n77 Sandbox Testing 2024-5

ON SIDE

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Director & CTO, Neutral Wireless Ltd

StrathSDR

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Open Network Shared Spectrum Innovation & Design Environment

ONSIDE

Department for Science, Innovation, & Technology

Phase 1: Oct 2023 – March 2025

Lead

CISCO

BBC R&D

Co-Lead

University of Strathclyde Glasgow

StrathSDR

Neutral Wireless

University of Glasgow

CSI Communication Sensing & Imaging

AMD

Scottish Wireless Connectivity for All

Glasgow City Council

StrathSDR

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High Level Objectives of OnSide Project

1. Developing **5G private network technology for applications and use-cases** that are not currently well served by public mobile networks.

2. **n77 Spectrum sandbox** – ‘special’ licence covering the Glasgow City area for a period of 2 years, during which time we will aim to explore innovative ways of managing spectrum for pop-up 5G SA networks in the 3.8-4.2 Shared Access band.

3. A **'living lab' research, development, and design environment** for testing and demonstrating state-of-the-art communications across the Glasgow City area …integrating **spectrum sensing & monitoring** and innovative spectrum management

4. **100 MHz of n77 spectrum** allocated in 3.8-4.2 GHz band for interoperability, interference testing, distance, indoor/outdoor testing.

5. **Engaging and reporting to Stakeholders** throughout the project, disseminating findings and learnings & discussing potential innovative approaches to spectrum management.

n77 Spectrum Sandbox
Ofcom T&D Licence

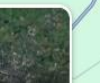
15km radius

700km² area

27dBm power

100 MHz channel

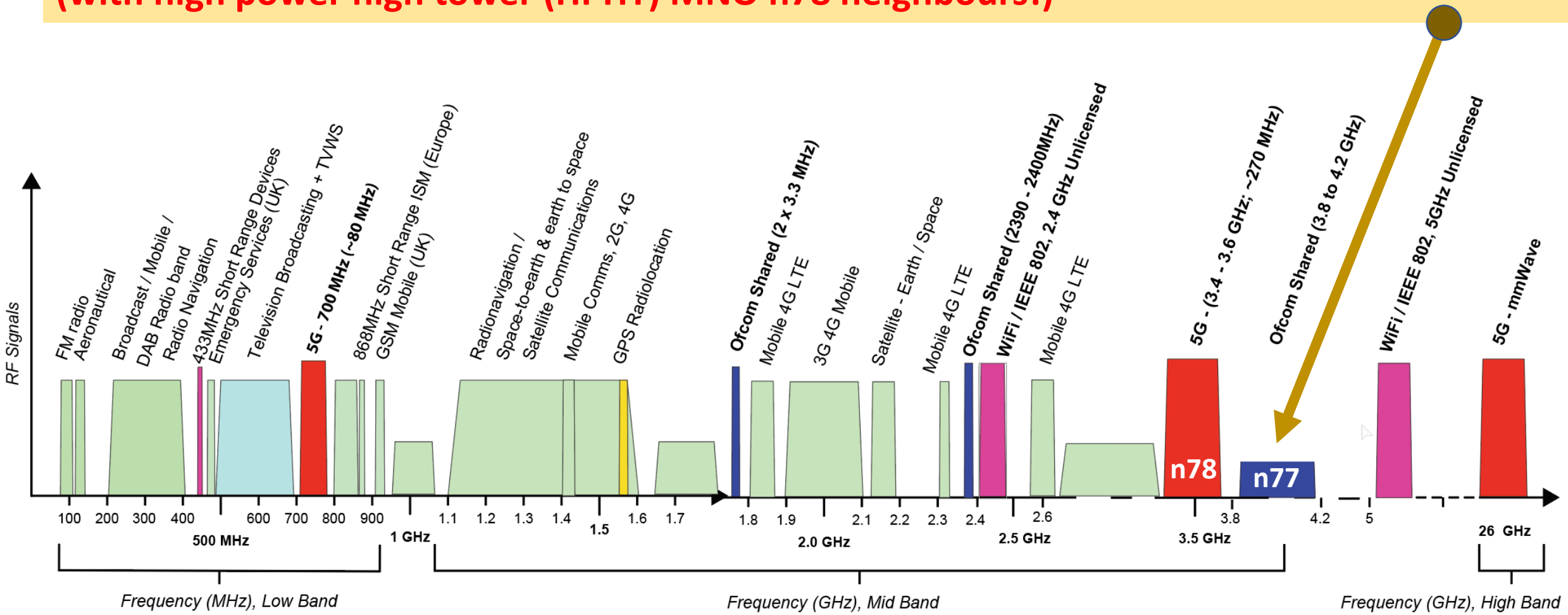
Glasgow City Centre



Spectrum – Licensed, Unlicensed & Shared (low/mid)

‘n77’ (upper) – Shared Spectrum: 3800 – 4200 MHz (400 MHz)

(with high power high tower (HPHT) MNO n78 neighbours!)



Use Cases for n77 Private 5G SA

- Stadium
- Urban
- Live Events
- Studio/Theatre
- Ports and Industrial
- Rural and Open Area

6 Years to get Ready for n77 Sandbox Tests

2019-21	**Operative:**	*It just needs to work*
2022-23	**Performative:**	*Functional for demo live use case*
2023-24	**Qualitative:**	*Delivering QoS on a real world use case*
2024-25	**Quantitative:**	*Empirical measurements - Sandbox*

- **Operative**, **performative**, & **qualitative** experience means we know **what to test**, **where to test** and **what performance to expect** for **quantitative empirical sandbox** measurements.

Operative:

Working and operating the lab & field

2019

from 2019 we designed and operated n77 radios and networks. UEs were using modems. 5G SA operable handsets only arrived 2023/24. Networks were lab and T&D based

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Product Brief

Overview of NW 5G Solutions

5G Network in a Box (NIB) and Disaggregated Configurations

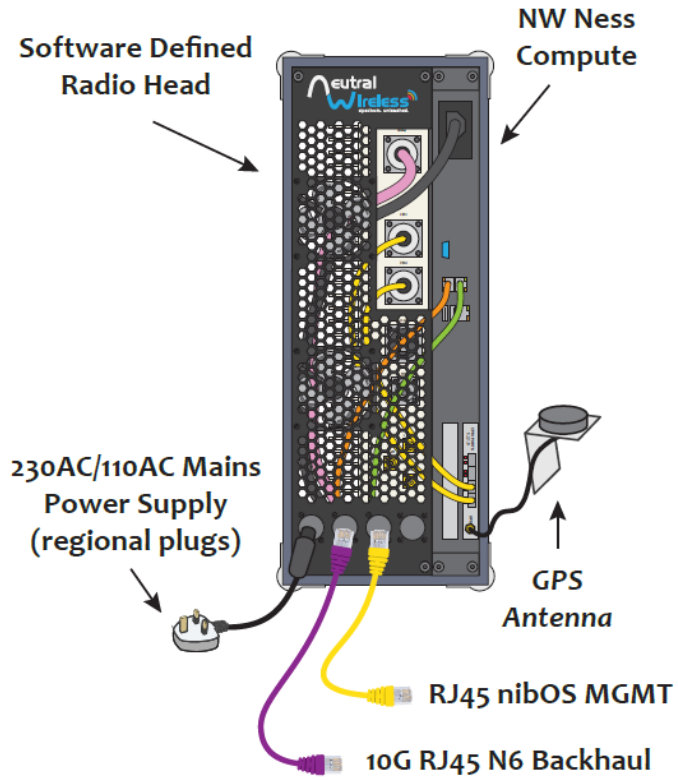
2019/20

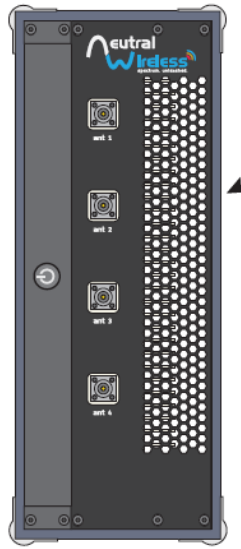
NW Lomond Network in a Box (NIB)

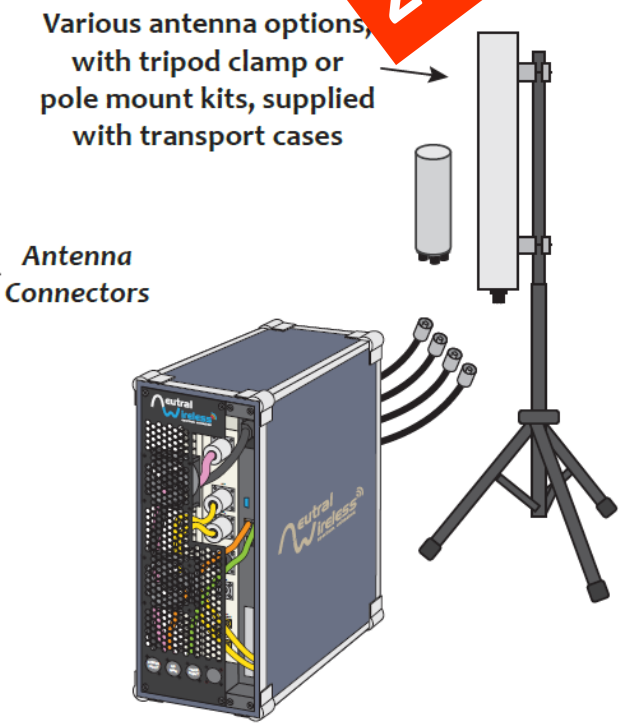
An all-in-one network with the radio head and computer featuring the vBBU gNB stack and mini-5GC, packaged in a rugged wheeled 19 inch rack case. Suitable for the pop up networks, events, and the lab.

Omni or sector antennas are supplied with a transport case and 3m tripod stand. This solution is not water resistant, and therefore generally not suitable for outdoor use. For outdoor-friendly networks, the Disaggregated Lomond is recommended.

Note: You can start with a NIB, and add on more disaggregated radios to build a multi-cell network







NW Lomond NIB can be transported like a wheeled suitcase

Performative:

Robust enough to be deployed & work

2022

From 2022 live performing networks for demonstration of live broadcast use case. Sports, civic, and live events demonstrated

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Live in Scotland, September 2022

Pitlochry Highland Games – Traditional Scottish Sports and Culture

Stone-X – Saracens vs Nottingham

2022

Live in Ireland – August 2022

Fleadh Cheoil – Mullingar 'The Homecoming' traditional music festival

2022

Qualitative:

2023/24

Fully operational and engineered to perform

The 2023 **King's Coronation** and the 2024 **Paris Olympics** n77 provided live event coverage for international markets with sufficient QoS, reliability and quality for broadcasters.

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The Coronation of His Majesty King Charles III – May 2023

Network deployment & verification

- ✓ Measurements agree well with RF simulations
- ✓ (Coverage actually ***better*** than predicted)
- ✓ Allocated 80 MHz spectrum
  - 2x 40 MHz channels (**A**/**B**)
  - Original 40 MHz licence at CG (**C**)
- ✓ Provided over 1 Gbps of uplink
- ✓ connectivity; cell handover
- ✓ Frequency re-use across 1km

2023

BBC R&D

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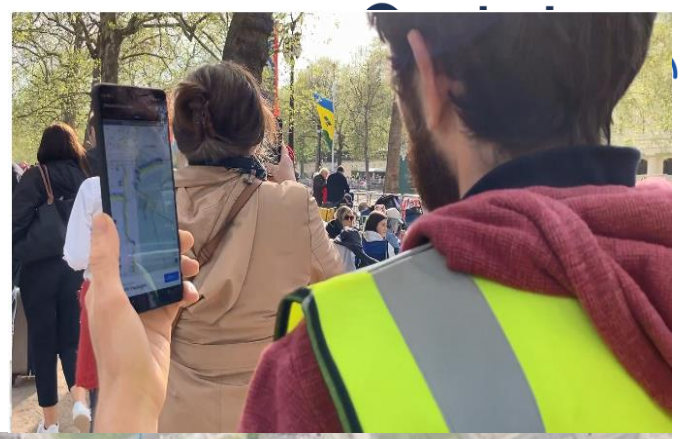

