Not in use	
QCI	In use	QCI 65, QCI 84, QCI 70

GBR = Guaranteed Bit Rate  
ARP = Allocation and Retention Priority  
QoS = Quality of Service

EPS = Enhanced Packet Service  
ACB = Access Class Barring  
QCI = QoS Class Identifier

# Measurement System Networking



APN = Access Point Name  
MPLS = Multi-Protocol Label Switching

# Measurement Vehicle (EMMA)



Measurement System & monitoring in action

EMMA (Ttr151) maximum speed is 120 km/h



# DIGI RATA

## Measurement Thresholds

Measurement baseline(s), comparison values,  
measurement modes

# Subset-093 Based Requirements vs. Digirail Targets

ITEM	SUBSET-093 REQUIREMENT	DIGIRAIL TARGETS (FRMCS Draft SRS values)
Packet Service Setup Attach Delay PDP Context Activation	$\leq 35$ s (99%) $\leq 5$ s (99%) $\leq 3$ s (99%)	Altogether $\leq 10$ s (99%)
Transaction Transfer Delay OBU Originated 100 octets <b>1)</b>	$\leq 2.6$ s (99%)	$\leq 500$ ms (roundtrip)(99%)
Transaction Transfer Delay RBC Originated 320 octets <b>2)</b>	$\leq 3.0$ s (99%)	$\leq 500$ ms (roundtrip)(99%)
ETCS-DNS Lookup Delay	$\leq 3$ s (99%)	$\leq 500$ ms (roundtrip)(99%)
HTTP Request/Response	Not defined	$\leq 1$ s (roundtrip)(99%)
IP Traffic Jitter (DNS, TCP, POS, MA)	Not defined	$\leq 20$ ms
Packet Loss	Not defined	$\leq 1\%$

- 1) In simulated ETCS traffic these messages are Position Reports and MA Requests. Acknowledgement messages are added to calculate roundtrip delay.
- 2) In simulated ETCS traffic these messages are messages containing MA. Acknowledgement messages are added to calculate roundtrip delay.

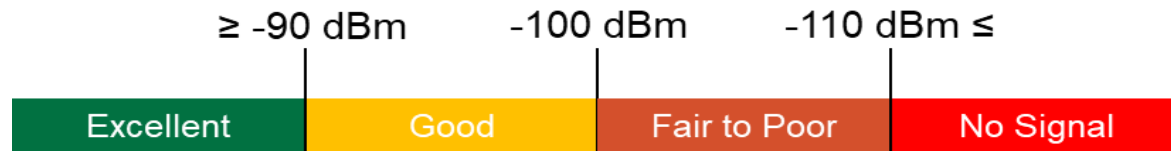
# Traffic Types (ETCS Simulation)

- ❑ All measured traffic was performed between simulated OBU (Proxion Measurement System) and ROK Server located @ Kouvola
- ❑ To simulate ETCS traffic, some procedures were selected and these procedures used correct-length ETCS messages. In some procedures the acknowledgement message was added to the procedure in order to measure round-trip delay of the procedure.
- ❑ The selected procedures were as follows:
  1. **TCP Connection Establishment:** OBU requests setup and ROK responds. Delay measured. Procedure done once per second.
  2. **Position Report:** OBU sends and ROK acknowledges with ETCS General Message. Delay measured. Procedure done once per second.
  3. **MA (Movement Authority) Request:** OBU requests and ROK responds with MA. Delay measured. Procedure done once per 10 seconds.
  4. **DNS Query:** OBU starts query and ROK responds. Delay measured. Procedure done once per second.
  5. **HTTP Query:** OBU starts query and ROK responds. Delay measured. Procedure done once per second.

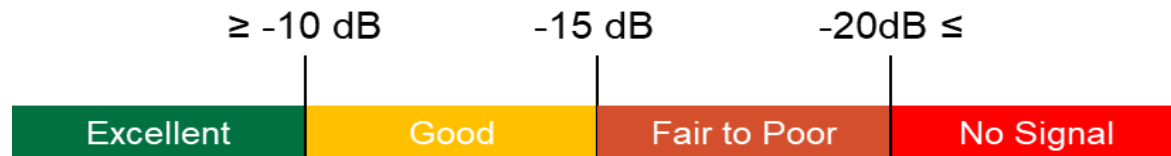
# Radio Connection Classification

- ❑ Classification is based on collected RF scanner data and the values the Celerway Arcus radio modems were frequently producing.

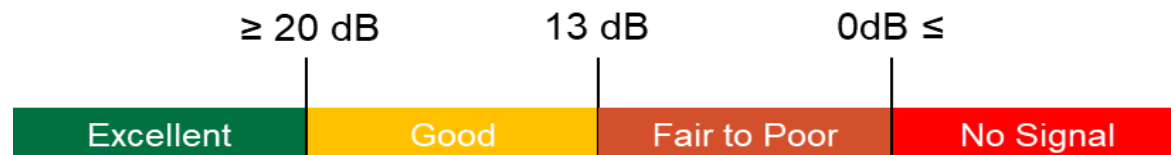
RSRP (Reference Signal Received Power [dBm]):



RSRQ (Reference Signal Received Quality [dB]):



SINR (Signal to Interference plus Noise Ratio [dB]):



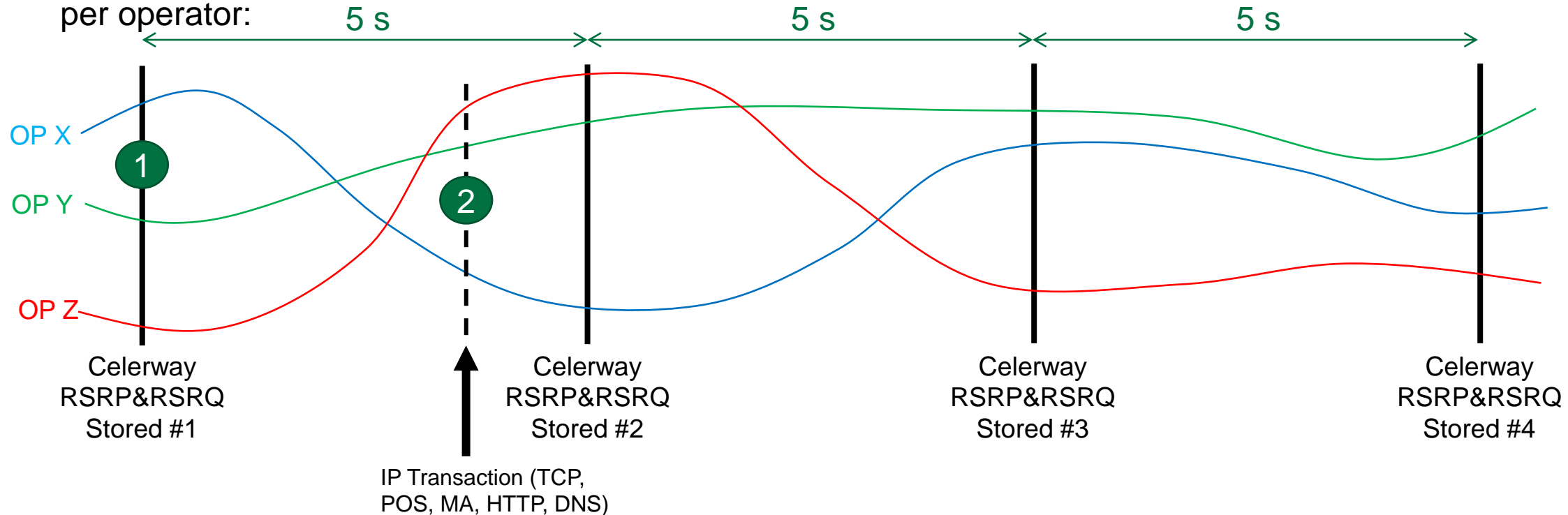
# Measurement Mode: Best Quality (Celerway Arcus Setting) 1/2

- ❑ When the radio conditions face challenges, it is typically due to continuously changing RSRQ value. Best Quality Mode was selected to easier find out possible radio network challenges.
- ❑ In this operation mode, Celerway Arcus takes a "snapshot" once per every 5 seconds and based on this snapshot, the router generates ranking list in terms of received RSRQ value.
- ❑ Like the mode name suggests, the router sends IP traffic to the network having the best RSRQ value
- ❑ If there are challenges in radio conditions (=RSRQ rapid changes), those are exposed now in accuracy of 5 seconds and these challenges produce delay spikes due to retransmissions etc. The next slide explains this phenomena a bit closer with an example.

# Measurement Mode: Best Quality Mode (Celerway Arcus Setting)

## 2/2

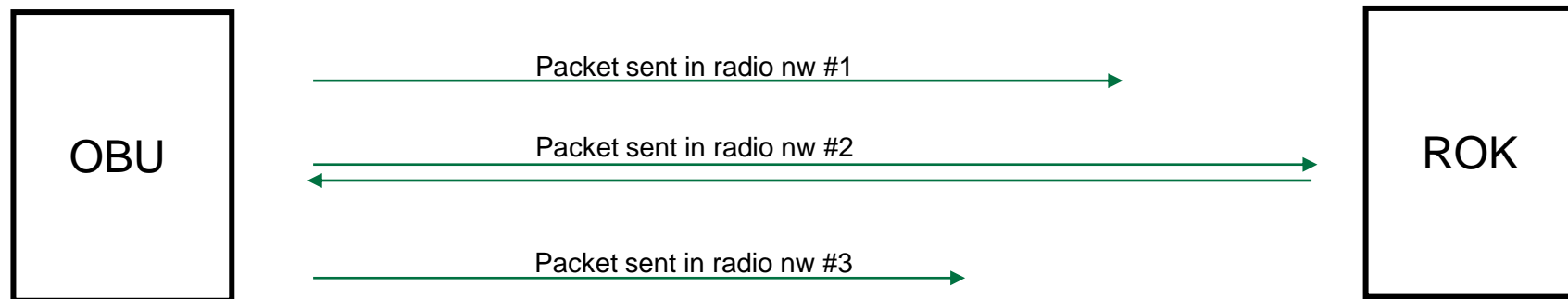
Router used in this measurement takes snapshots with 5 s interval. Graphs show how the RSRQ changes per operator:



1. Router takes a snapshot and generates ranking list. In this example, the order is operator X, operator Y and operator Z.
2. Sometime within 5 s time window a ETCS transaction takes place. Based on ranking list, the router sends the IP packet to operator X network, though its quality is not the best anymore. Retransmissions etc. might follow.

# Measurement Mode: Packet Duplication Mode

- ❑ In Packet Duplication Mode, the router sends IP packet through all radio connections simultaneously and ignores any received RSRQ information.
- ❑ In receiving end, the first packet arrived is responded and the others are ignored



The logo consists of the words "DIGI" and "RATA" stacked vertically in a bold, green, sans-serif font, centered within a white circle. The background of the slide is dark green with decorative horizontal lines in a lighter shade of green.

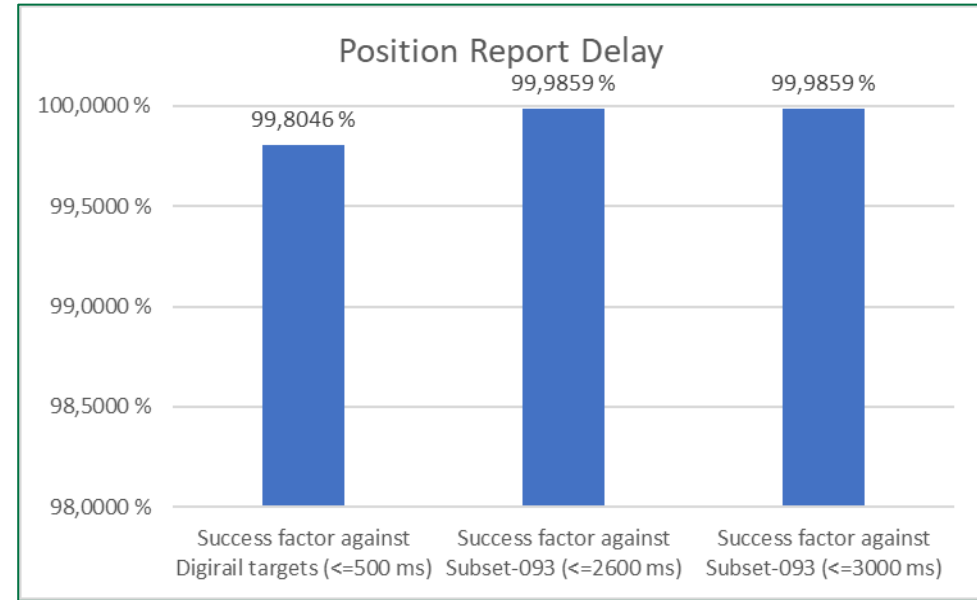
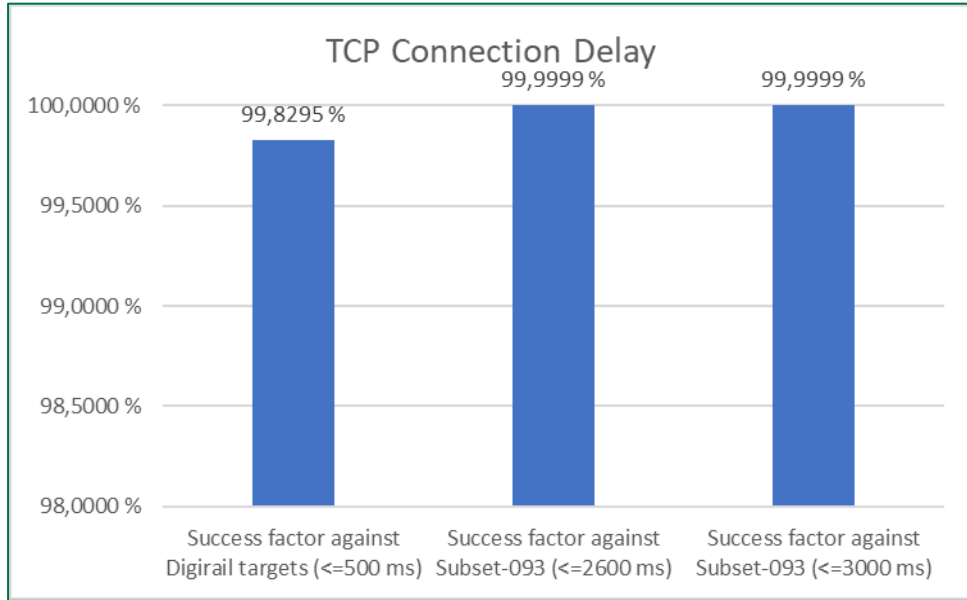
# DIGI RATA

## A High-Level Comparison Between Best Quality Mode and Packet Duplication Mode

Summary results of Best Quality Mode and Packet Duplication Mode Measurements against Subset-093, pre-FRMCS (Digirail) Target values and UIC limits