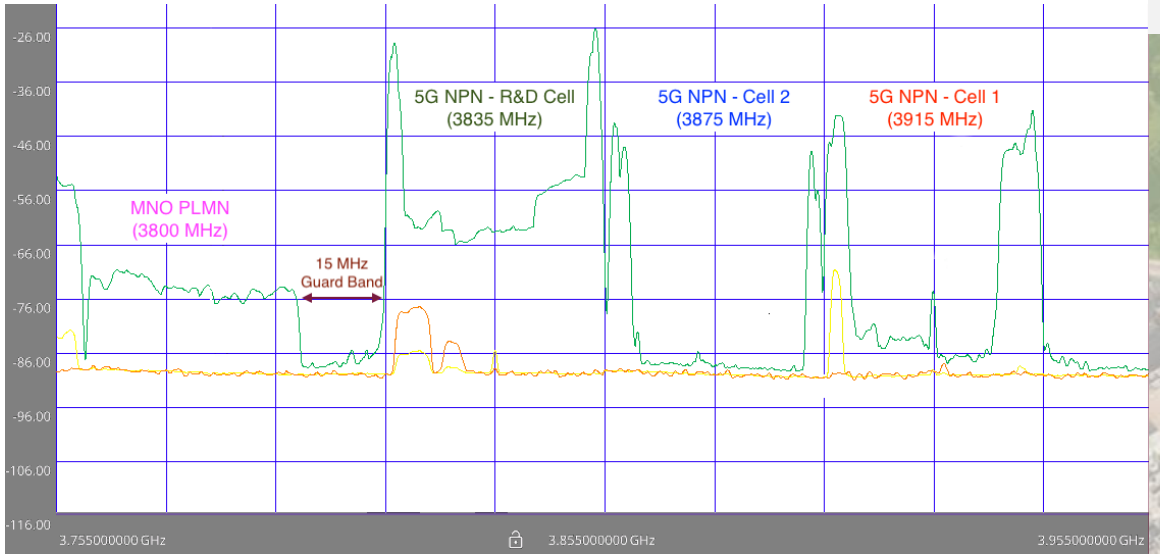

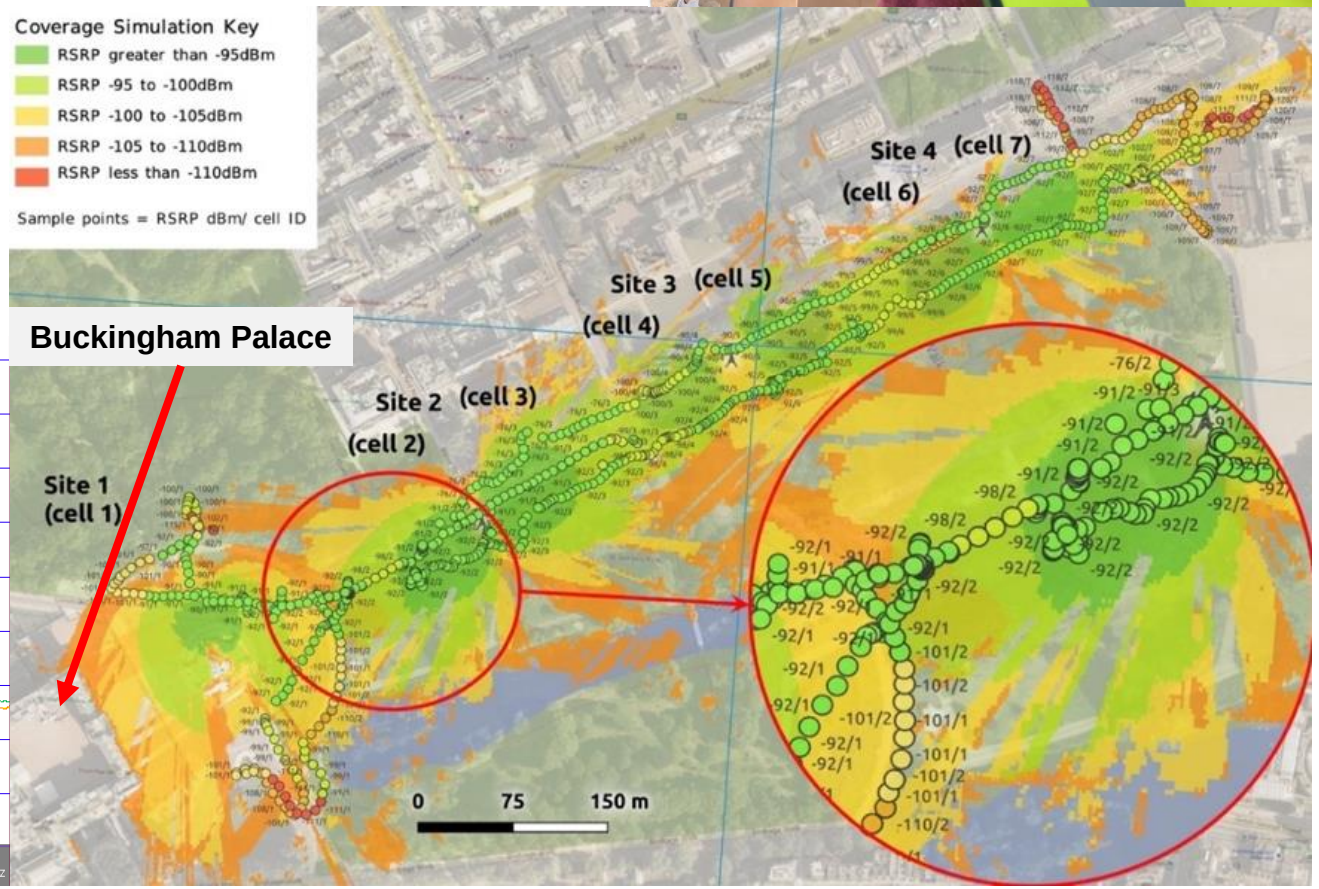


OBS
orange
intel
CISCO
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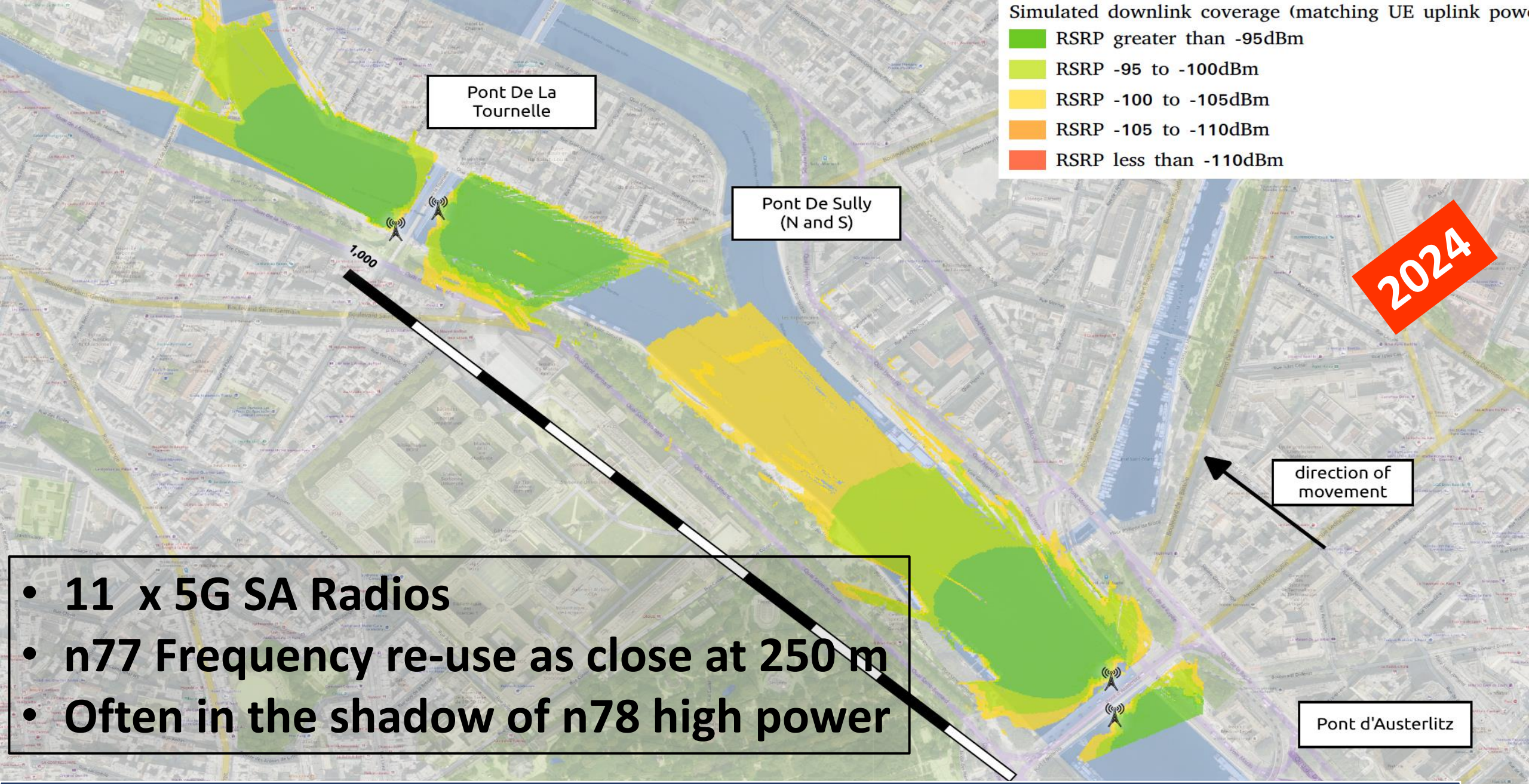
HAIVISION
SAMSUNG
Private 5G
Paris 2024
• Opening Ceremony on River Seine
• 3 Event Stadiums
• Sailing Events, Marseille
2024
VEDETTES·DE·PARIS
PARIS ETOILE

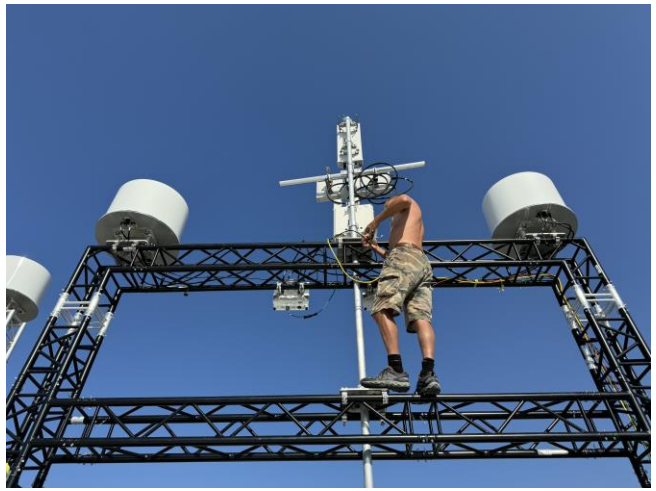
Measuring and designing on the River Seine

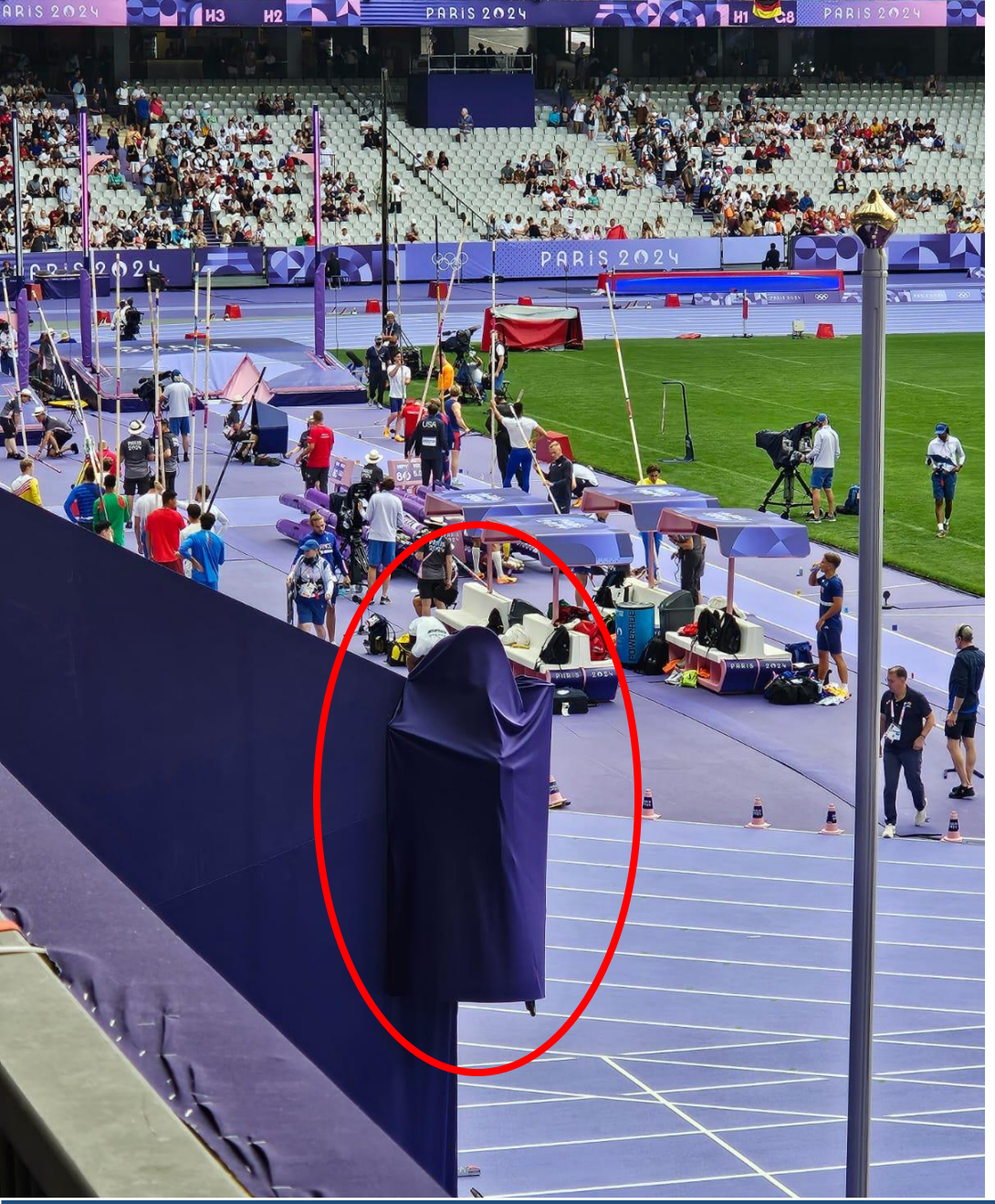


- **11 x 5G SA Radios**
- **n77 Frequency re-use as close at 250 m**
- **Often in the shadow of n78 high power**

Planned, deployed, engineered, tested and operated …

In Marseille with Private 5G at Sea





Live in 3 stadiums including Stade de France

Olympic Swimming Venue

Quantitative

2024/25

Sandbox Testing, Modelling & Measurement

From 2024 we know n77 can be engineered to work well in many challenging environments. With this **OnSide Sandbox**, we empirically measure, quantify and verify what has been learned.

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Product Brief

NW Etive

Portable 5G Network Ecosystem

2024/25

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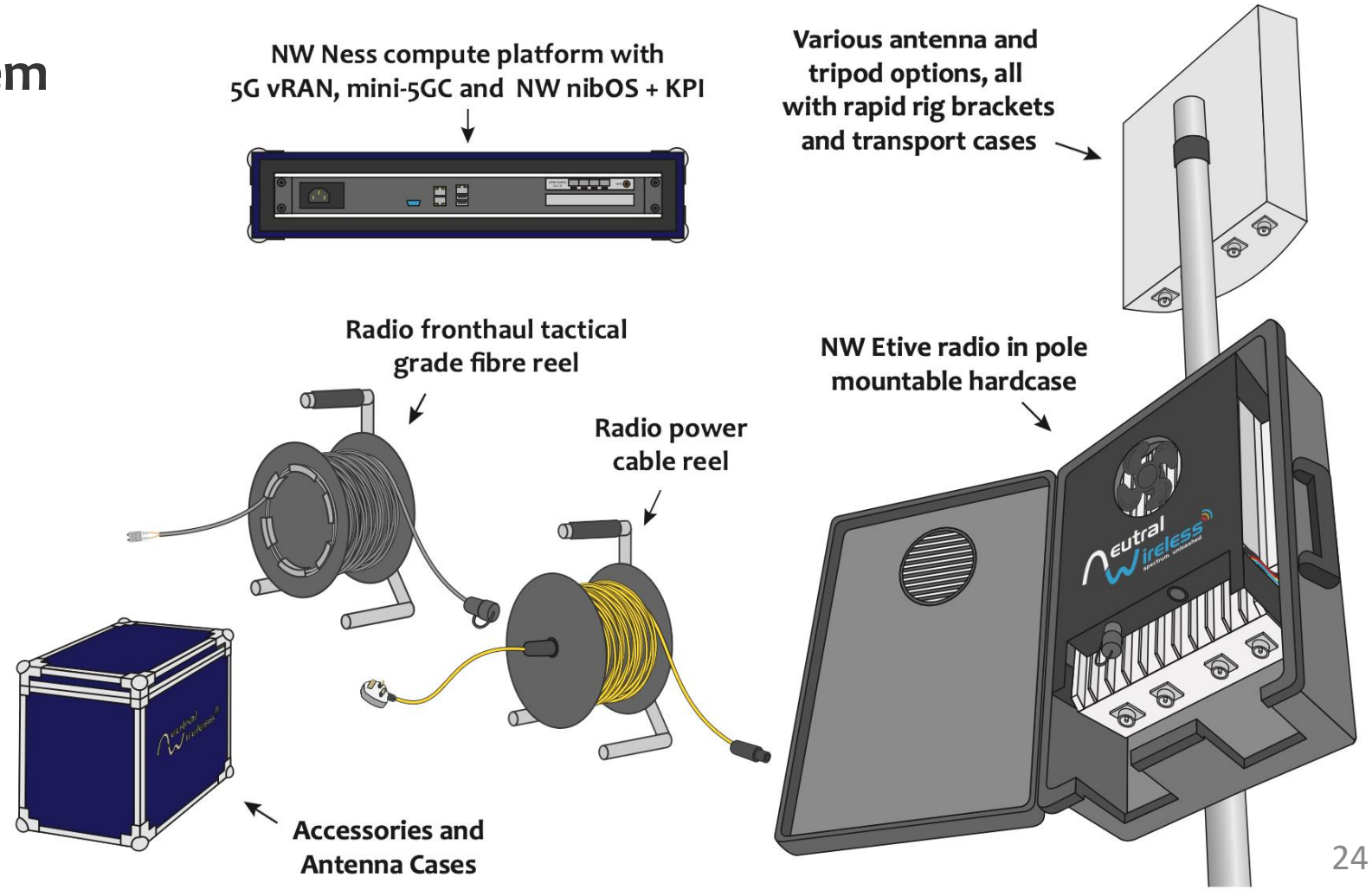
NW Etive Portable 5G Ecosystem

The Neutral Wireless **Etive** is a fully portable 5G network ecosystem, with Release 18 aligned vRAN software stack and integrated mini-5GC for subscriber management and local data breakout. **Etive** is the perfect solution for lab work and field trials, and also for deploying a pop-up 5G network at events for sports broadcasting, music festivals, and conferences.

The NW **Etive** is a truly mobile private 5G SA solution, with radio heads, the NW Ness compute platform, antennas and accessories packaged in rugged transport cases ready for rapid deployment. The hardcase containing the radio (pictured right) can be directly pole mounted, and the 5G network can be unpacked and operational in as little as 5 minutes.



Operational Dashboard: Radio health, network, UE performace

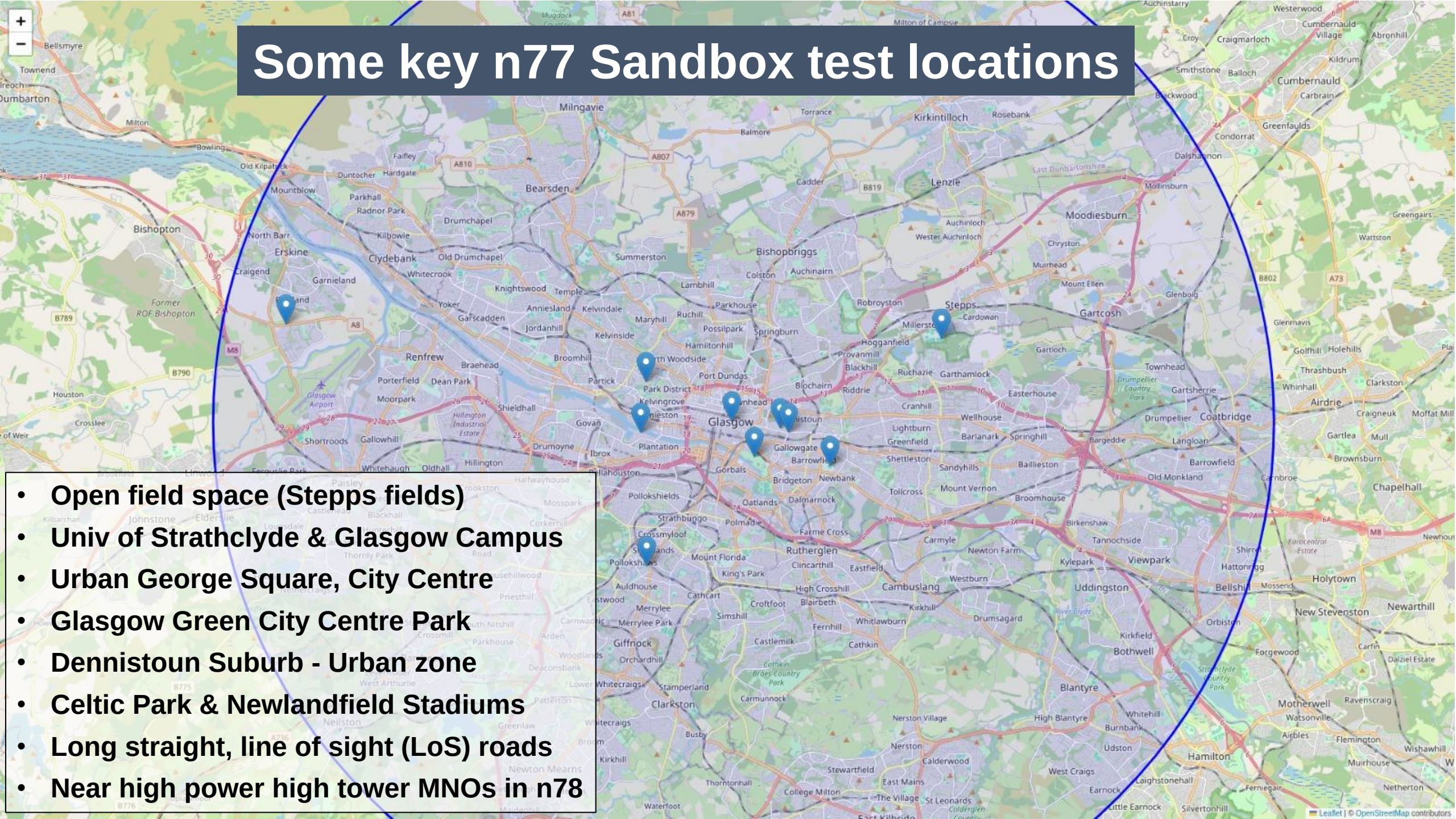
2024/25

Neutral Wireless operations dashboard presents details and statistics for all connected devices.

n77 Sandbox: Activities and Measurements

- **Distances achievable** line of sight, bit rates for low power – whisper networks!
- **RF modelling** and prediction with models/lidar
- **Outdoor clutter** performance (city centre buildings, landscape/geography)
- Characterise key **indoor clutter** performance (BBC Studios)
- **Interference performance**: n77 in empty stadium versus 60,000 people
- **Synchronised and unsynchronised** operation (with other n77 and n78)
- Measure on performance aiming to **understand all UEs/Radios not equal**
- In-radio **live spectrum monitoring** operational demonstration benefits