# Measurement Results in Best Quality Mode

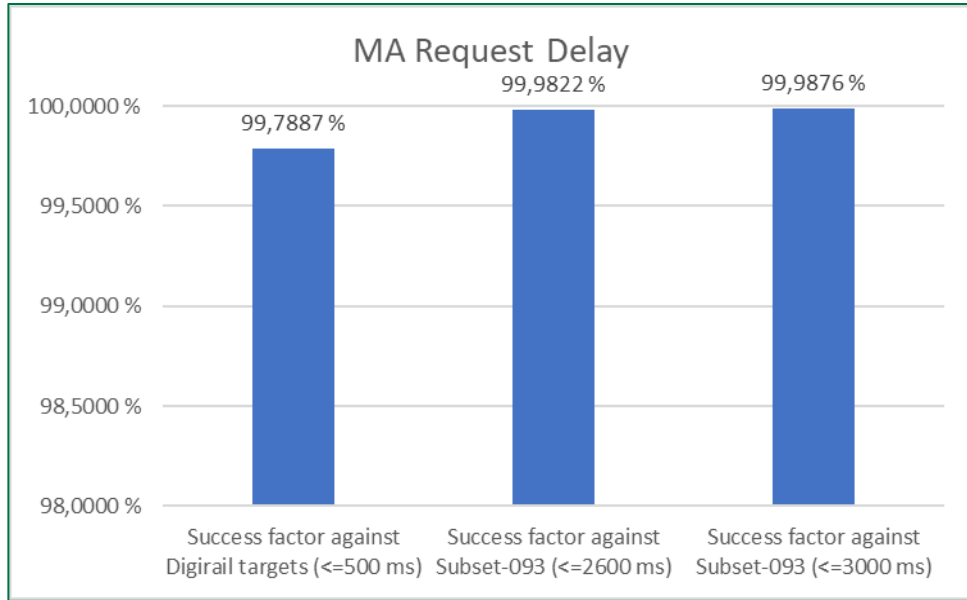
# Best Quality Mode – 8000 Km



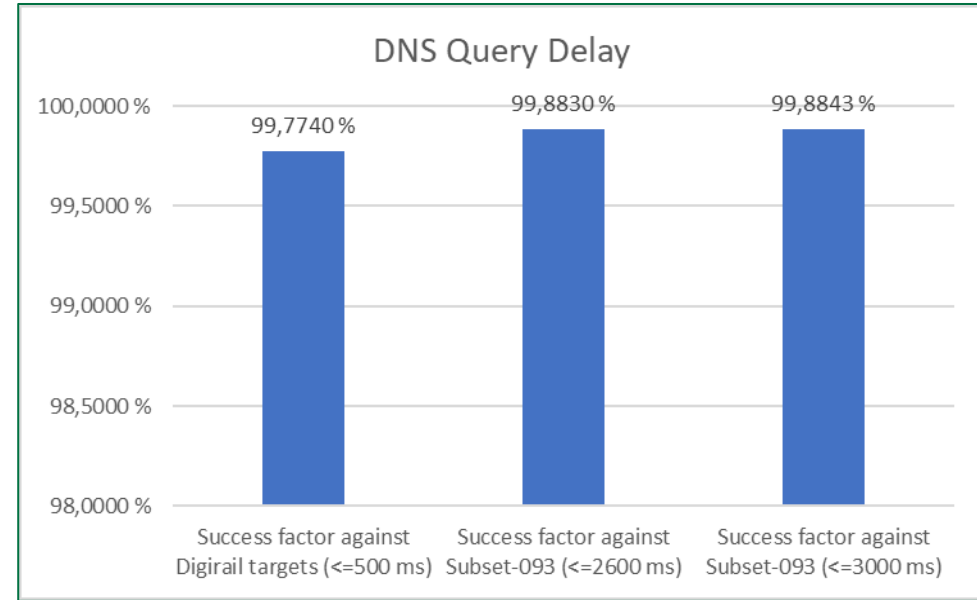
Total Samples	705613
Jitter (ms)	15,62
Average Delay (ms)	60,20

Total Samples	688444
Jitter (ms)	18,45
Average Delay (ms)	83,35

# Best Quality Mode – 8000 Km

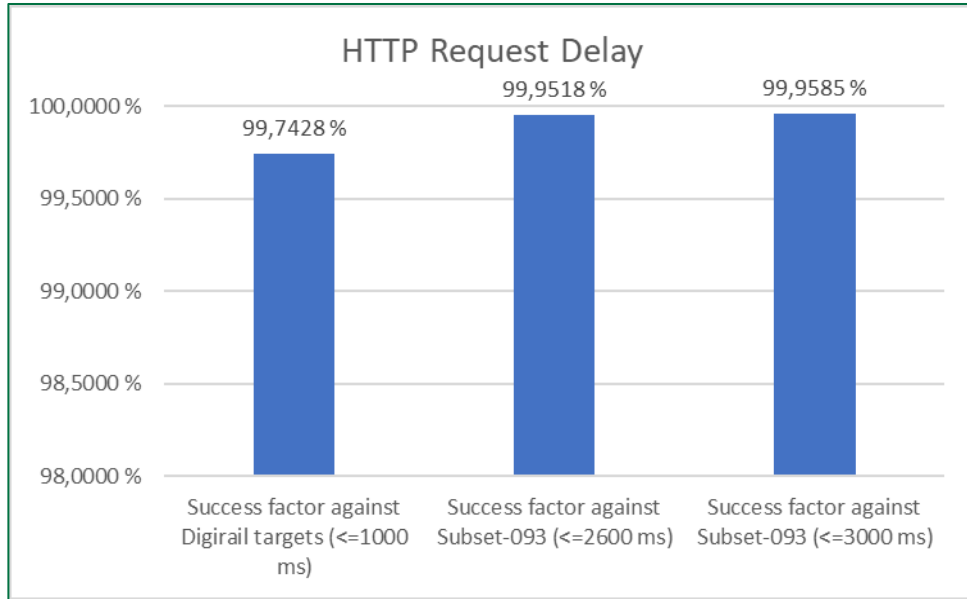


Total Samples	72870
Jitter (ms)	21,54
Average Delay (ms)	107,30



Total Samples	715549
Jitter (ms)	18,36
Average Delay (ms)	67,11

# Best Quality Mode – 8000 Km



- ❑ The 99% limit is clearly exceeded with all traffic types when judging against Subset-093 limits and pre-FRMCS targets

Total Samples	676506
Jitter (ms)	23,31
Average Delay (ms)	119,75

# Delay Iteration – Best Quality Mode

Delay Upper Limit (ms)	TCP 705613 samples	MA 72870 samples	POS 688444 samples	HTTP 676506 samples	DNS 715549 samples
10	0,03 %	0,00 %	0,00 %	0,00 %	0,00 %
20	0,03 %	0,00 %	0,00 %	0,00 %	0,00 %
30	3,25 %	0,00 %	0,00 %	0,00 %	0,01 %
40	20,51 %	0,00 %	0,00 %	0,00 %	11,67 %
50	46,39 %	0,00 %	0,09 %	0,00 %	32,24 %
60	75,52 %	0,00 %	9,46 %	0,02 %	63,03 %
70	88,18 %	0,06 %	31,07 %	2,88 %	82,16 %
80	96,11 %	6,10 %	55,66 %	12,06 %	93,86 %
90	98,17 %	23,94 %	76,12 %	22,92 %	97,57 %
100	98,70 %	47,38 %	86,96 %	37,69 %	98,44 %
110	98,96 %	69,68 %	91,62 %	52,64 %	98,79 %
120	99,13 %	82,29 %	95,57 %	70,03 %	99,00 %
130	99,22 %	89,23 %	97,48 %	81,50 %	99,12 %
140	99,29 %	92,62 %	98,41 %	90,07 %	99,19 %
150	99,34 %	95,53 %	98,94 %	94,01 %	99,25 %
160	99,39 %	97,73 %	99,18 %	96,83 %	99,31 %
170	99,44 %	98,68 %	99,28 %	97,95 %	99,36 %
180	99,48 %	99,04 %	99,34 %	98,33 %	99,40 %
190	99,51 %	99,17 %	99,39 %	98,54 %	99,44 %
200	99,54 %	99,24 %	99,45 %	98,75 %	99,47 %
210	99,57 %	99,33 %	99,49 %	98,86 %	99,50 %
220	99,59 %	99,41 %	99,52 %	98,93 %	99,52 %
230	99,61 %	99,45 %	99,54 %	99,00 %	99,54 %
240	99,63 %	99,48 %	99,57 %	99,07 %	99,56 %
250	99,65 %	99,50 %	99,58 %	99,13 %	99,58 %
260	99,66 %	99,53 %	99,60 %	99,18 %	99,59 %
270	99,67 %	99,55 %	99,61 %	99,22 %	99,60 %
280	99,68 %	99,57 %	99,63 %	99,26 %	99,62 %
290	99,69 %	99,58 %	99,64 %	99,29 %	99,63 %
300	99,70 %	99,59 %	99,65 %	99,32 %	99,64 %
310	99,71 %	99,60 %	99,66 %	99,35 %	99,64 %
320	99,72 %	99,62 %	99,67 %	99,37 %	99,66 %
330	99,73 %	99,63 %	99,68 %	99,39 %	99,66 %
340	99,74 %	99,65 %	99,69 %	99,41 %	99,67 %
350	99,74 %	99,66 %	99,70 %	99,43 %	99,68 %
360	99,75 %	99,67 %	99,71 %	99,44 %	99,69 %
370	99,76 %	99,68 %	99,72 %	99,46 %	99,70 %
380	99,77 %	99,69 %	99,73 %	99,47 %	99,70 %
390	99,77 %	99,70 %	99,73 %	99,48 %	99,71 %
400	99,78 %	99,71 %	99,74 %	99,49 %	99,72 %
410	99,78 %	99,72 %	99,75 %	99,51 %	99,72 %
420	99,79 %	99,73 %	99,75 %	99,51 %	99,73 %
430	99,79 %	99,73 %	99,76 %	99,52 %	99,73 %
440	99,80 %	99,74 %	99,77 %	99,53 %	99,74 %
450	99,80 %	99,75 %	99,77 %	99,54 %	99,74 %
460	99,81 %	99,76 %	99,78 %	99,55 %	99,75 %
470	99,81 %	99,77 %	99,79 %	99,56 %	99,75 %
480	99,82 %	99,78 %	99,79 %	99,56 %	99,76 %
490	99,83 %	99,78 %	99,80 %	99,57 %	99,77 %
500	99,83 %	99,79 %	99,80 %	99,58 %	99,77 %

What is the minimum delay to achieve 99% (Subset-093 requirement) and 99.9% (UIC limit value):

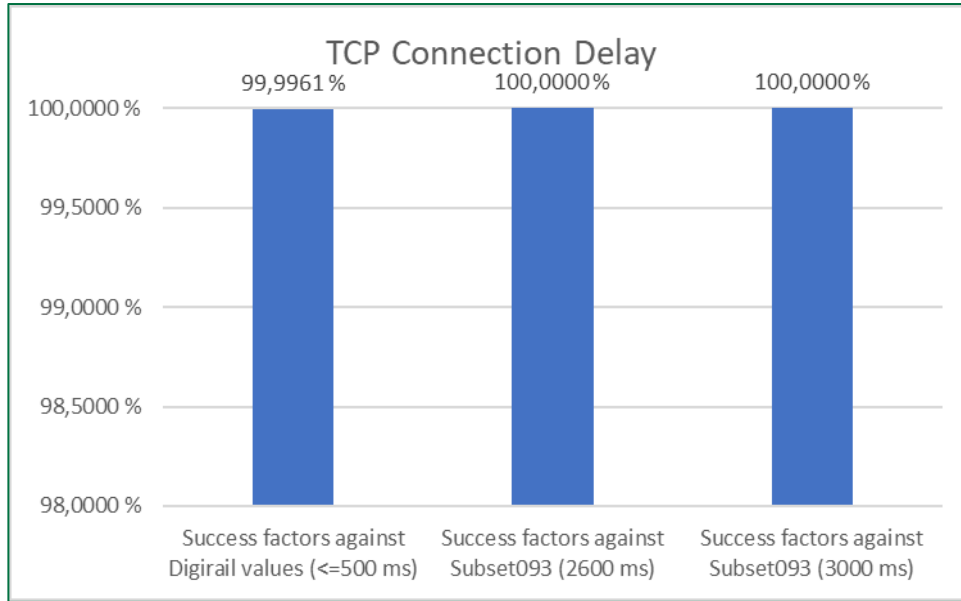
	Subset-093	UIC
TCP	120 ms	>500 ms
MA	180 ms	>500 ms
POS	160 ms	>500 ms
HTTP	140 ms	>500 ms
DNS	120 ms	>500 ms

As conclusion:

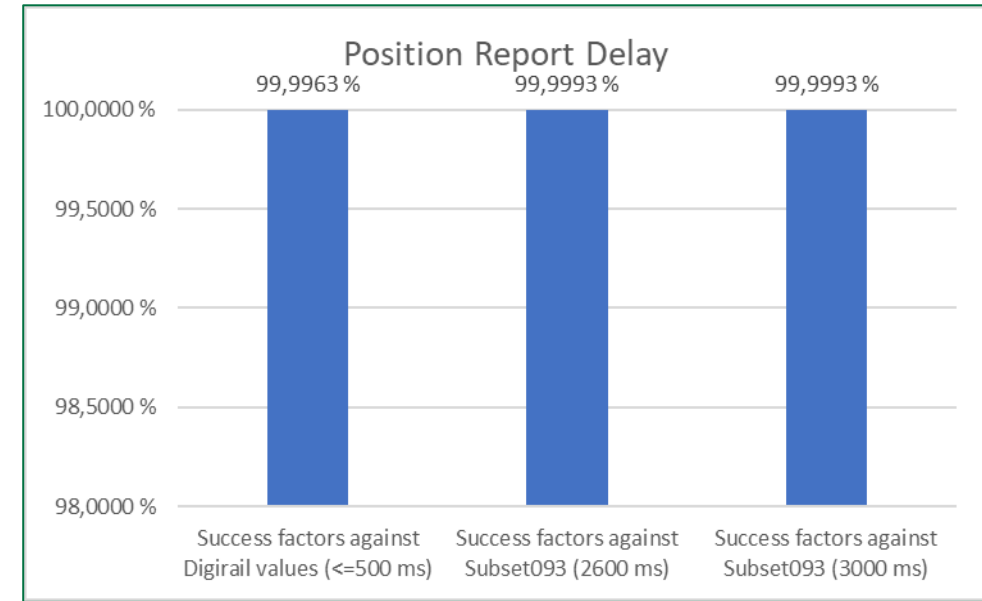
- ❑ Subset-093 limit value 99% is achieved with 144 ms delay (average)
- ❑ UIC limit value 99.9% is **not** achieved within 500 ms delay. Minimum value is somewhere between 500 ... 1000 ms