Some key n77 Sandbox test locations

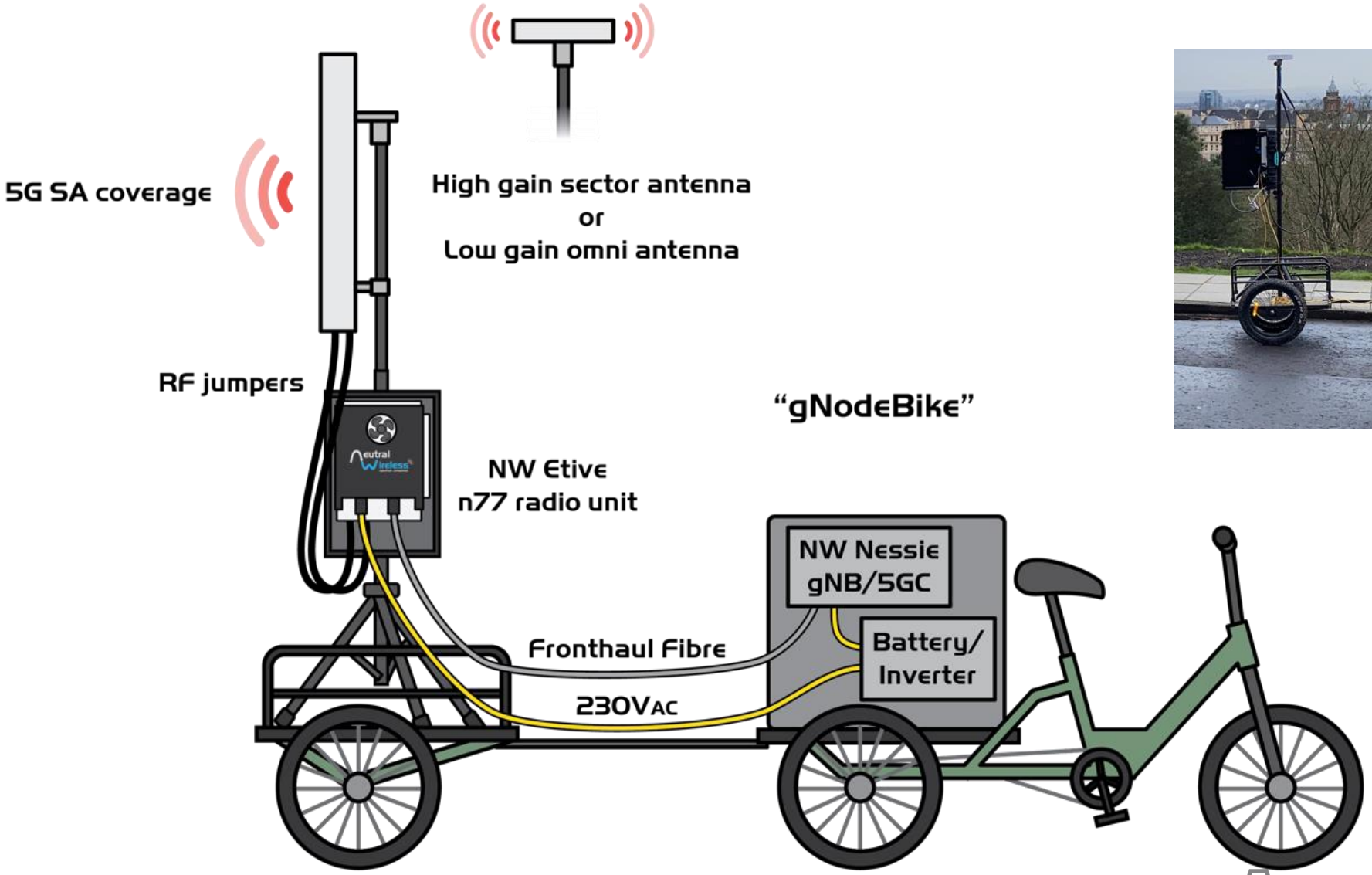


- Open field space (Stepps fields)
- Univ of Strathclyde & Glasgow Campus
- Urban George Square, City Centre
- Glasgow Green City Centre Park
- Dennistoun Suburb - Urban zone
- Celtic Park & Newlandfield Stadiums
- Long straight, line of sight (LoS) roads
- Near high power high tower MNOs in n78

Sandbox Measurements Efforts (so far)

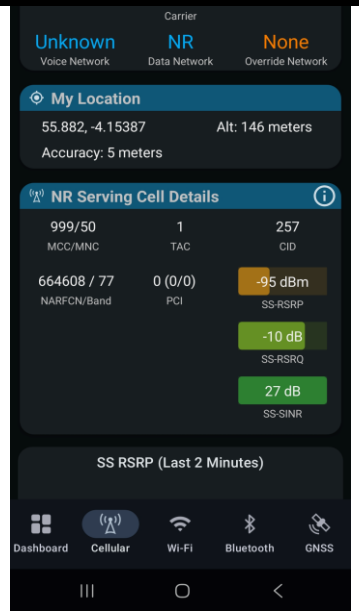
- **105 measurement** campaign files captured for n77.
- **71.8 km** walked with test UEs.
- **1454 minutes** of network operation and recording.
- **71589 sample points** recorded and being analysed.

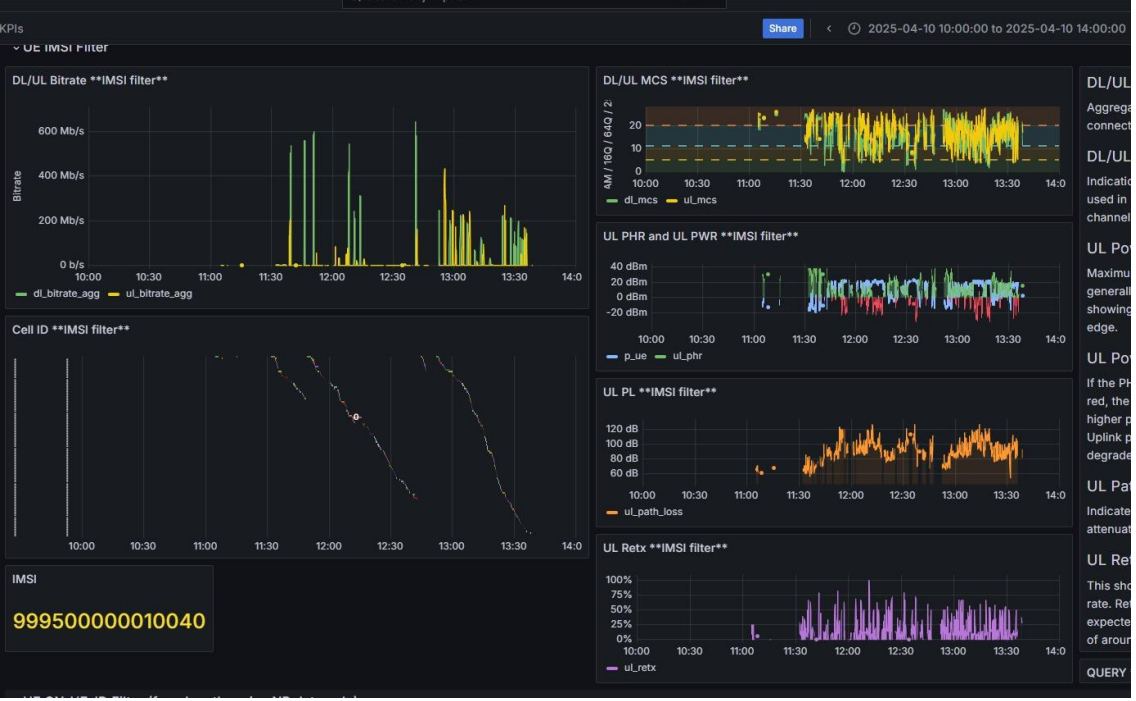
gNodeBike: Goes ‘anywhere’ for n77 Testing

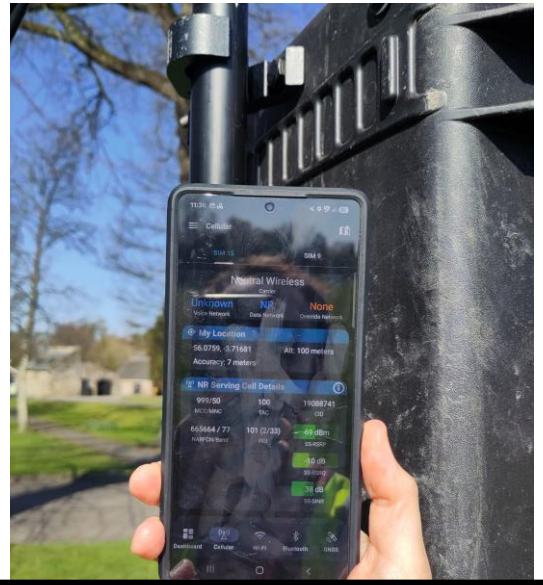


Go anywhere with the 2 x gNodeBikes

Open Terrain measurements (in rain)

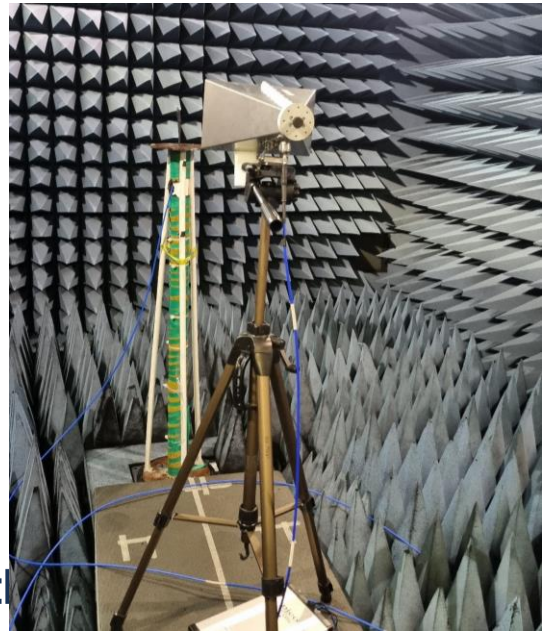






UE and gnodeB live measurements

Not all UEs are equal – Receiver sensitivity, adjacent channel leakage

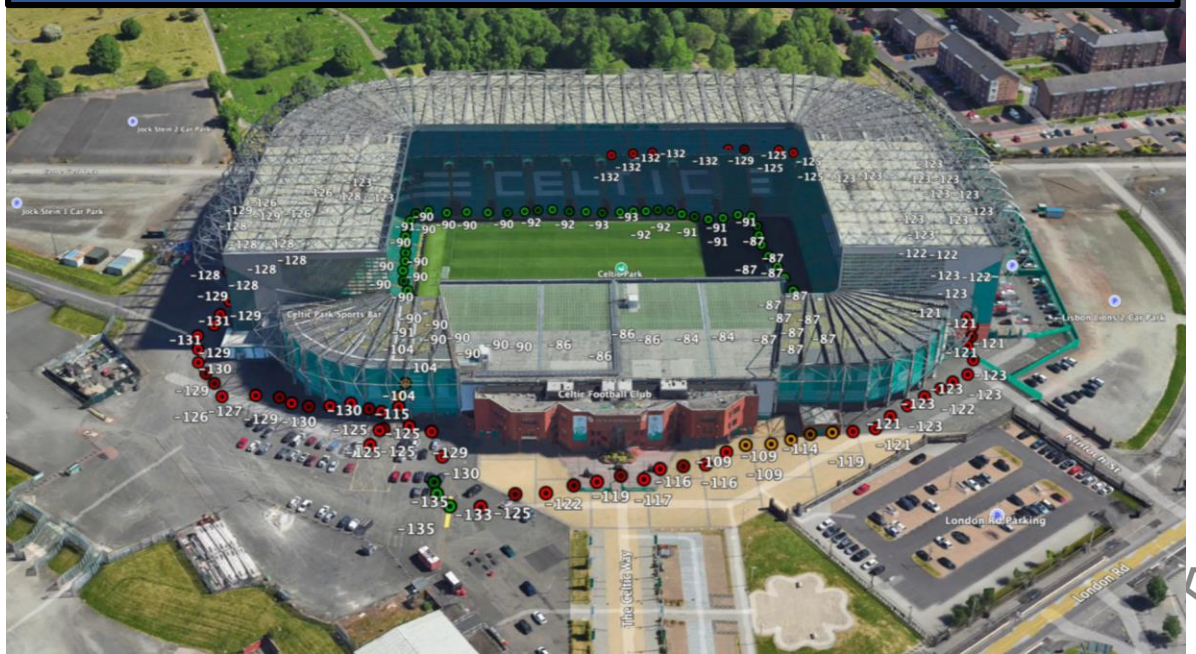


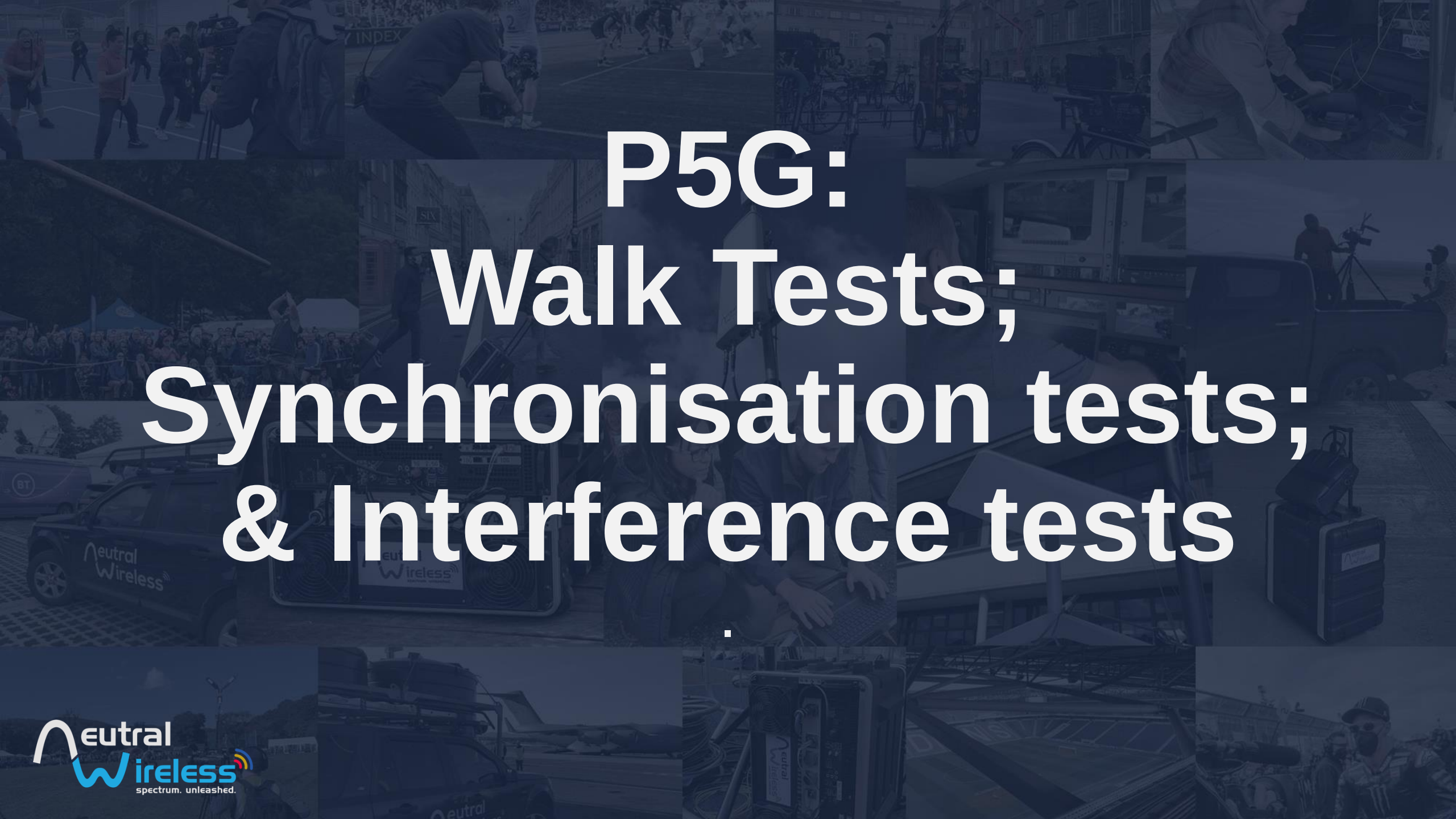
Everything batteries: gnodeB, UEs, test kit

1.1km LOS (Line of Sight)

Stadium Testing

n77 ‘green’ inside – ‘red’ outside!