# Measurement Results in Packet Duplication Mode

# Packet Duplication – 2000 Km

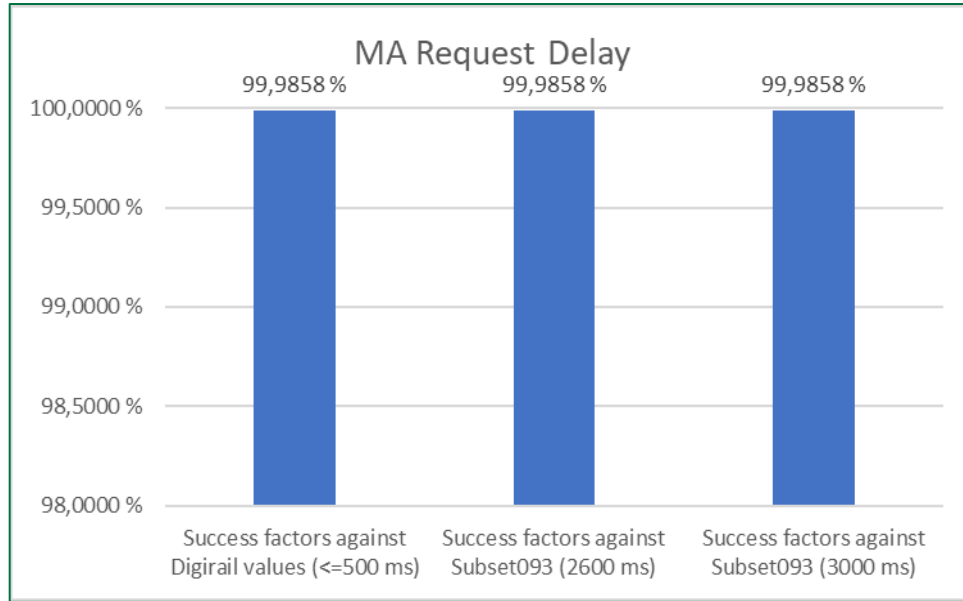


Total Samples	128927
Jitter (ms)	5,92
Average Delay (ms)	36,66

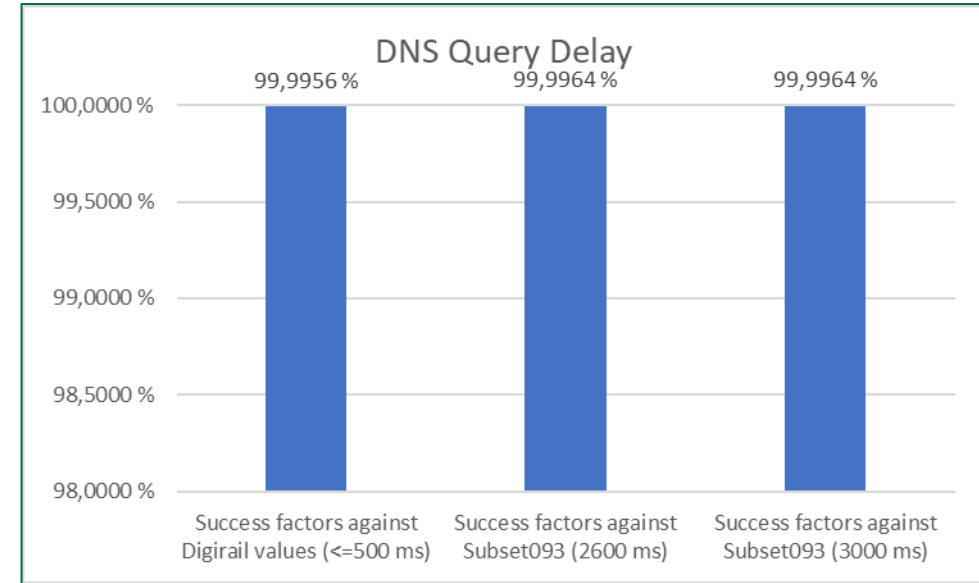


Total Samples	133352
Jitter (ms)	7,76
Average Delay (ms)	67,06

# Packet Duplication – 2000 Km

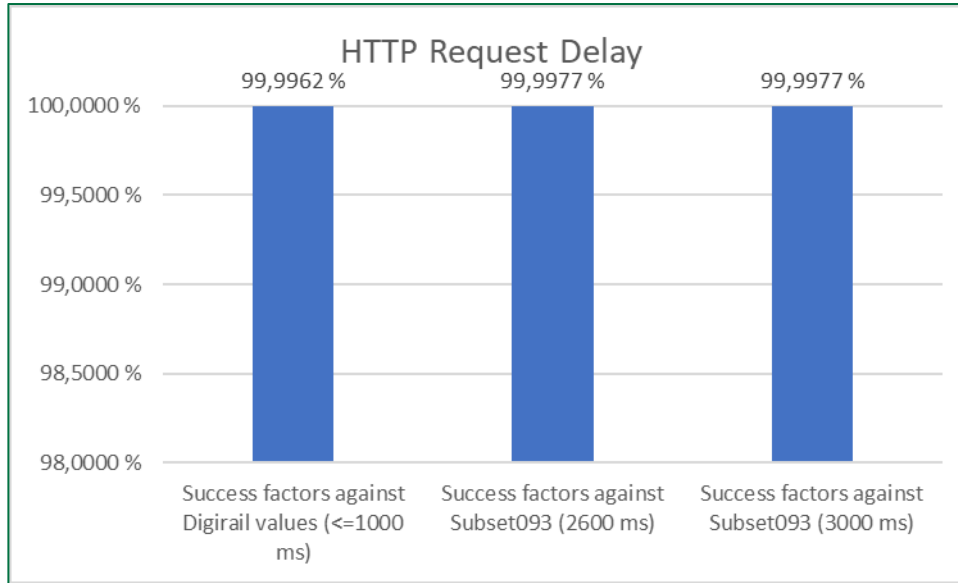


Total Samples	14043
Jitter (ms)	10,71
Average Delay (ms)	90,64



Total Samples	137764
Jitter (ms)	6,97
Average Delay (ms)	43,08

# Packet Duplication – 2000 Km



Total Samples	132937
Jitter (ms)	9,06
Average Delay (ms)	80,99

- ❑ The 99% limit is clearly exceeded with all traffic types when judging against Subset-093 limits and pre-FRMCS targets. In fact, simulated ETCS traffic is 99.98%, which is better than UIC limit value for legacy apps.
- ❑ When running in Packet Duplication Mode, the radio network challenges are minimized
- ❑ Connection and message flow is a bit more stable since jitter values are smaller. With Packet Duplication Mode the jitter values are around 10 ms or less. With Best Quality Mode the jitter values are around 20 ms
- ❑ Average delay values are also a bit smaller with Packet Duplication Mode

# Comparison Drive Results against TR22.889 and 22.989

(Router Mode: Packet Duplication)

❑ **Mentioned specifications define UIC limit values being:**

- ❑ Critical Data (legacy apps) Latency <= 500 ms and reliability 99.9%
- ❑ Critical Data (future apps) Latency <= 100 ms and reliability 99.9999% (N/A in this measurement campaign)

TCP	OK /500 ms	OK /100 ms	POS	OK /500 ms	OK /100 ms	MA	OK /500 ms	OK /100 ms
Total samples: 128927	128922 Pcs	128892 Pcs	Total samples: 133352	133347 Pcs	132556 Pcs	Total samples: 14043	14041 Pcs	11870 Pcs
Success-%	99.9961 %	99.9729 %	Success-%	99.9963 %	99.4031 %	Success-%	99.9858 %	84.5261 %
Average delay	36.6581 ms	36.6581 ms	Average delay	67.0636 ms	67.0636 ms	Average delay	90.6373 ms	90.6373 ms

DNS	OK /500 ms	OK /100 ms	HTTP	OK /500 ms	OK /100 ms
Total samples: 137764	137758 Pcs	137720 Pcs	Total samples: 132937	132932 Pcs	121896 Pcs
Success-%	99.9956 %	99.9681 %	Success-%	99.9962 %	91.6946 %
Average delay	43.0819 ms	43.0819 ms	Average delay	80.9911 ms	80.9911 ms

Legacy apps: fully compliant  
 Future apps: partially compliant

# Delay Iteration – Packet Duplication

Delay Upper Limit (ms)	TCP 128927 samples	MA 14043 samples	POS 133352 samples	HTTP 132937 samples	DNS 137764 samples
10	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %
20	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %
30	23,00 %	0,00 %	0,00 %	0,00 %	2,66 %
40	71,10 %	0,00 %	0,00 %	0,00 %	40,02 %
50	83,98 %	0,00 %	0,33 %	0,01 %	83,24 %
60	<b>99,05 %</b>	0,00 %	25,87 %	3,97 %	<b>96,58 %</b>
70	<b>99,88 %</b>	0,21 %	67,49 %	25,61 %	<b>99,51 %</b>
80	<b>99,96 %</b>	17,22 %	90,50 %	50,61 %	<b>99,92 %</b>
90	<b>99,97 %</b>	57,40 %	<b>97,69 %</b>	75,72 %	<b>99,96 %</b>
100	99,97 %	84,53 %	<b>99,40 %</b>	91,69 %	<b>99,97 %</b>
110	99,98 %	95,48 %	99,77 %	<b>97,92 %</b>	99,97 %
120	99,98 %	<b>98,85 %</b>	<b>99,89 %</b>	<b>99,53 %</b>	99,97 %
130	99,98 %	<b>99,66 %</b>	<b>99,94 %</b>	<b>99,86 %</b>	99,98 %
140	99,98 %	99,81 %	99,97 %	<b>99,93 %</b>	99,98 %
150	99,98 %	<b>99,89 %</b>	99,98 %	99,95 %	99,98 %
160	99,98 %	<b>99,96 %</b>	99,98 %	99,96 %	99,98 %
170	99,98 %	99,96 %	99,99 %	99,96 %	99,98 %
180	99,99 %	99,96 %	99,99 %	99,97 %	99,98 %
190	99,99 %	99,97 %	99,99 %	99,97 %	99,98 %
200	99,99 %	99,97 %	99,99 %	99,97 %	99,98 %
210	99,99 %	99,97 %	99,99 %	99,97 %	99,99 %
220	99,99 %	99,97 %	99,99 %	99,97 %	99,99 %
230	99,99 %	99,97 %	99,99 %	99,98 %	99,99 %
240	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
250	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
260	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
270	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
280	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
290	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
300	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
310	99,99 %	99,98 %	99,99 %	99,98 %	99,99 %
320	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
330	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
340	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
350	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
360	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
370	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
380	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
390	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
400	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
410	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
420	99,99 %	99,98 %	99,99 %	99,99 %	99,99 %
430	100,00 %	99,98 %	99,99 %	99,99 %	99,99 %
440	100,00 %	99,98 %	99,99 %	99,99 %	100,00 %
450	100,00 %	99,98 %	100,00 %	99,99 %	100,00 %
460	100,00 %	99,98 %	100,00 %	99,99 %	100,00 %
470	100,00 %	99,98 %	100,00 %	99,99 %	100,00 %
480	100,00 %	99,98 %	100,00 %	99,99 %	100,00 %
490	100,00 %	99,98 %	100,00 %	99,99 %	100,00 %
500	100,00 %	99,99 %	100,00 %	99,99 %	100,00 %

What is the minimum delay to achieve 99% (Subset-093 requirement) and 99.9% (UIC limit value):

	Subset-093	UIC
TCP	60 ms	80 ms
MA	130 ms	150 ms
POS	100 ms	120 ms
HTTP	120 ms	140 ms
DNS	70 ms	90 ms

As conclusion:

- ❑ Subset-093 limit value 99% is achieved with 96 ms delay (average)
- ❑ UIC limit value 99.9% is achieved with 116 ms delay (average)

The logo consists of the words "DIGI" and "RATA" stacked vertically in a bold, green, sans-serif font, centered within a white circle. The background of the slide is dark green with decorative light green horizontal lines that have a segmented, digital appearance.

**DIGI  
RATA**

## Analysis & Conclusions

# Summary of Measurement Results and Analysis

Digirail Measurement Campaign (Apr – Jun 2022) provides solid baseline for future ETCS development indicating that:

- ❑ Finnish mobile networks with level 4G/LTE provide excellent transport for ETCS connections when utilizing these networks with multi-channel router and in Packet Duplication Mode.
- ❑ It is expected that 5G improves results when 5G coverage is adequately provided to railway environment.
- ❑ Findings in Packet Duplication Mode:
  - ❑ Coverage holes: 4 identified places
  - ❑ Radio connection challenges: 4 identified places
  - ❑ Tunnels: these will require further study
- ❑ When radio connections are established like in this Measurement Campaign, it is strongly suggested to use Packet Duplication Mode –arrangement for IP traffic routing, since, based on the measurement results, this method offers more stability and less delay for traffic delivery and is also future-proof method when checking the measurement results against Subset-093 and UIC definitions.



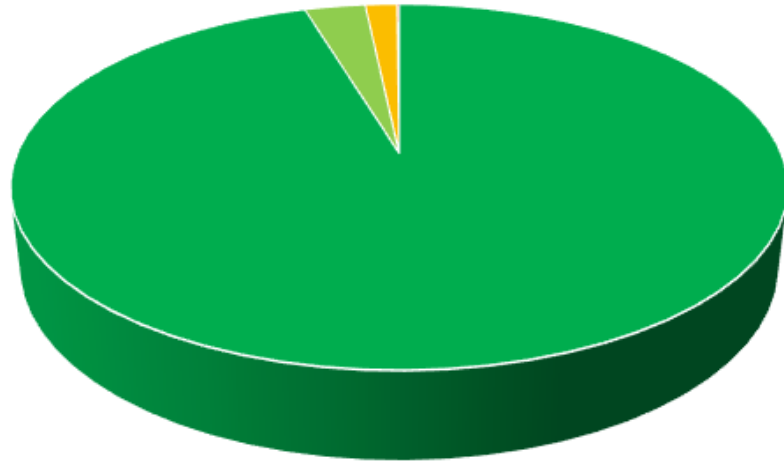
# Coverage Holes

- Near Vartius
- Near Saviaho
- Near Tohmajärvi
- Near Hamina

# Multi-channel Router – Operator Visibility

Following maps describe how many operators have coverage (RSRP stronger than -110 dBm) in Packet Duplication Mode.

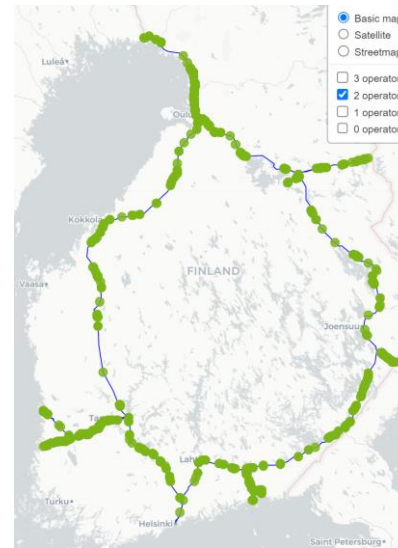
Operator Visibility over the Measured Route



■ 3 Operators visible 95.31% ■ 2 Operators visible 3.01%  
■ 1 Operator visible 1.58% ■ 0 Operators visible 0.10%

## All 3 operators visible:

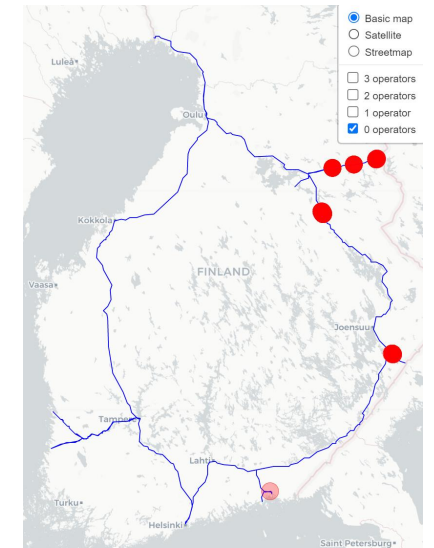
All three operators are visible for communication **95.31%** of the route.



**Only 2 operators visible**  
(RSRP for 1 operator <-110 dBm and for two others >= -110 dBm)



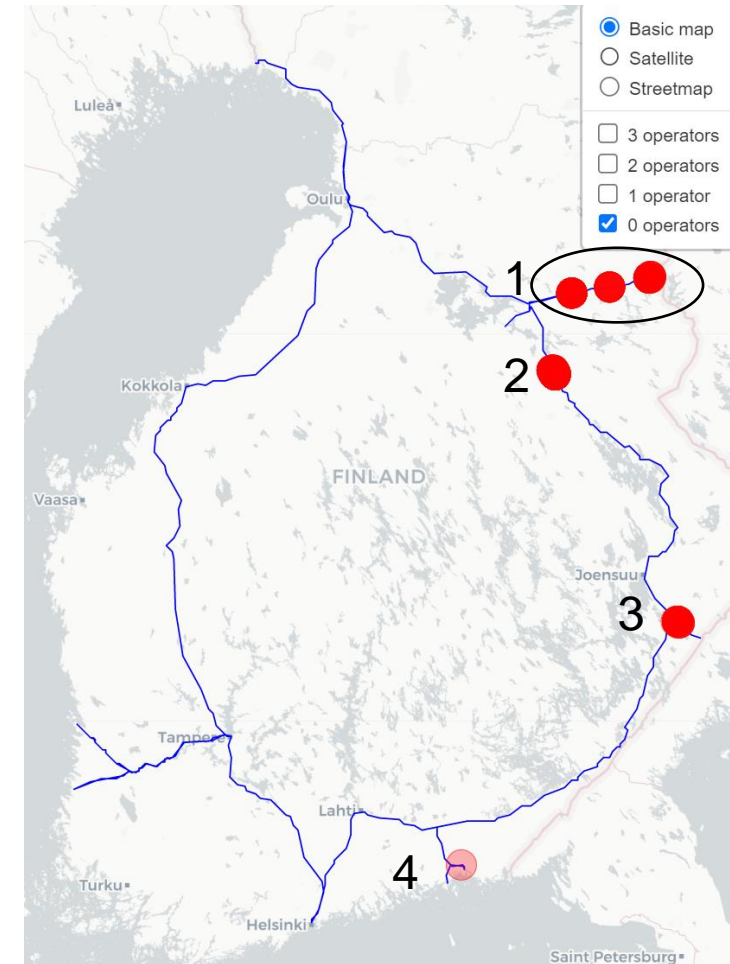
**Only 1 operator visible**  
(RSRP for 2 operators <-110 dBm and for one >= -110 dBm)



**0 operators visible**  
(RSRP for all <-110 dBm)

# Places where all three network operators have RSRP <-110 dBm (Coverage Holes)

- ❑ 1. Near Vartiuss. Challenges with coverage on forested and uninhabited area due to proximity of Russian border and the agreement of not using 800Mhz radio.
- ❑ 2. Near Saviaho. Challenges with coverage on forested and uninhabited area. RSRP between -110 and -120.
- ❑ 3. Near Tohmajärvi. Challenges with coverage on forested area due to proximity of Russian border and the agreement of not using 800Mhz radio.
- ❑ 4. Near Hamina. Railway tunnel of Suurivuori.





# Radio Challenges

- Near Luumäki
- Near Vartius
- Near Sweden border
- Haaparanta

# Radio Challenges in Router Packet Duplication Mode #1

LAT: 60.910337 LONG: 27.598662

Observation near Luumäki. Challenges with DNS, TCP, HTTP and POS tests. All have poor coverage and interference at observation point. Operator Y and Operator Z have also quality issues at observation point. Downlink speed with ROK-server is poor or 0 in this area.

Observation point is at rural area, in the valley between two hills. Nearest base station is on top of the hill.

Probably antenna tilts are too big for observation point. In south there is over 8 km to nearest base station. On 25.4.2022 there was also lack of coverage with all operators on observation point. Both measurements were done in same direction.

DNS

**Difference:** 1363.97

Peak > 500 ms

2022-06-27 16:25:45

Operators X,Y and Z

RSRP	-103	-104	-102
RSRQ	-20	-17	-15
RSSI	-68	-67	-67
SINR	-4.4	-0.4	9

Latitude: 60.910337

Longitude: 27.598662



# Radio Challenges in Router Packet Duplication Mode #2

Observations between 11:40:21 – 11:41:14 and 11:42:18 – 11:43:10 near Vartius and Russian border. Challenges with DNS, TCP, MA and HTTP tests. All operators have challenges with coverage and interference on first observation area.

On second observation area Operator X and Operator Y have challenges with coverage. All have interference except Operator Z with last observation. Operator X modem resetting at the end of second observation area.

In west there is over 15 km to nearest base stations. In east nearest base station is about 4 km away and cell alignment is away from track. Downlink speed with ROK -server is bad on this area. Both observation area is on rural and uninhabited area, there is also some sections with observations points.

Observations were only when heading to east. From the measured RF-data it can be found out, that the closure of Russian border and the agreement of not using certain bands from 800MHz 4G causes coverage challenges for all operators. On 18.5.2022 there was matching observations on same area.