P5G: Walk Tests; Synchronisation tests; & Interference tests

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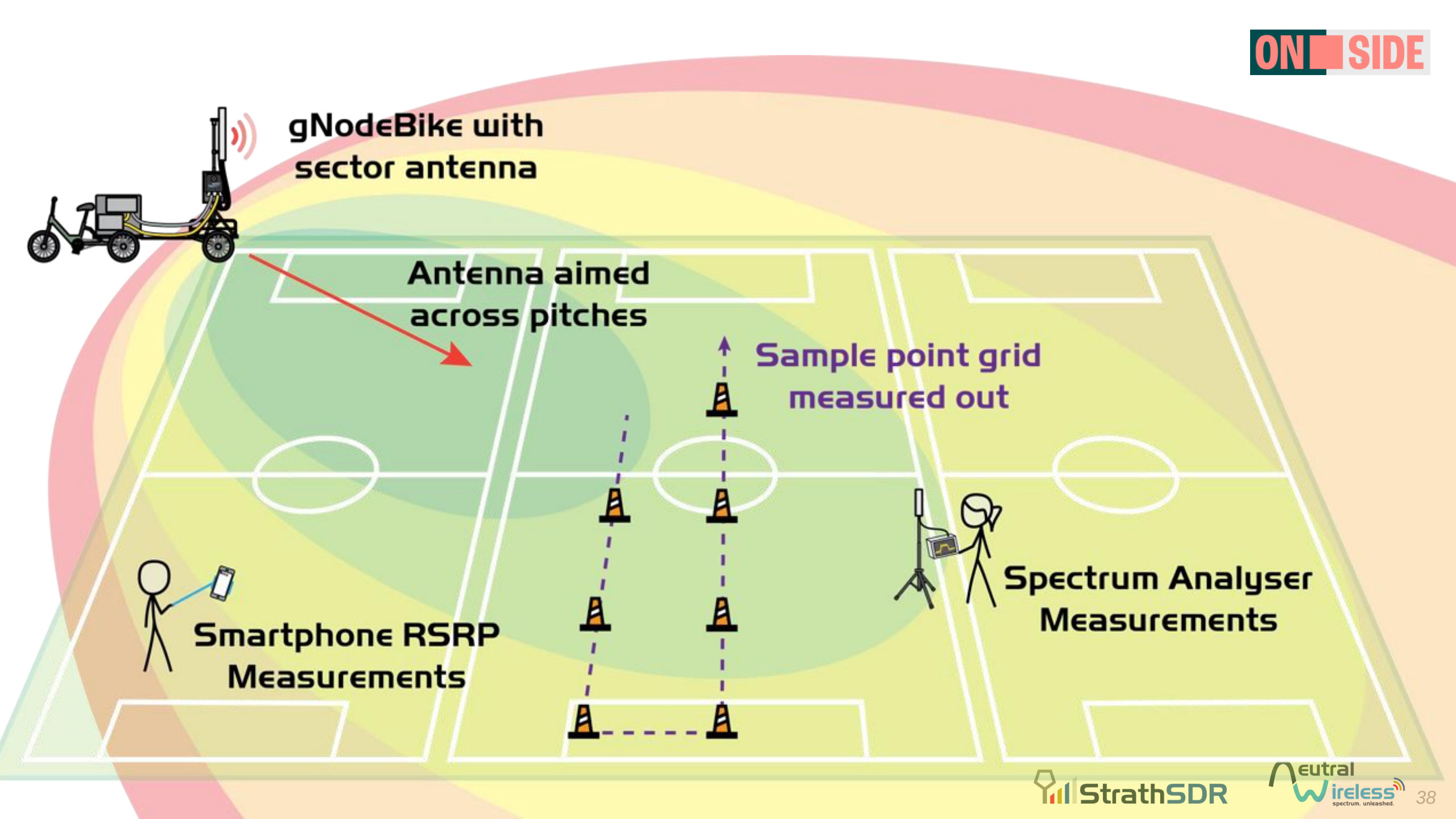
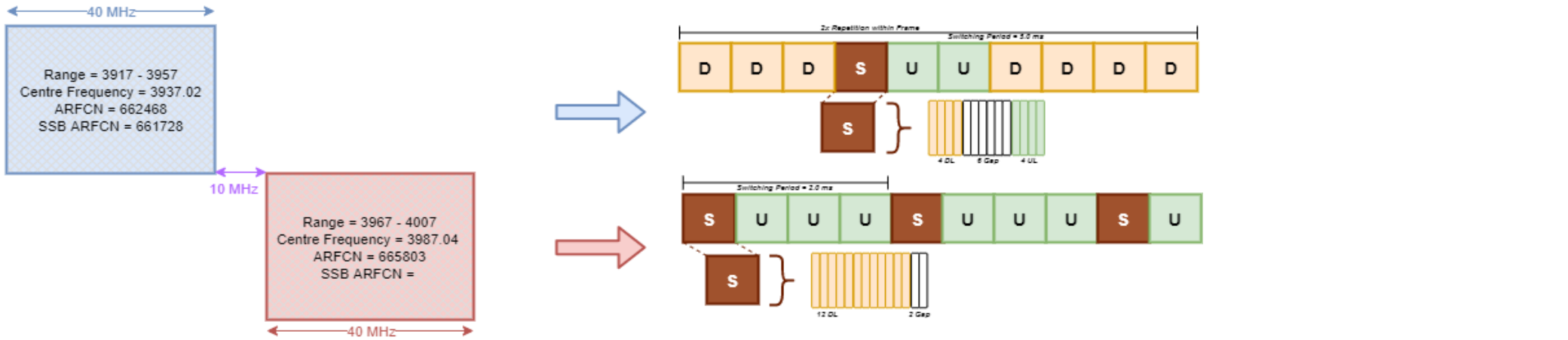
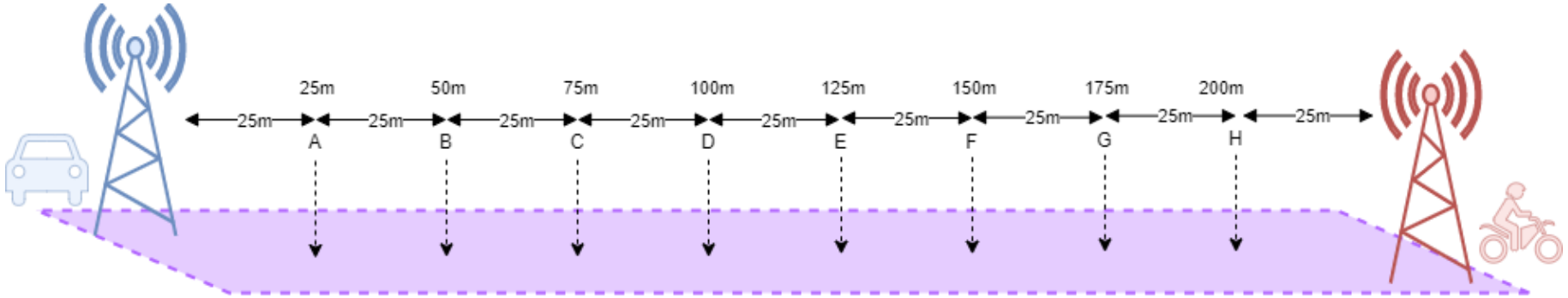
STEPPS PLAYING FIELDS, G33 6ND


gNodeBike with
sector antenna
Antenna aimed
across pitches
Sample point grid
measured out
Smartphone RSRP
Measurements
Spectrum Analyser
Measurements

Using Adjacent Operating Channels





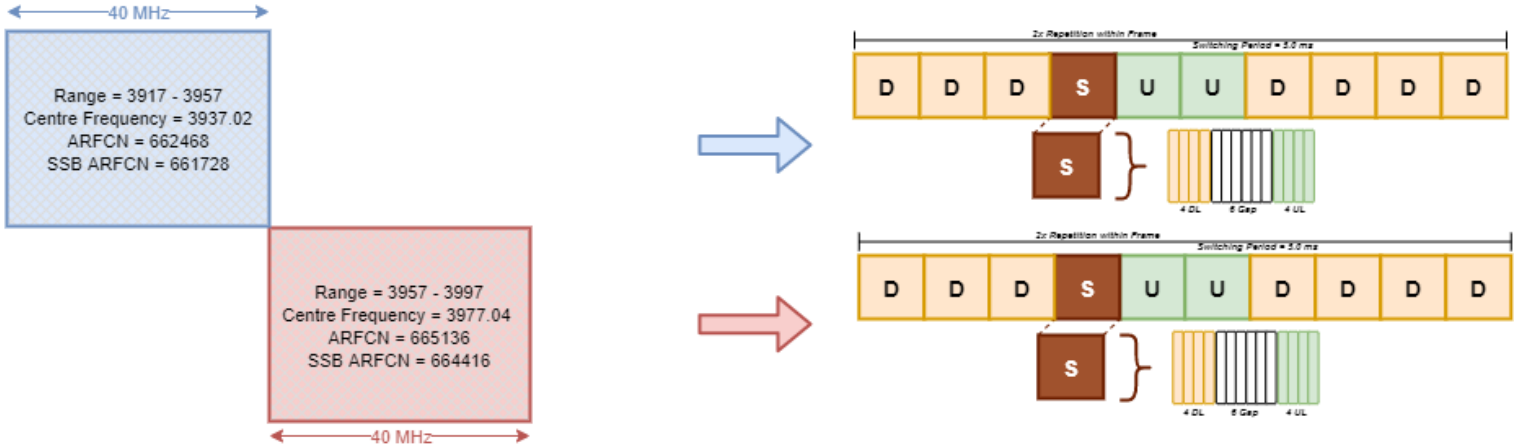
Primary Parameters

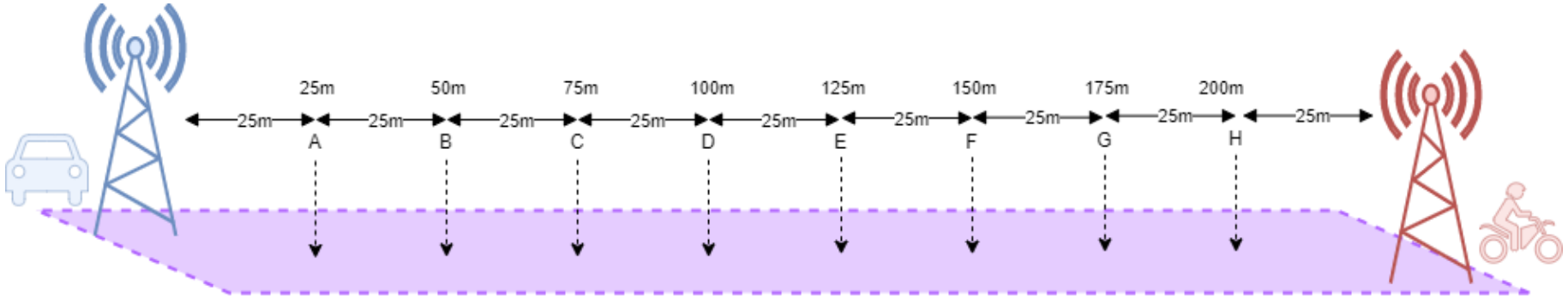
- PLMN = 99901
- TX PWR = 27 dBm (EIRP)
- 30 (TX) + 7 (Antenna) - 10 (Attenuator)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

Interferer Parameters

- PLMN = 99950
- TX PWR = 27 dBm (EIRP)
- 30 (TX) + 7 (Antenna) - 10 (Attenuator)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

Using Adjacent Operating Channels





Primary Parameters

- PLMN = 99901
- TX PWR = 27 dBm (EIRP)
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- Cell Load = 1 UE @ Max
- GPS Sync = True
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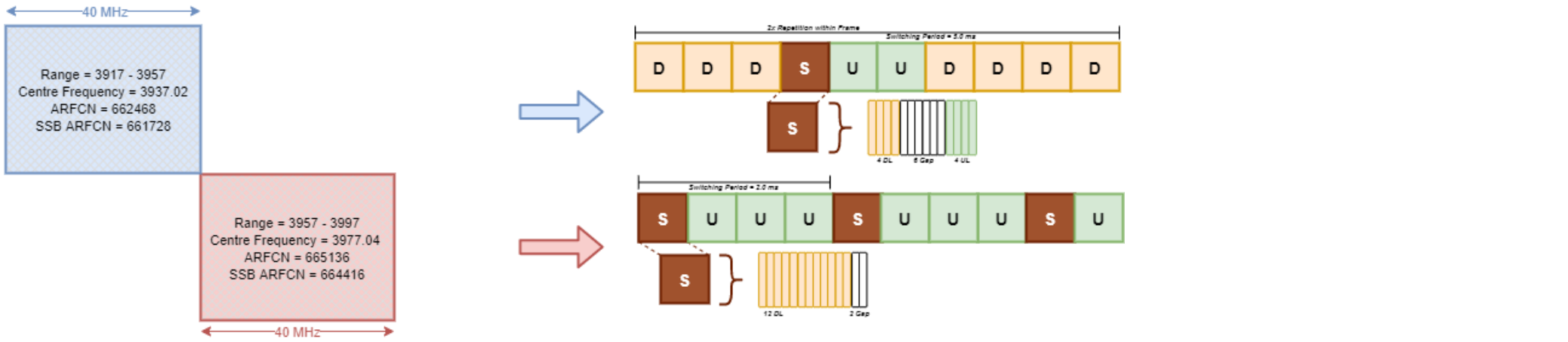
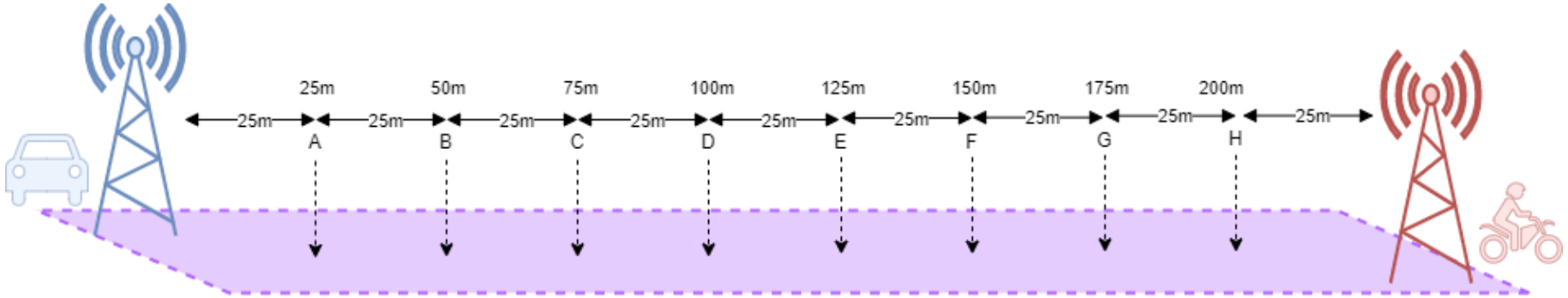
Using Adjacent Operating Channels





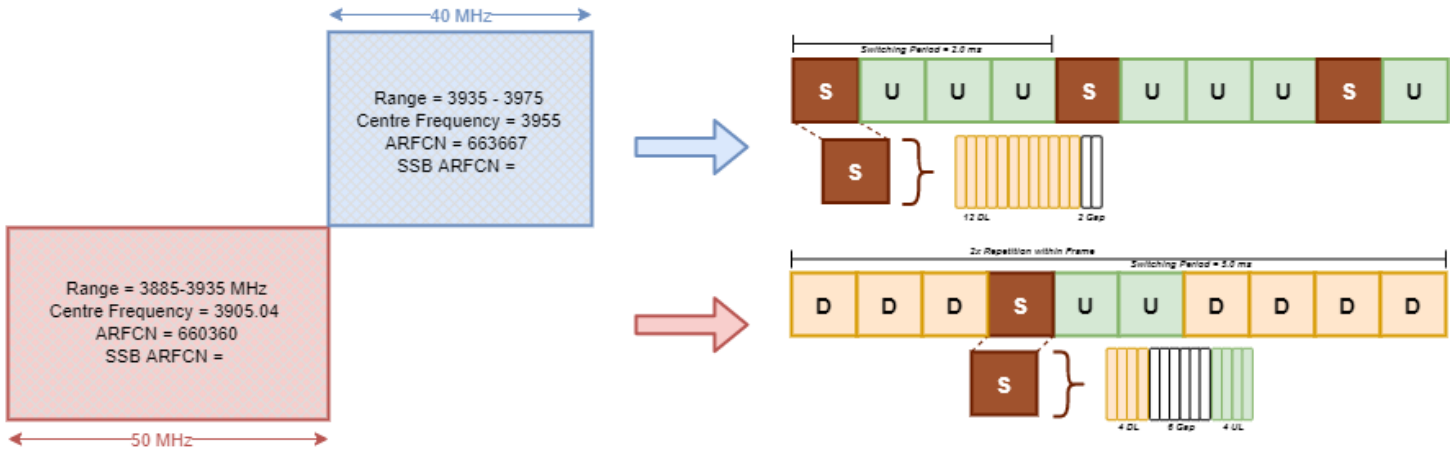
Primary Parameters

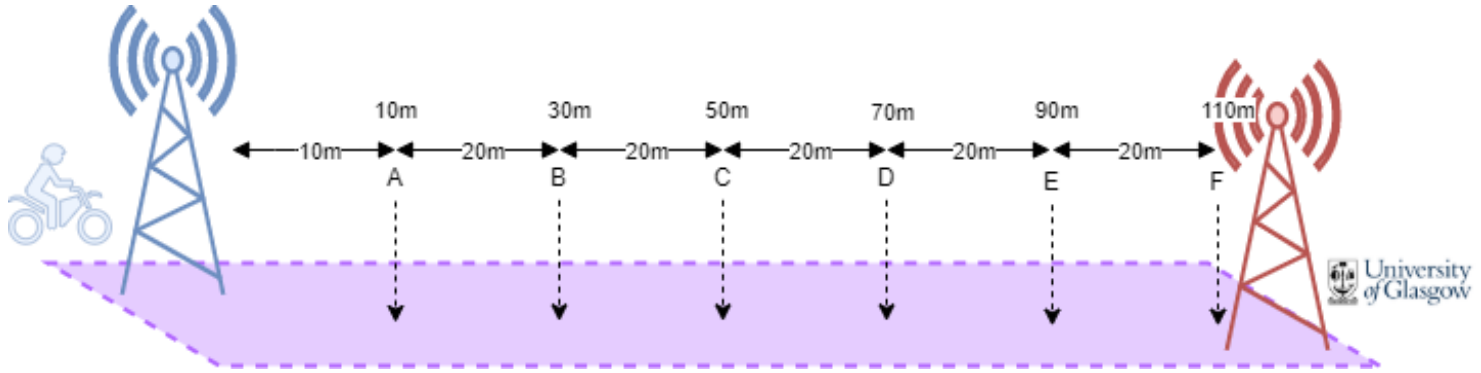
- PLMN = 99901
- TX PWR = 27 dBm (EIRP)
- 30 (TX) + 7 (Antenna) - 10 (Attenuator)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

Interferer Parameters

- PLMN = 99950
- TX PWR = 27 dBm (EIRP)
- 30 (TX) + 7 (Antenna) - 10 (Attenuator)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

Private Network Deployments Using Adjacent Operating Channels – Glasgow University Campus





Primary Parameters

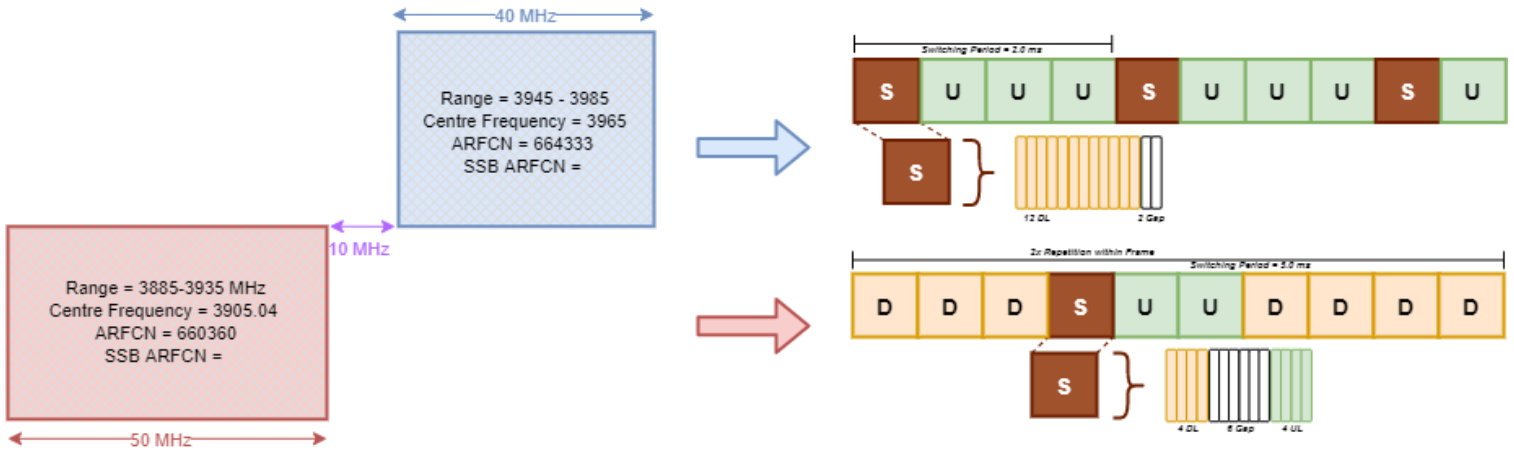
- PLMN = 99950
- TX PWR = 27 dBm (EIRP)
- 32 (TX) + 5 (Antenna) - 10 (Attenuator)
- SISO (1 Tx, 1 Rx)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