## HTTP

**Difference:** 15546.89  
 Peak > 1000 ms  
 2022-06-29 11:40:21  
 Operators X,Y and Z  
 RSRP | -107 | -119 | -117  
 RSRQ | -12 | -12 | -11  
 RSSI | -83 | -88 | -86  
 SINR | 6 | 0.4 | 10  
  
 Latitude: 64.520472  
 Longitude: 29.826475

## TCP

**Difference:** 2003.52  
 Peak > 500 ms  
 2022-06-29 11:40:27  
 Operators X,Y and Z  
 RSRP | -106 | -120 | -119  
 RSRQ | -11 | -14 | -13  
 RSSI | -79 | -86 | -86  
 SINR | 6.4 | -1.8 | 9  
  
 Latitude: 64.520891  
 Longitude: 29.829426

## ETCS MA

**Difference:** 6029.01  
 Peak > 500 ms  
 2022-06-29 11:41:14  
 Operators X,Y and Z  
 RSRP | -106 | -116 | -117  
 RSRQ | -15 | -14 | -13  
 RSSI | -74 | -85 | -85  
 SINR | 5 | -0.6 | 8  
  
 Latitude: 64.523735  
 Longitude: 29.849431

## HTTP

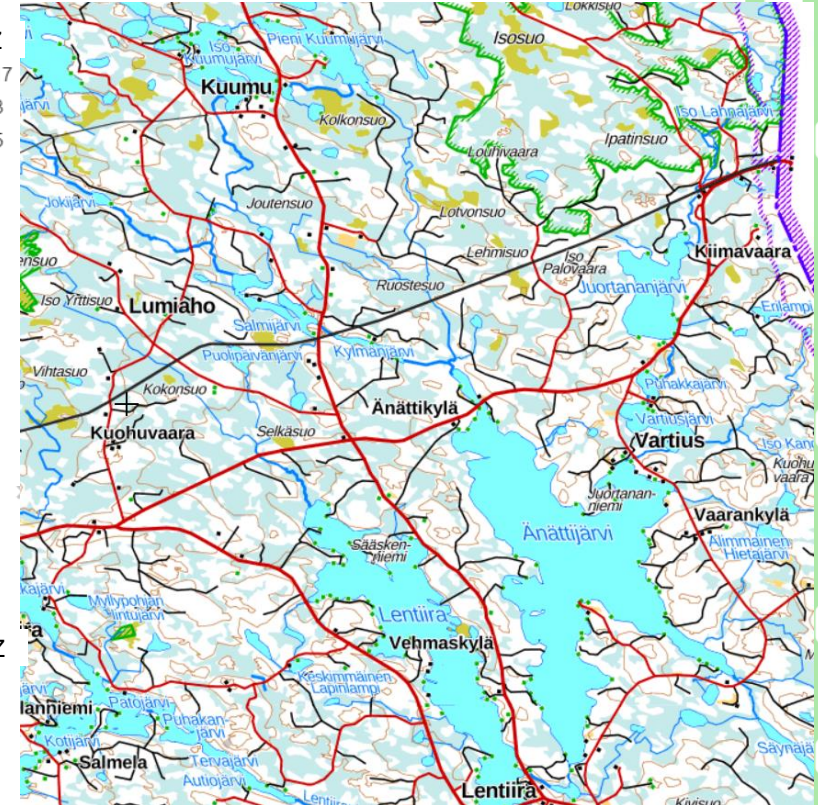
**Difference:** 31569.19  
 Peak > 1000 ms  
 2022-06-29 11:42:18  
 Operators X,Y and Z  
 RSRP | -88 | -130 | -128  
 RSRQ | -10 | -15 | -16  
 RSSI | -63 | -94 | -91  
 SINR | 10.8 | -4 | 8  
  
 Latitude: 64.527914  
 Longitude: 29.878816

## DNS

**Difference:** 10071.37  
 Peak > 500 ms  
 2022-06-29 11:42:34  
 Operators X,Y and Z  
 RSRP | -86 | -131 | -130  
 RSRQ | -13 | -18 | -18  
 RSSI | -56 | -96 | -91  
 SINR | 8.4 | -1.8 | NA  
  
 Latitude: 64.529064  
 Longitude: 29.885523

## ETCS MA

**Difference:** 6558.32  
 Peak > 500 ms  
 2022-06-29 11:43:10  
 Operators X,Y and Z  
 RSRP | -89 | -126 | NA  
 RSRQ | -9 | -17 | NA  
 RSSI | -61 | -90 | NA  
 SINR | 15.6 | -5.4 | NA  
  
 Latitude: 64.531845  
 Longitude: 29.901427



# Radio Challenges in Router Packet Duplication Mode #3

LAT: 65.827902 LONG: 24.153819

Observation near the Sweden border.  
Challenges with DNS, TCP, HTTP  
and POS tests.

All operators have challenges with  
quality and interference at  
observation point because area is on  
the edge of nearest cells. Downlink  
speed with ROK -server is poor or 0  
in this area.

Observation point is in urban area,  
crossing border between Finland and  
Sweden. On 1.6.2022 there was  
matching observations on same area.  
Observations were only when  
heading to west.

HTTP

**Difference:** 1427.06

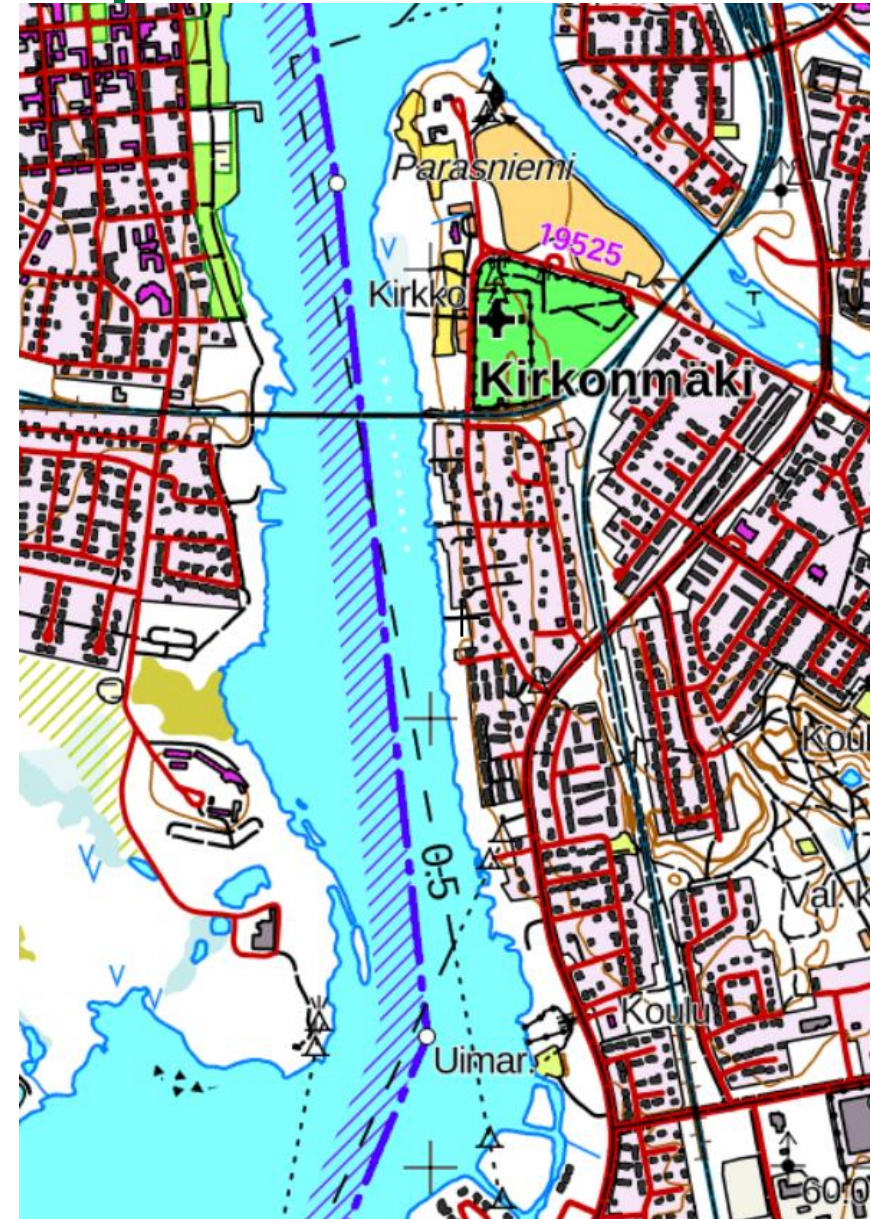
Peak > 1000 ms

2022-06-29 17:10:06

	Operators X,Y and Z		
RSRP	-81	-87	-92
RSRQ	-18	-18	-20
RSSI	-48	-38	-46
SINR	-3	-8.2	3

Latitude: 65.827902

Longitude: 24.153819



# Radio Challenges in Router Packet Duplication Mode #3

LAT: 65.828260 LONG: 24.131414

Observation at Haaparanta.  
Challenges with DNS, TCP, HTTP  
and POS tests.

All operators have challenges with  
coverage, quality and interference at  
observation point because area is on  
the edge of nearest cells.

Downlink speed with ROK -server is  
poor or 0 in this area. Observation  
point is at Haaparanta railway yard  
on Sweden.