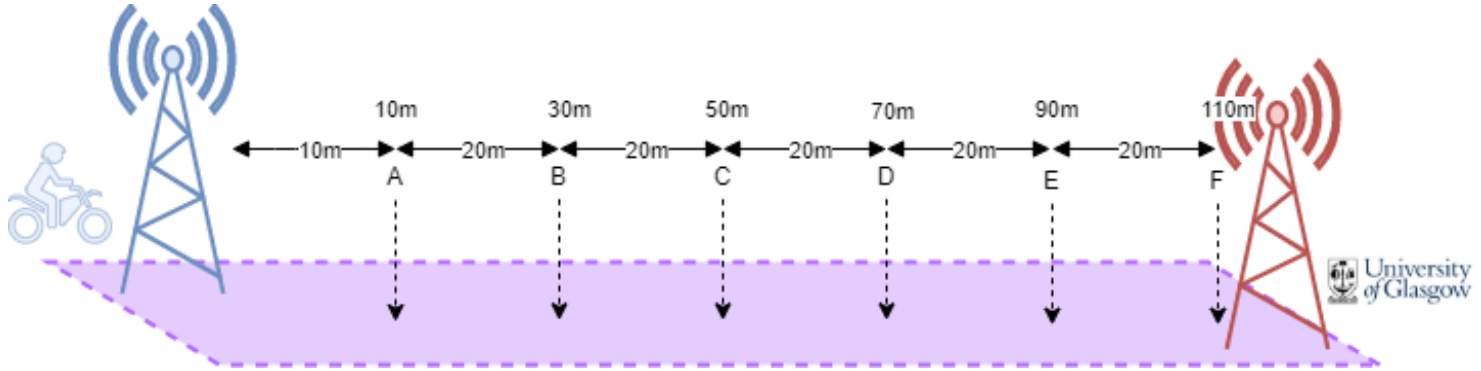
Interferer Parameters

- PLMN = 99940
- TX PWR = 36 dBm (EIRP
- SISO (4 Tx, 2 Rx)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

University of Glasgow

Private Network Deployments Using Adjacent Operating Channels – Glasgow University Campus





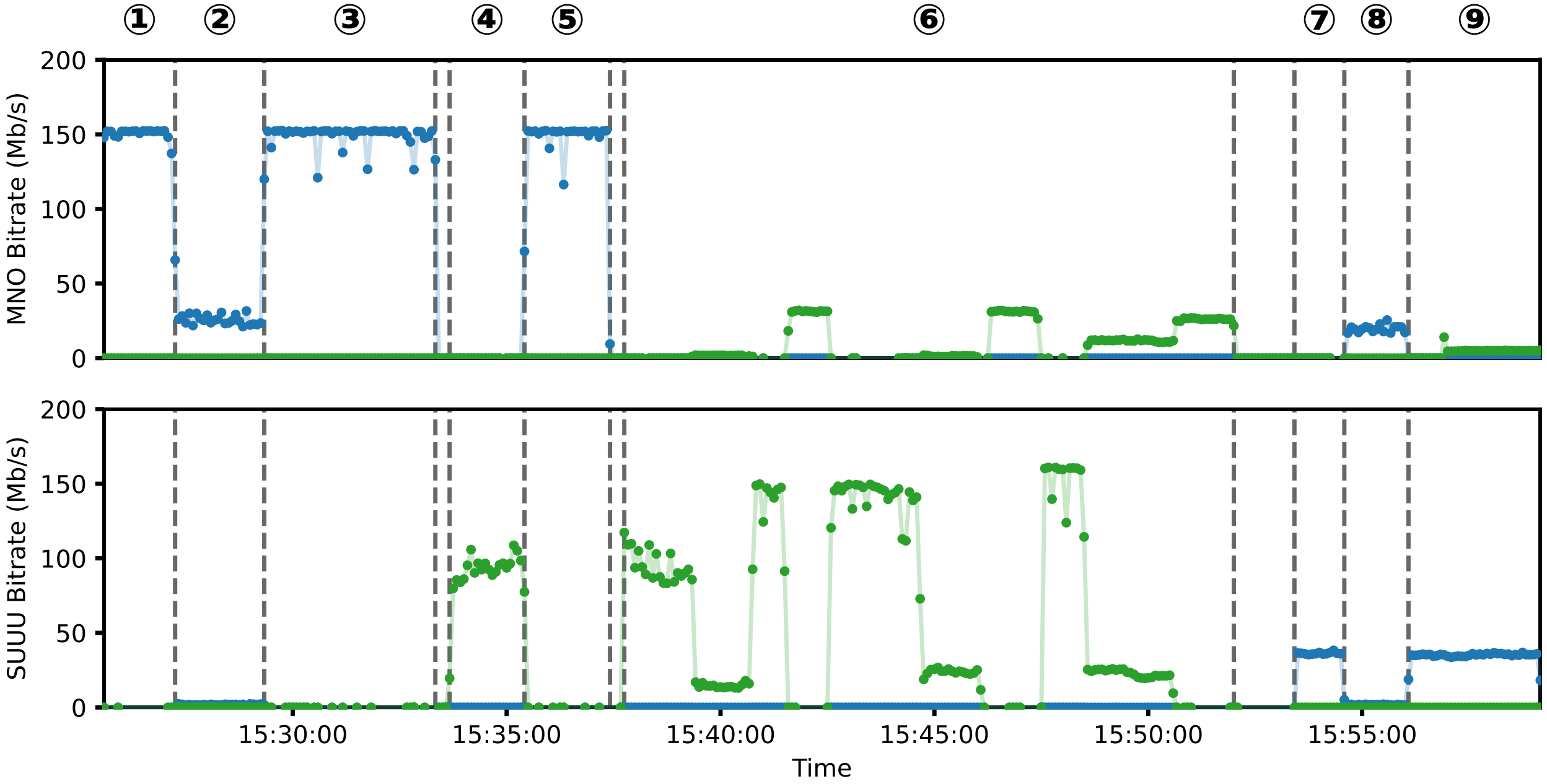
Primary Parameters

- PLMN = 99950
- TX PWR = 27 dBm (EIRP)
- 32 (TX) + 5 (Antenna) - 10 (Attenuator)
- SISO (1 Tx, 1 Rx)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

Interferer Parameters

- PLMN = 99940
- TX PWR = 36 dBm (EIRP
- SISO (4 Tx, 2 Rx)
- Cell Load = 1 UE @ Max
- GPS Sync = True
- NO RF FILTER

University of Glasgow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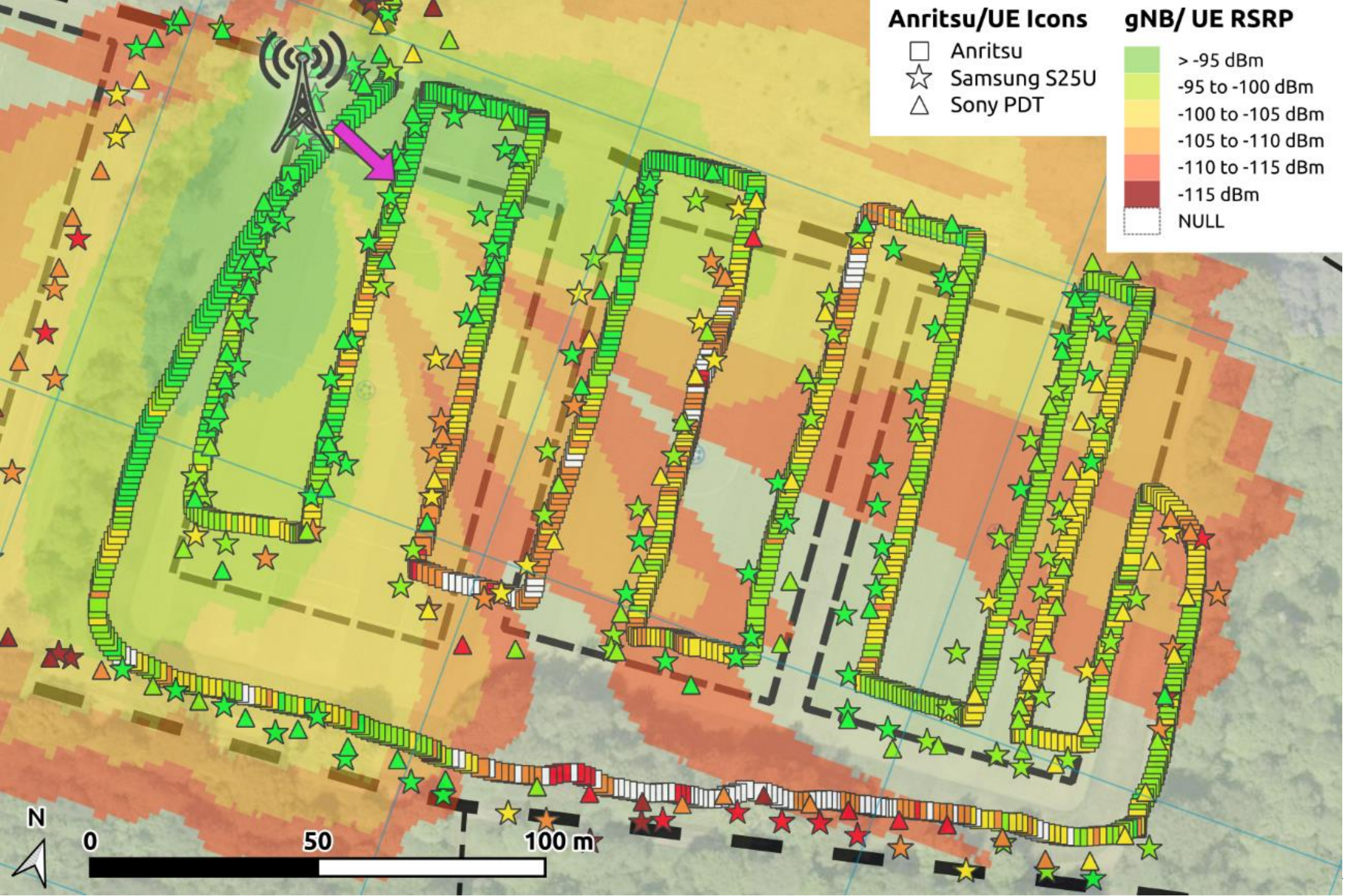
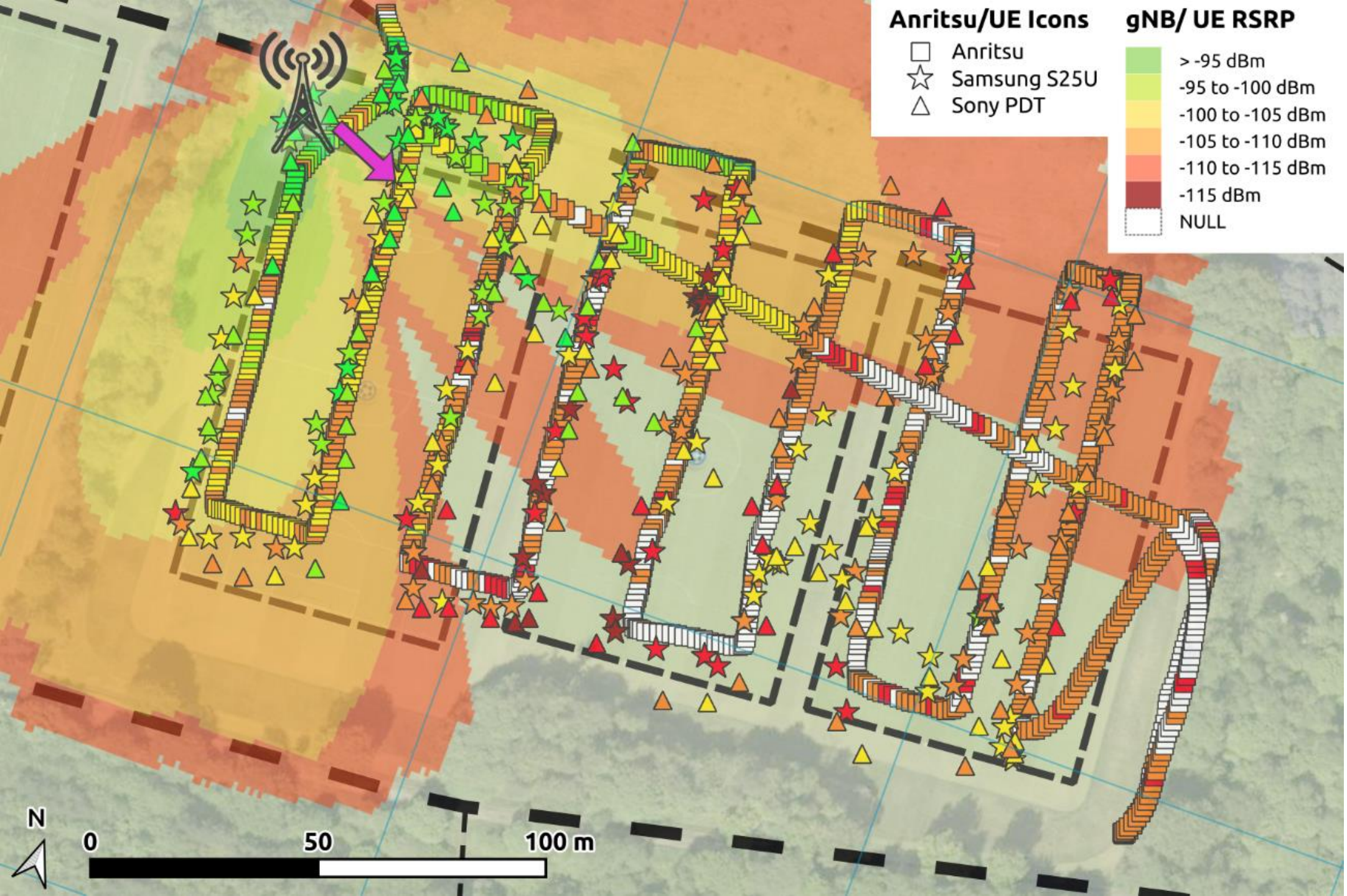
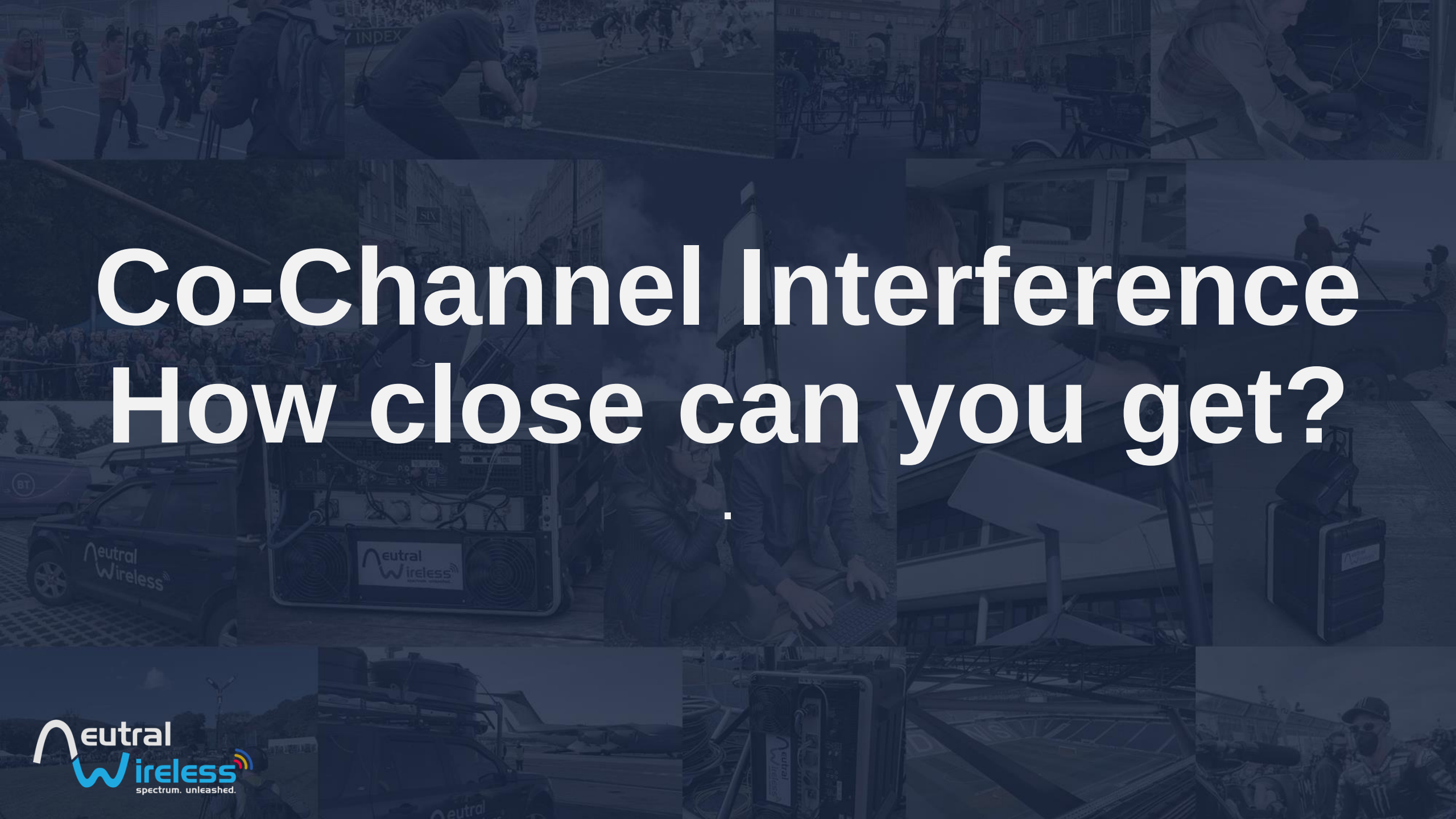
MNO Bitrate (Mb/s)
SUUU Bitrate (Mb/s)
200
150
100
50
0
15:30:00
15:35:00
15:40:00
15:45:00
15:50:00
15:55:00
Time


Anritsu/UE Icons
Anritsu
Samsung S25U
Sony PDT
gNB/ UE RSRP
> -95 dBm
-95 to -100 dBm
-100 to -105 dBm
-105 to -110 dBm
-110 to -115 dBm
-115 dBm
NULL
N
0
50
100 m


Anritsu/UE Icons
Anritsu
Samsung S25U
Sony PDT
gNB/ UE RSRP
> -95 dBm
-95 to -100 dBm
-100 to -105 dBm
-105 to -110 dBm
-110 to -115 dBm
-115 dBm
NULL
N
0
50
100 m


Anritsu/UE Icons
Anritsu
Samsung S25U
Sony PDT
gNB/ UE RSRP
> -95 dBm
-95 to -100 dBm
-100 to -105 dBm
-105 to -110 dBm
-110 to -115 dBm
-115 dBm
NULL
N
0
50
100 m



Co-Channel Interference How close can you get?

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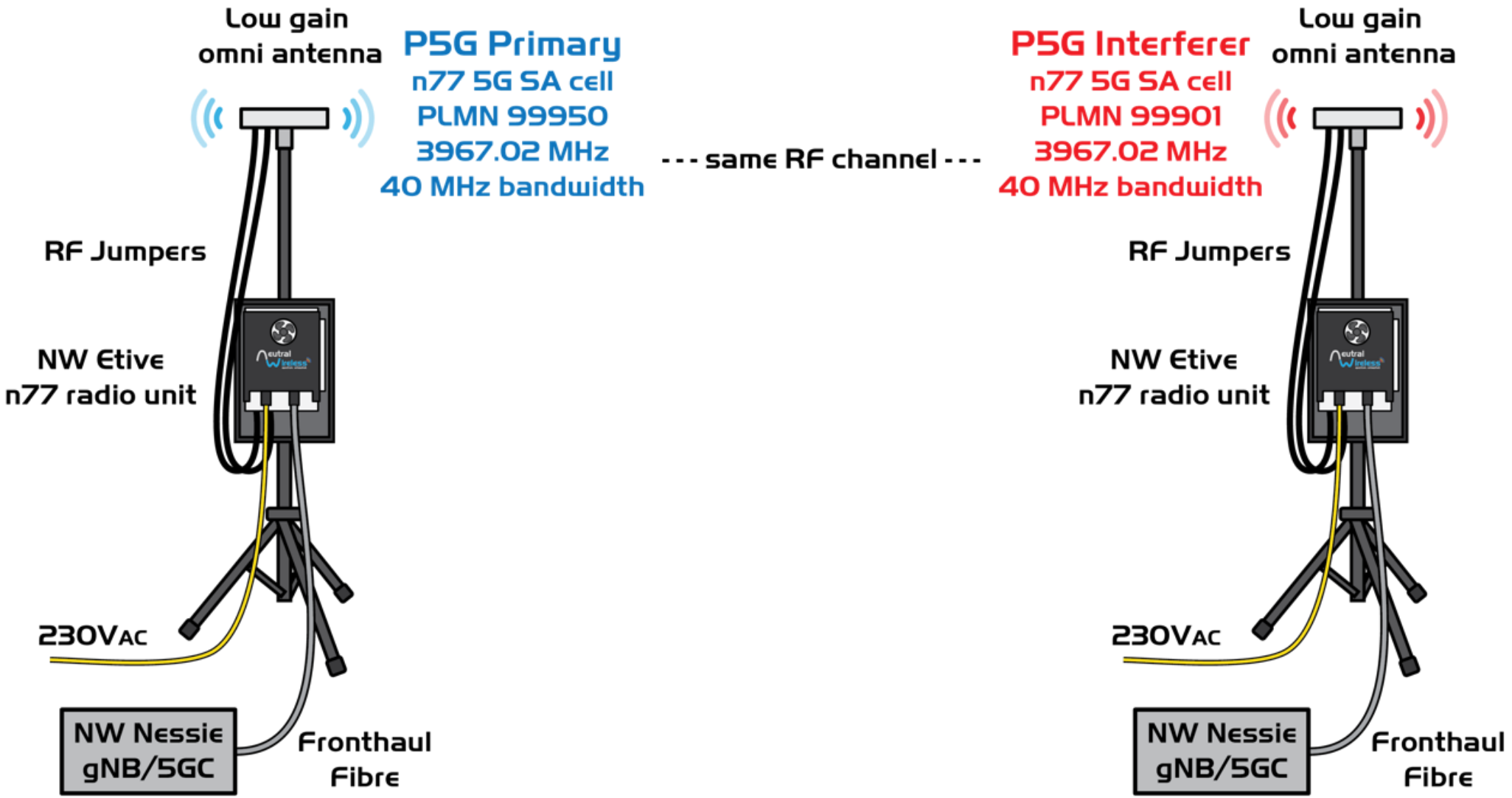
Low gain
omni antenna
P5G Primary
n77 5G SA cell
PLMN 99950
3967.02 MHz
40 MHz bandwidth
--- same RF channel ---
P5G Interferer
n77 5G SA cell
PLMN 99901
3967.02 MHz
40 MHz bandwidth
Low gain
omni antenna
RF Jumpers
NW Etive
n77 radio unit
230VAC
NW Nessie
gNB/5GC
Fronthaul
Fibre
RF Jumpers
NW Etive
n77 radio unit
230VAC
NW Nessie
gNB/5GC
Fronthaul
Fibre

Co-Channel from 1.5km down to 500m

Location of fixed Primary Network

Starting Position of mobile "Interfering" Network

Define Test Network Parameters – Primary + Interferer

Parameter	Primary	Interferer
Antenna	n77 Sector, 65 Deg, 18dBi	n77 Sector, 65 Deg, 18dBi
Centre Frequency(MHz)	3,967	3,967
Bandwidth(MHz)	60	60
EIRP(dBm)	27	27
Frame Structure	Uplink Biased (2:7)	Downlink Biased(7:2)
Number of UEs	2	1

At around 800m (in this test!) all good, 1km no issues

- The graph below shows the Uplink and downlink MCS at 1km distance dropping to a low of ~5 as the Trike moved towards the primary cell down to 150m (unuseable).

Performance in Presence of High Power High Tower MNO

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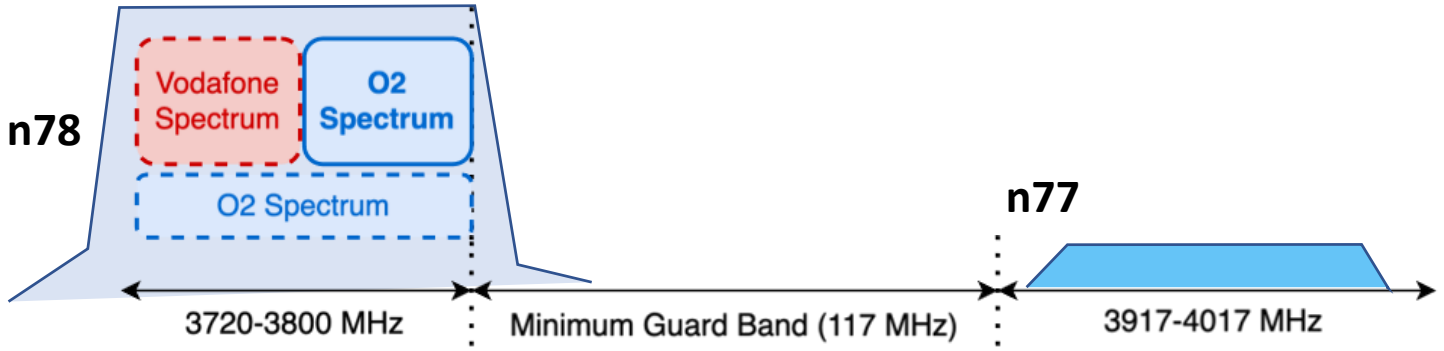
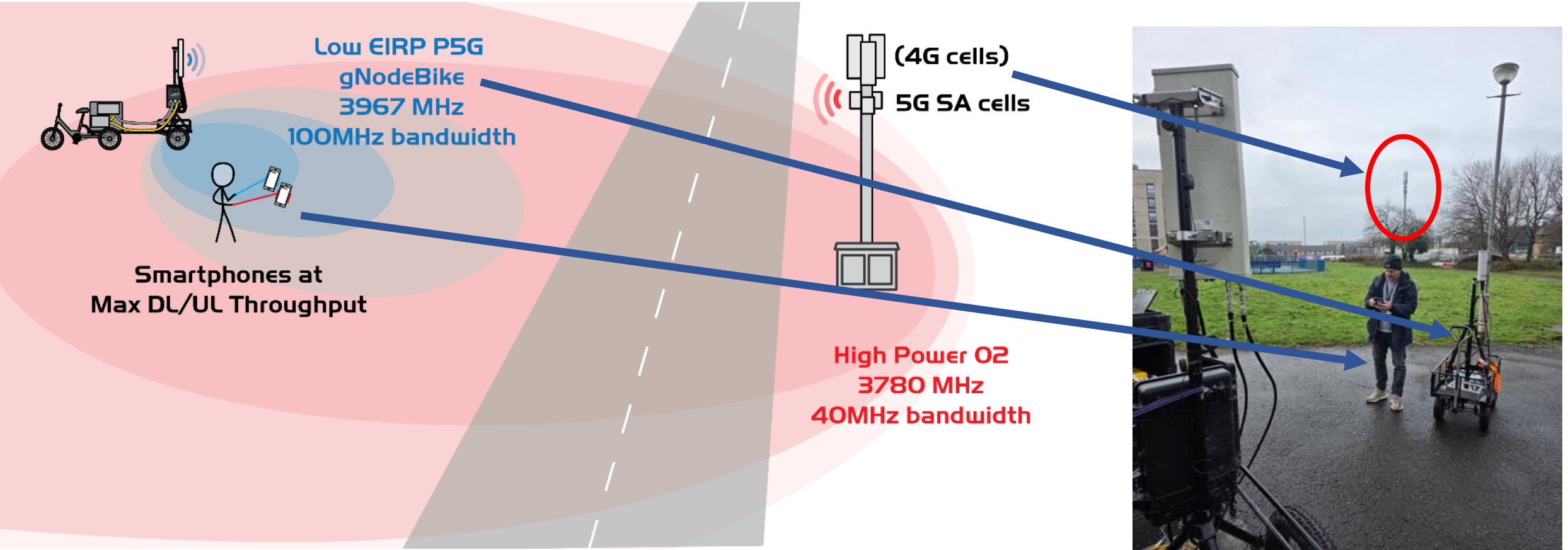
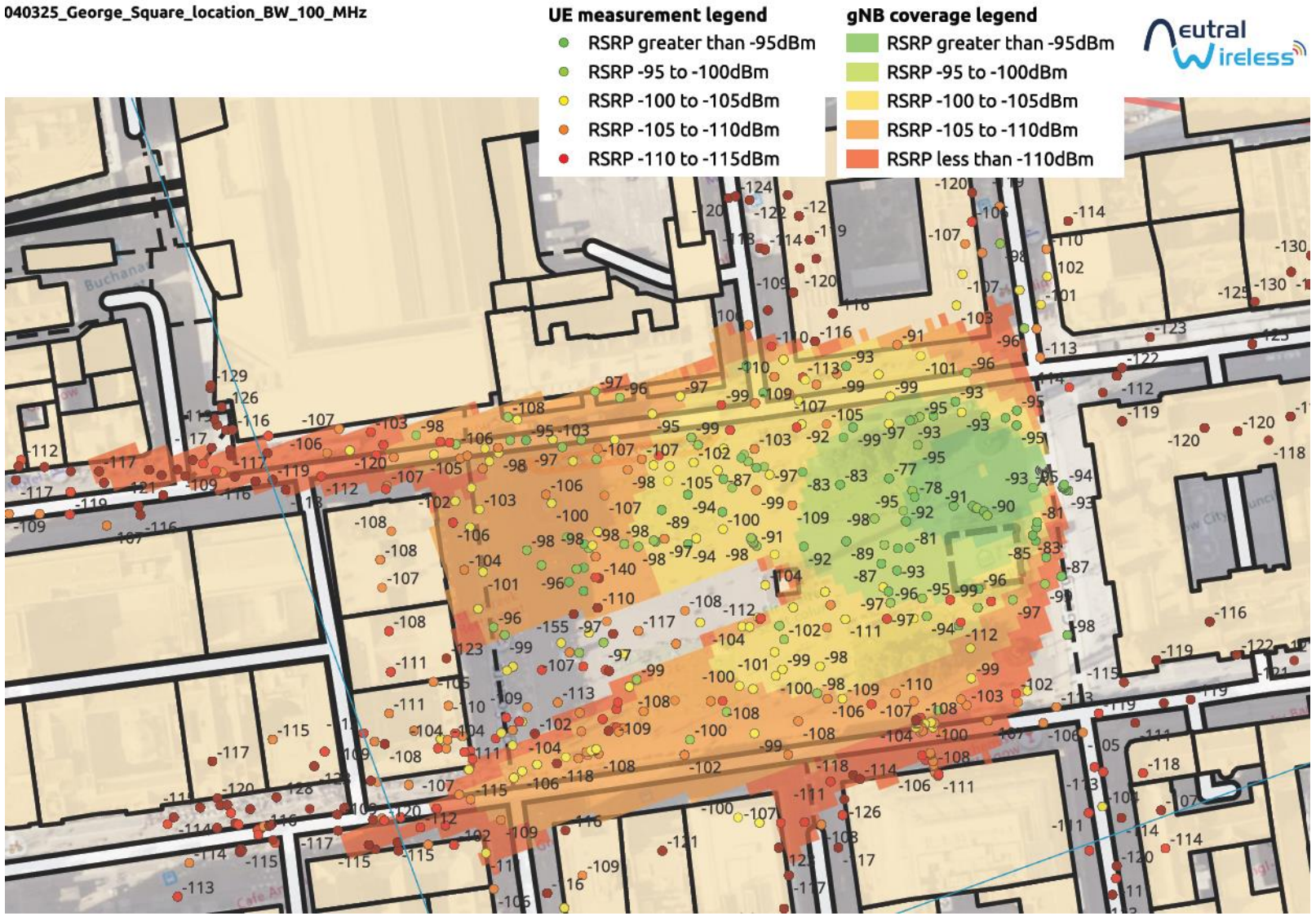
n77 in the Shadow of High Power High Tower (HPHT)