HTTP

**Difference:** 8939.65

Peak > 1000 ms

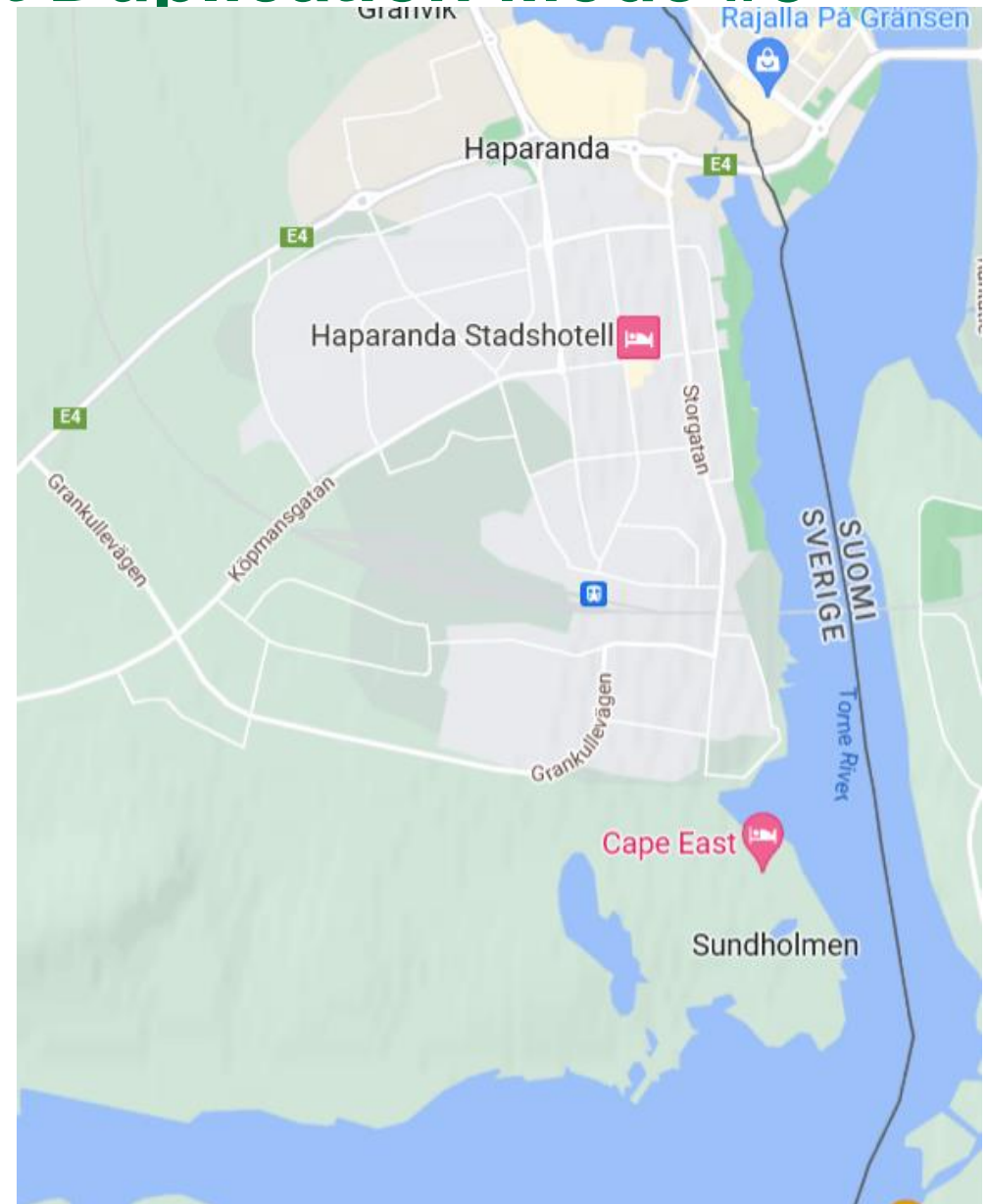
2022-06-29 17:13:28

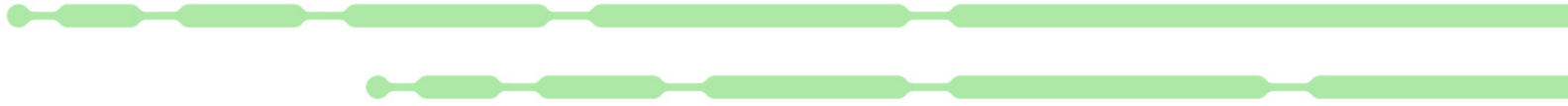
Operators X,Y and Z

RSRP	-98	-106	-113
RSRQ	-20	-15	-17
RSSI	-45	-68	-74
SINR	-8.8	-6.2	7

Latitude: 65.828260

Longitude: 24.131414





# Railway Tunnels

# Railway tunnels

With following results on the next page can be seen that most of the Finnish railway tunnels have decent 4G radio network coverage. 5G coverage on tunnels is lesser than 4G. In urban area 5G 3500 MHz causes more observation data for 5G than 5G 700MHz alone. It can be expected that 5G coverage on tunnels will increase.

Some of the operators have excellent radio network or no coverage at all on some tunnels.

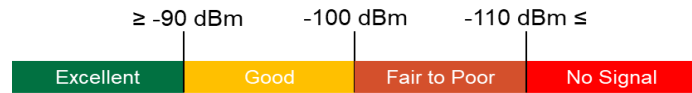
When RF-signal is excellent there is probably dedicated mobile cell configuration on tunnel. Like mobile cell with leaky RF-cable or straight head antenna to tunnel.

Under length of 193m tunnels are not analysed because of interval of measurements. These tunnels have only 1-2 measuring points per operator because of speed of Emma. On short tunnels surrounding mobile network coverage will carry inside of tunnel. Most of the tunnels have one-way analysis.

Results are gathered from RF-scanner and multi-channel router.

# Railway tunnels

RSRP (Reference Signal Received Power [dBm]):



**GREEN** = RF -signal excellent or better on whole tunnel

**ORANGE** = RF -signal between no signal and excellent signal

**RED** = No RF -signal on whole tunnel

Like the "traffic lights" suggest, there are quite many tunnels where RF-signal varies and may cause short, momentary breaks in radio connection.

	Measured tunnel	Operator Z	Operator Y	Operator X
1	24.5.2022 Kerava – Vuosaari, 13575m.	●	●	●
2a	19.4.2022 Kehärata / airport, 8230m. To east	●	●	●
2b	19.4.2022 Kehärata / airport, 8230m. To west.	●	●	●
3	13.5.2022 Lahdenvuori, 4290m.	●	●	●
4	17.5.2022 Kangasvuori, 2734m.	●	●	●
5	13.5.2022 Paasivuori, 2459m.	●	●	●
6	13.5.2022 Pönttövuori, 1429m.	●	●	●
7	19.4.2022 Märjänmäki, 1240m.	●	●	●
8	13.5.2022 Keljonkangas 1, 1064m.	●	●	●
9	13.5.2022 Pieni Neulamäki, 1002m.	●	●	●
10	19.4.2022 Lemunmäki, 775m.	●	●	●
11	13.5.2022 Paavalinvuori, 768m.	●	●	●
12	3.5.2022 Suurivuori, 765m.	●	●	●
13	24.5.2022 Labbacka, 651m.	●	●	●
14	19.4.2022 Lavianmäki, 580m.	●	●	●
15	19.4.2022 Pepallonmäki, 530m.	●	●	●
16	19.4.2022 Tottola, 520m.	●	●	●
17	19.4.2022 Haukkamäki, 436m.	●	●	●
18	8.6.2022 Kulonpalonvuori, 418m.	●	●	●
19	3.5.2022 Kehä 2, 388m.	●	●	●
20	13.5.2022 Lautakkomäki, 383m.	●	●	●
21	13.5.2022 Mustavuori 2, 373m.	●	●	●
22	5.5.2022 Möykynmäki, 350m.	●	●	●
23	26.4.2022 Kyrönniemi, 336m.	●	●	●
24	19.4.2022 Bäljens, 298m.	●	●	●
25	13.5.2022 Mustavuori 1, 282m.	●	●	●
26	19.4.2022 Riddarbacken, 274m.	●	●	●
27	19.4.2022 Harmaamäki, 265m.	●	●	●
28	13.5.2022 Mustamäki, 250m.	●	●	●
29	13.5.2022 Matomäki, 239m.	●	●	●
30	19.4.2022 Malminkartano, 230m.	●	●	●
31	19.4.2022 Högbacka, 200m.	●	●	●
32	13.5.2022 Keljonkangas 2, 193m.	●	●	●



# Thank you!