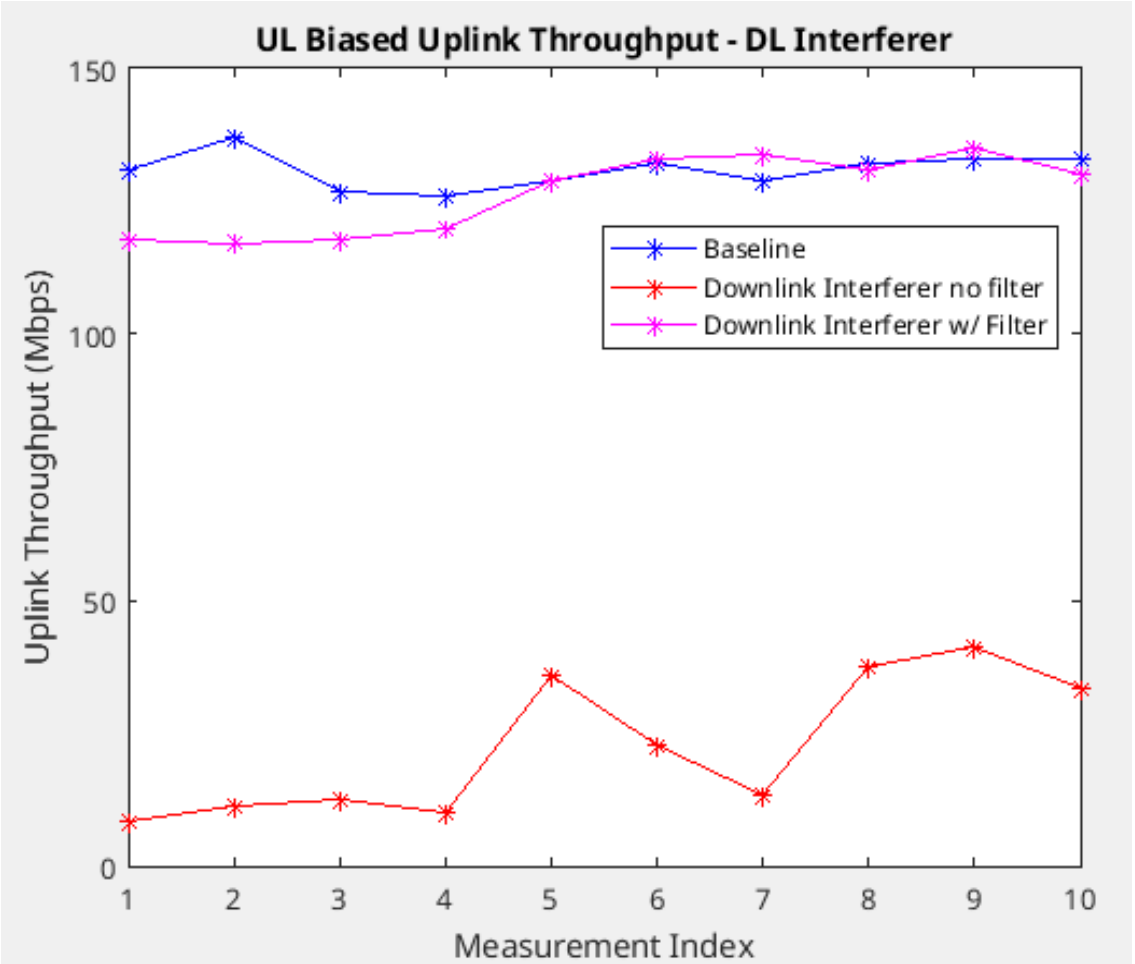


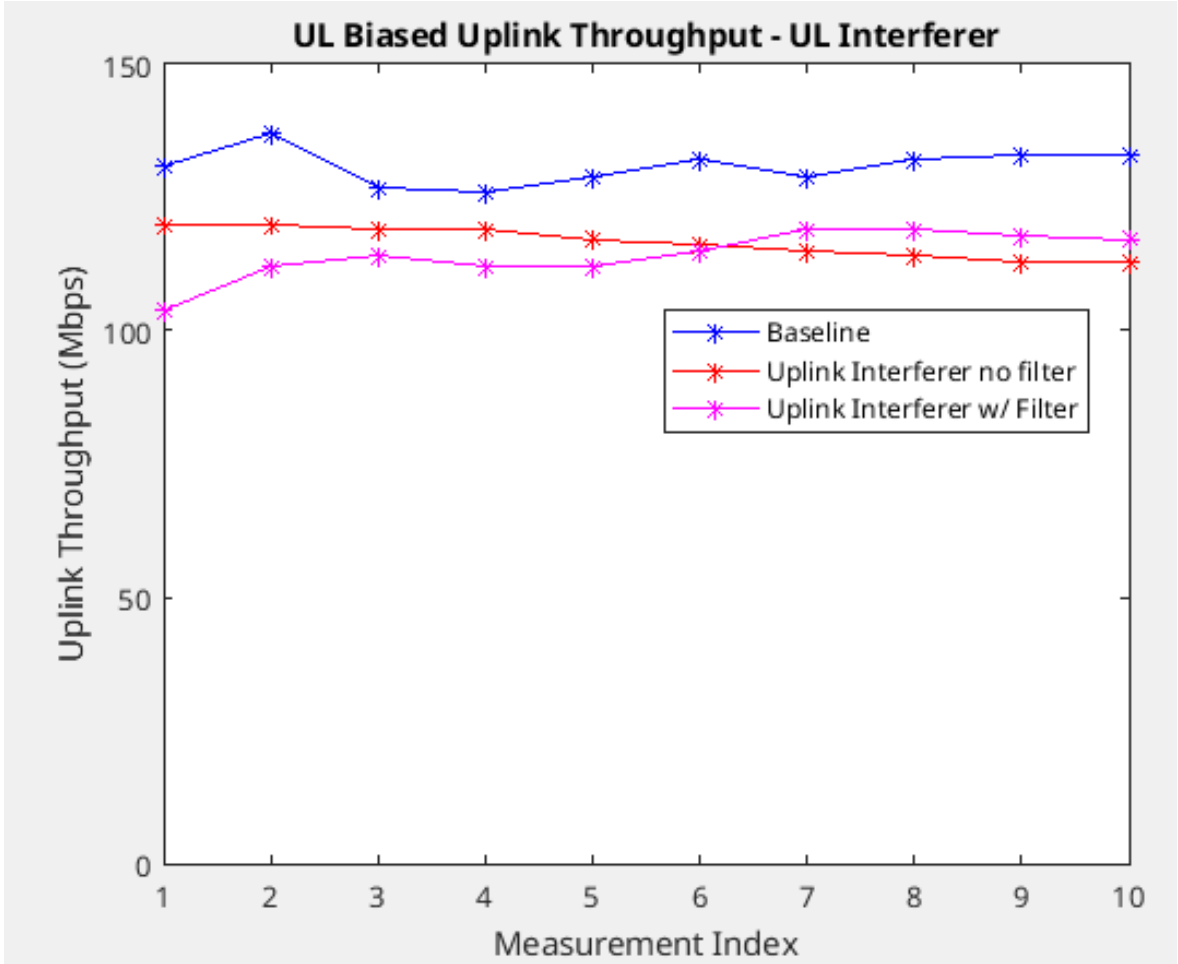
Operating In Proximity to MNO Neighbours

Operating In Proximity to MNO Neighbours



Filtering and Engineering to Operate Synchronised or unsynchronised





RF Modelling and Planning

Get the right model & verify

Terrain/Clutter vs 1m Lidar

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Neutral Wireless
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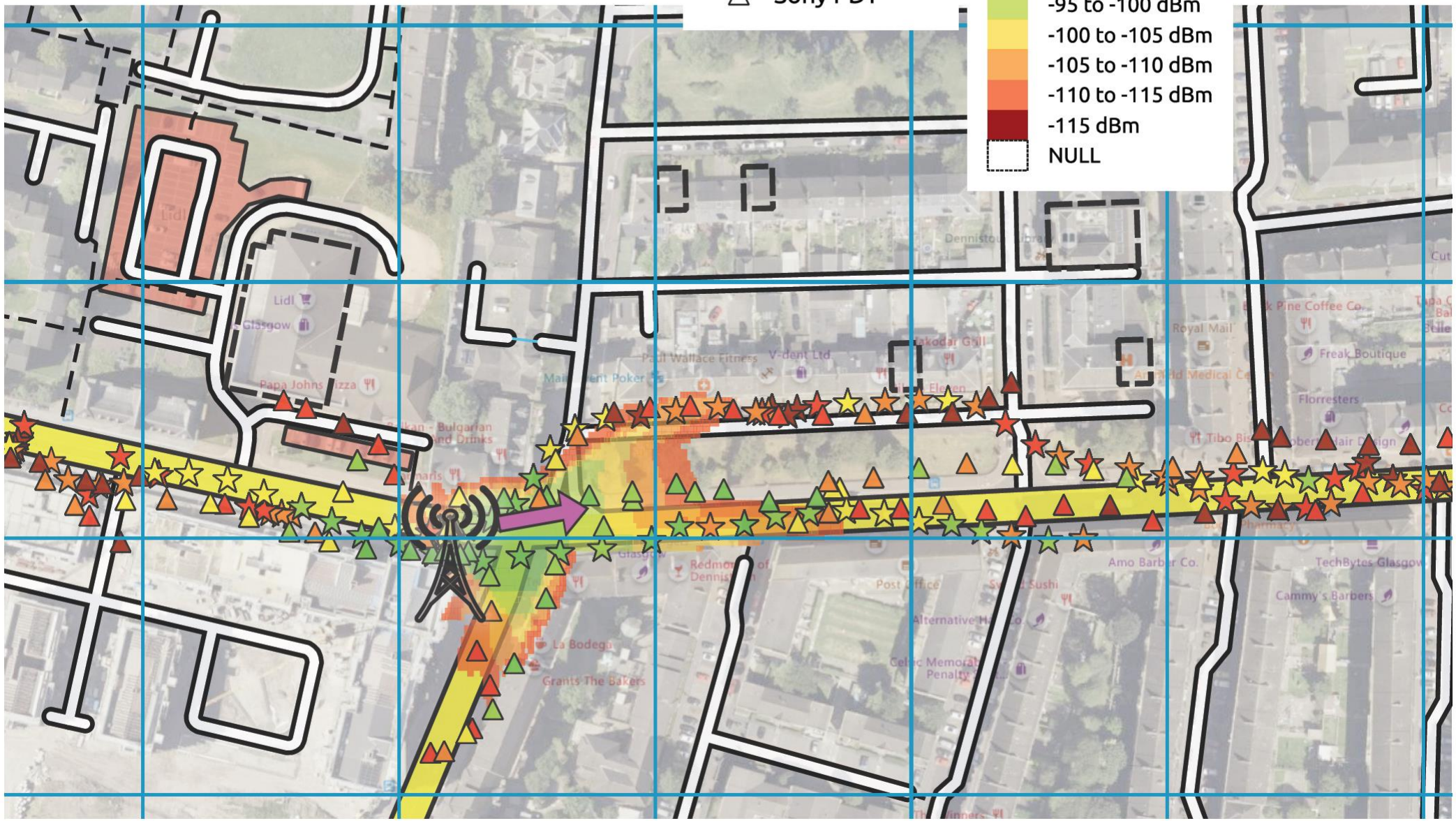
Each Test has a Key Parameter Set (KPS)

Centre Frequency	3967.02 MHz	Antenna Configuration	2x2 MIMO
Bandwidth	100 MHz	Antenna Model	Alpha Wireless AW3828 17.5 dBi Sector
Transmit Power	27 dBm (24 dBm per port)	Antenna Height	2.0 m
Antenna Latitude	55.861168°	Antenna Azimuth	278°
Antenna Longitude	-4.248787°	Antenna Tilt	0°
Environment Description	High clutter, dense urban environment. George Square is a semi-open concrete square surrounded by high buildings. A large amount of moving clutter from pedestrians and vehicle traffic.		

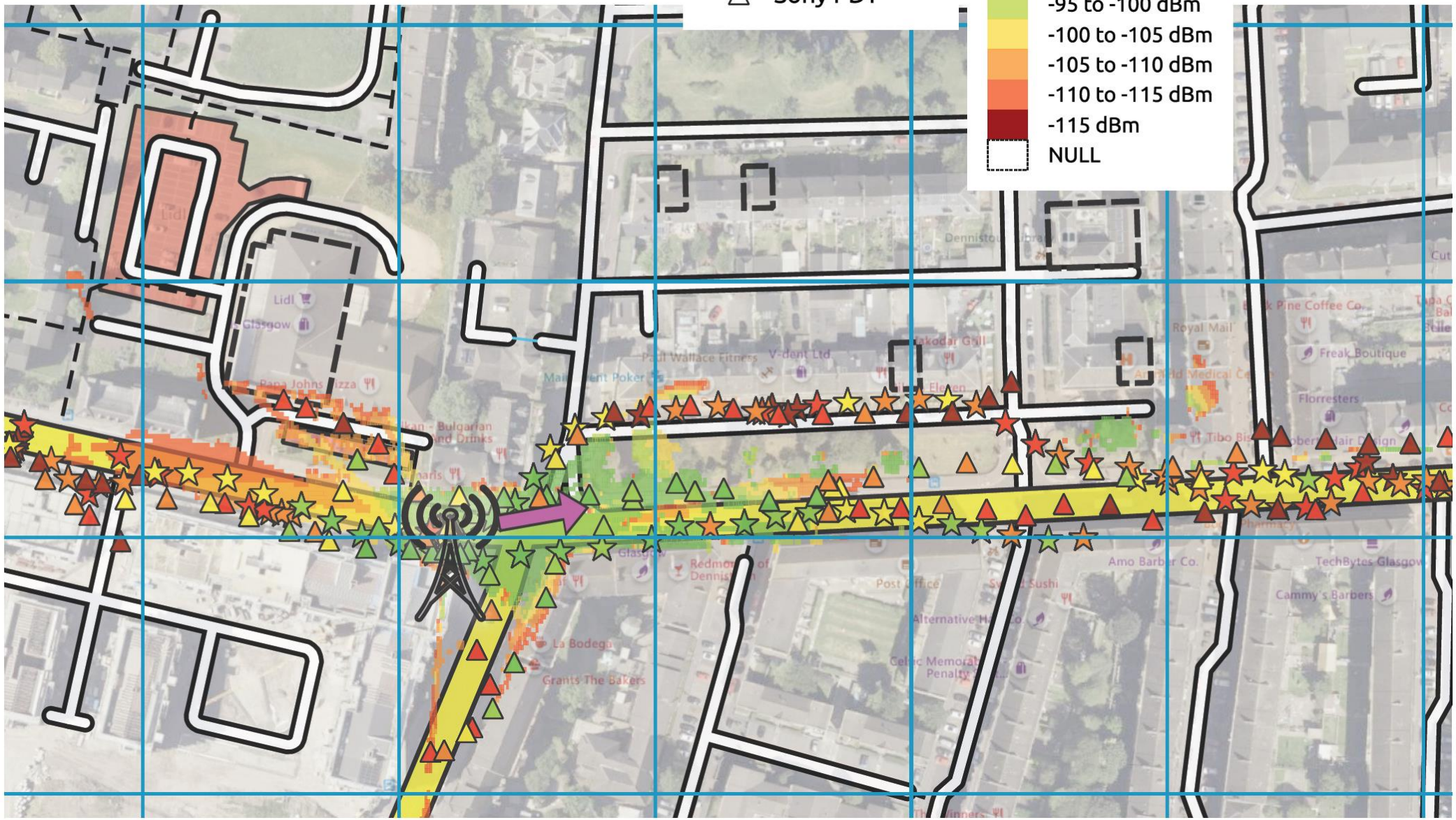
Propagation Models vs Real World Measurements
High clutter environment - Duke Street/ Bellgrove
gNodeBike EIRP 27dBm



Housing Area in East End

RF Model Terrain / Clutter model

Propagation Models vs Real World Measurements
High clutter environment - Duke Street/ Bellgrove
gNodeBike EIRP 27dBm



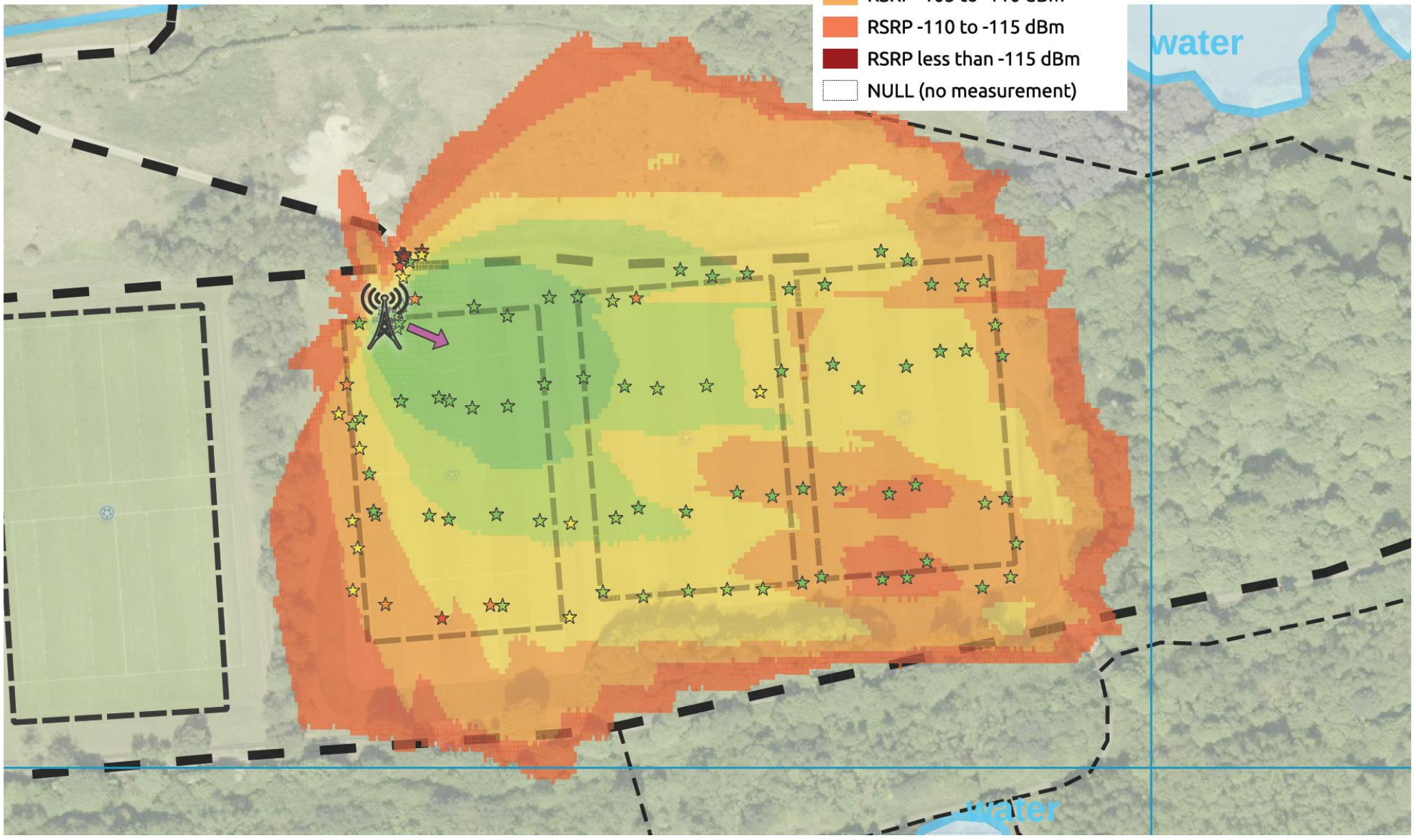
Housing Area in East End

RF Model 1 metre Lidar Model

Propagation Models vs Real World Measurements
Low clutter environment - Stepps
AW3828/AW3923 antenna
gNodeBike EIRP 27dBm

UE Icons
☆ Samsung S25U
△ Sony PDT

gNB Simulation/ UE Measurement
RSRP greater than -95 dBm
RSRP -95 to -100 dBm
RSRP -100 to -105 dBm
RSRP -105 to -110 dBm
RSRP -110 to -115 dBm
RSRP less than -115 dBm
NULL (no measurement)



Stepps Open and Flat Parkland Area

RF Model Terrain / Clutter Model

Propagation Models vs Real World Measurements
Low clutter environment - Stepps
AW3828/AW3923 antenna
gNodeBike EIRP 27dBm

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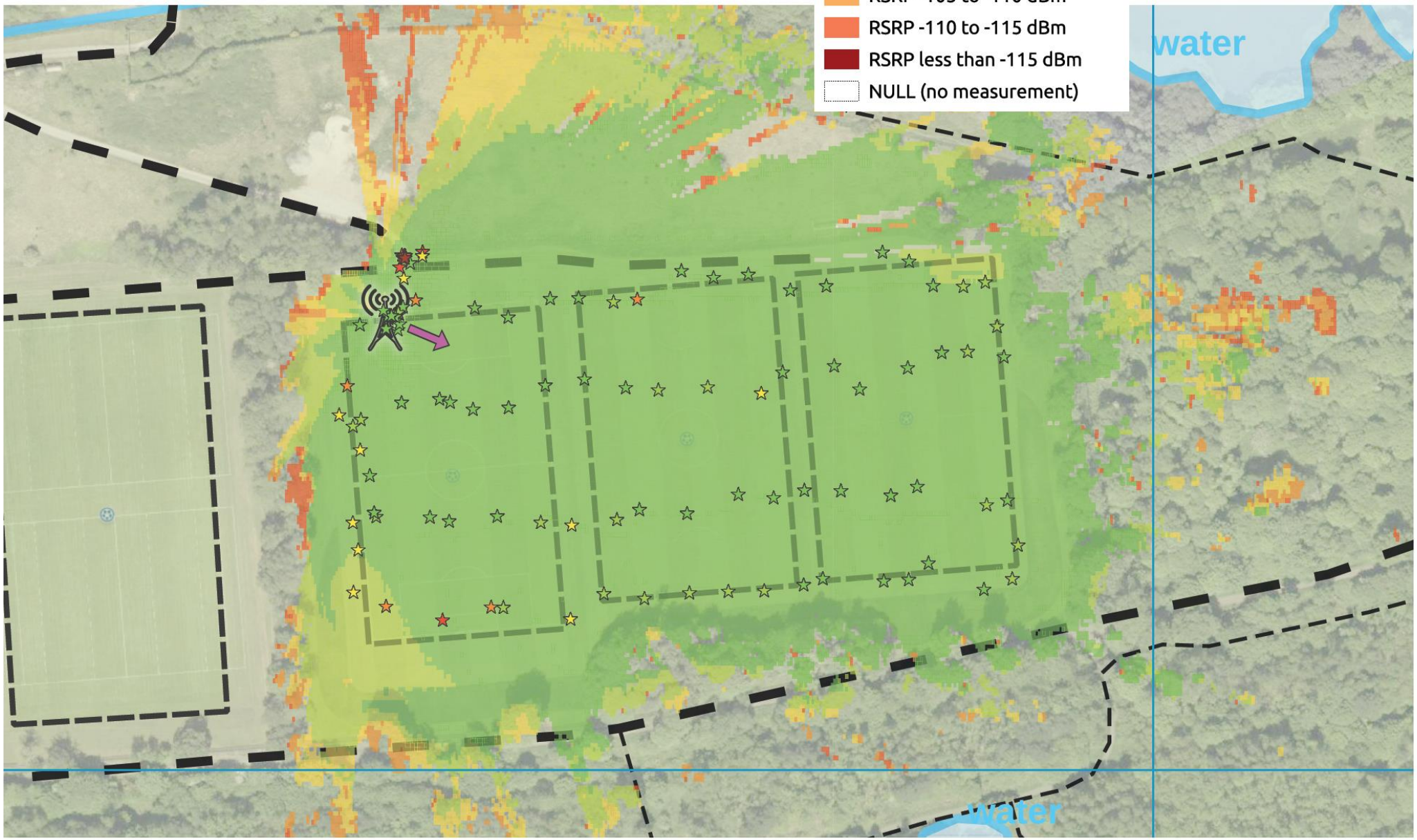

Stepps Open and Flat Parkland Area

RF Model 1 metre Lidar Model

Propagation Models vs Real World Measurements
High clutter environment - Duke Street/ Wellpark Brewery
gNodeBike EIRP 27dBm

UE Icons
☆ Samsung S25U
△ Sony PDT

gNB Simulation/ UE Measurement
- RSRP greater than -95 dBm
- RSRP -95 to -100 dBm
- RSRP -100 to -105 dBm
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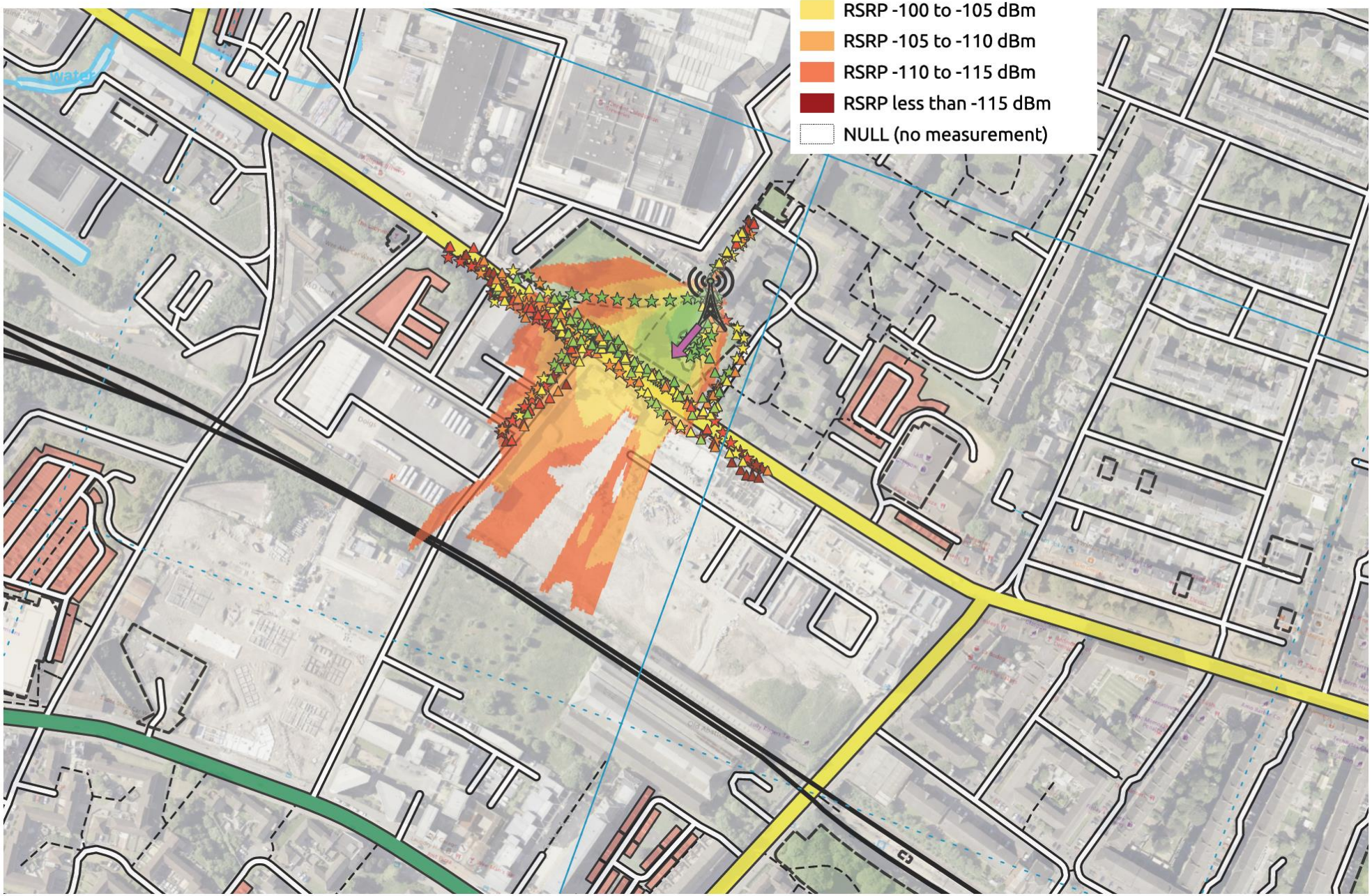

City scape and Main Road

RF Model Terrain / Clutter Model

Propagation Models vs Real World Measurements
High clutter environment - Duke Street/ Wellpark Brewery
gNodeBike EIRP 27dBm

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☆ Samsung S25U
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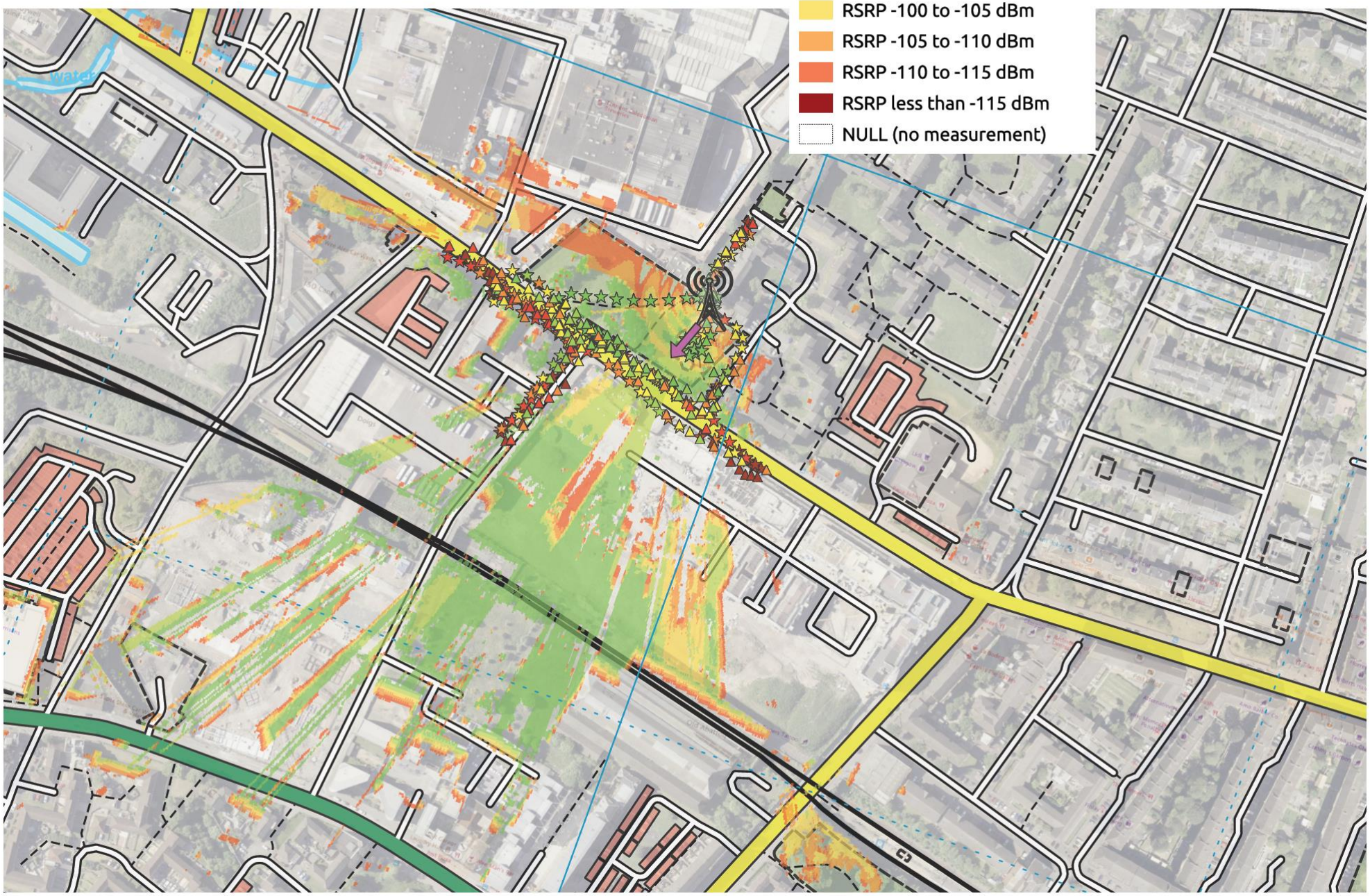

City scape and Main Road

RF Model 1 metre Lidar Model

Propagation Models vs Real World Measurements
Low clutter environment - Glasgow Green
AW3828/AW3923 antenna
gNodeBike EIRP 27dBm

UE measurement icons
☆ Samsung S25U
△ Sony PDT

gNB Simulation/ UE Measurement
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Glasgow Green River Parkway

RF Model Terrain / Clutter Model

Propagation Models vs Real World Measurements
Low clutter environment - Glasgow Green
AW3828/AW3923 antenna
gNodeBike EIRP 27dBm

UE measurement icons
☆ Samsung S25U
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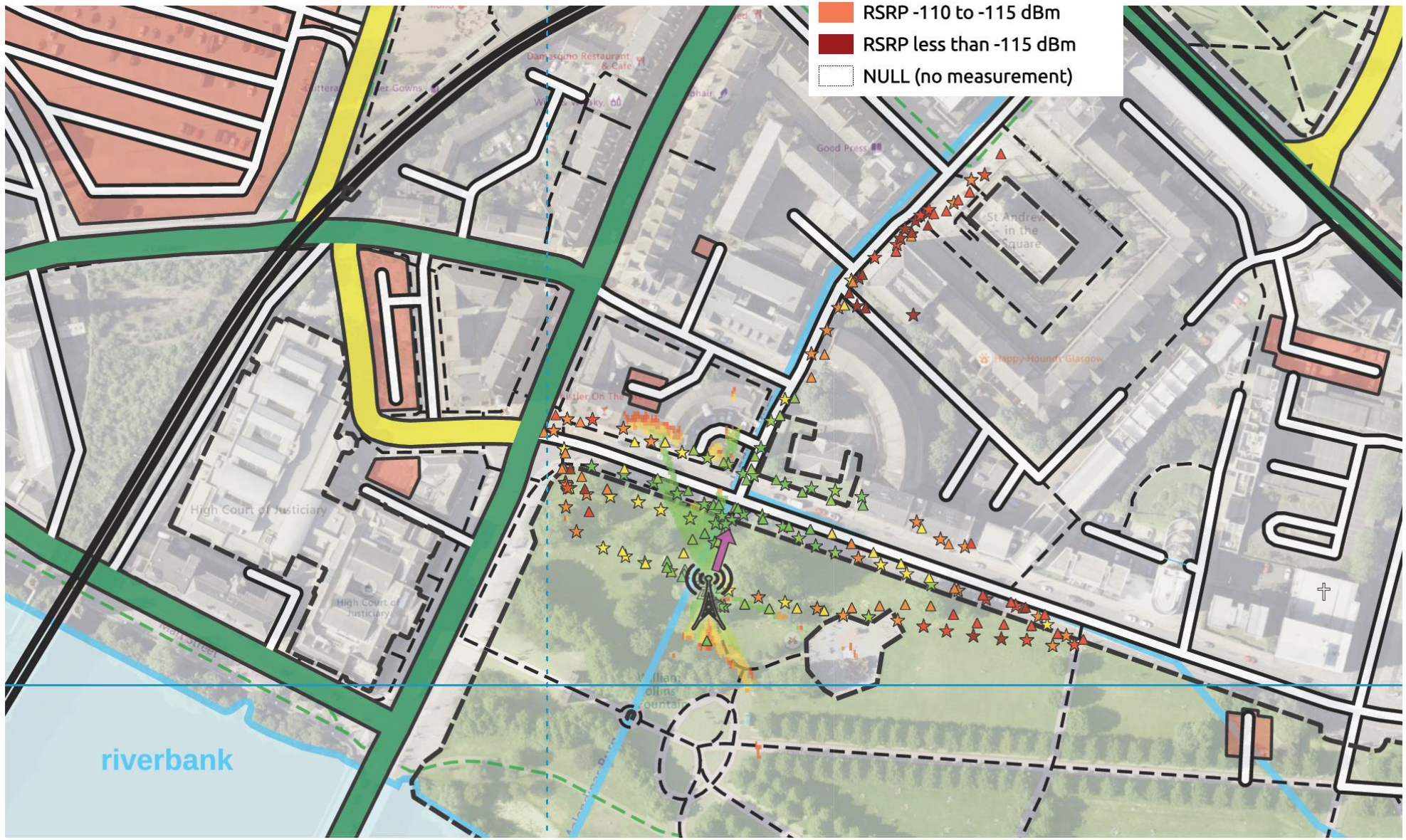

Glasgow Green River Parkway

RF Model 1 metre Lidar Model

Propagation Models vs Real World Measurements
High clutter environment - George Square
AW3828/AW3923 antenna
gNodeBike EIRP 27dBm

UE Icons
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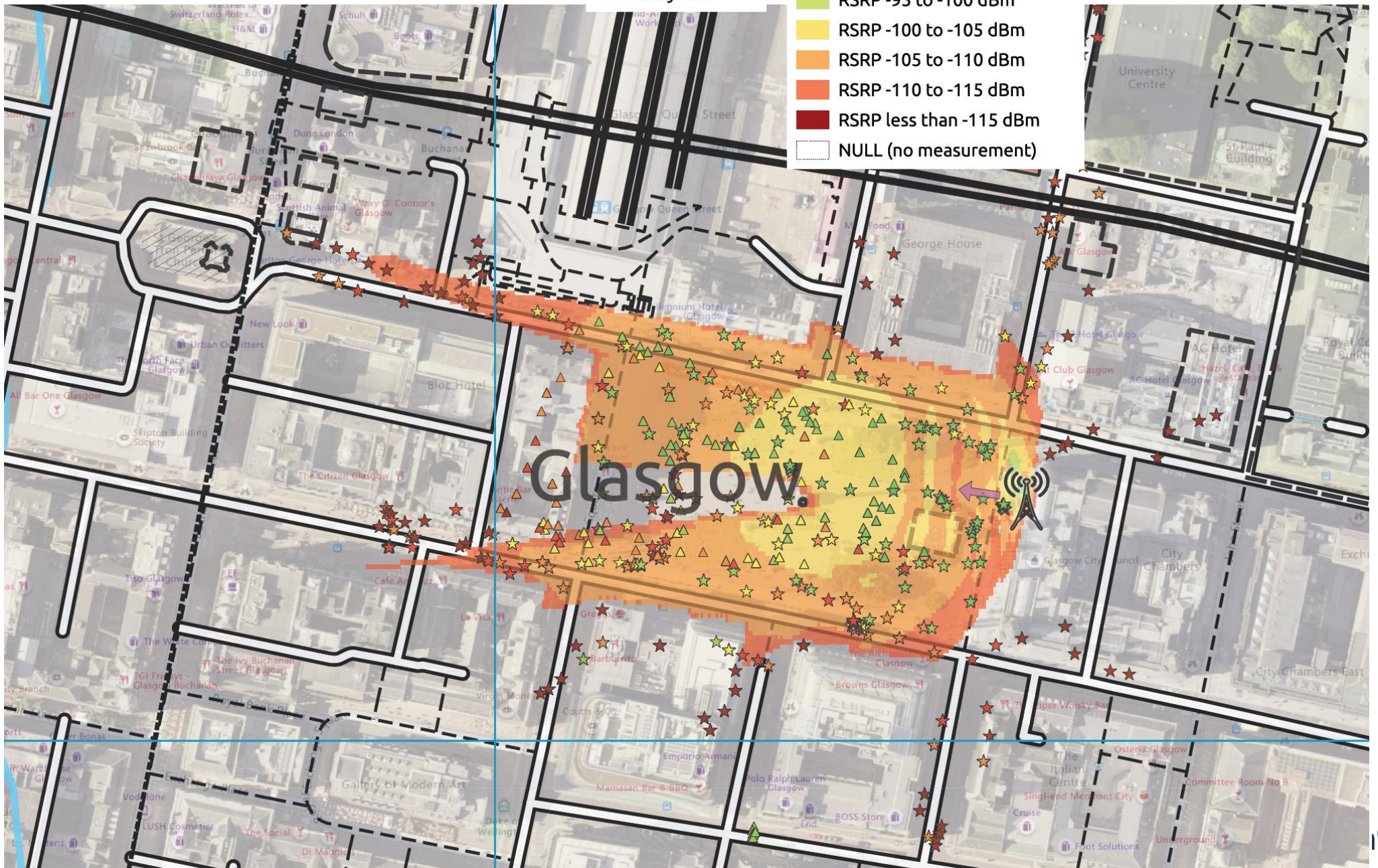

George Square City Centre

RF Model Terrain / Clutter Model

Propagation Models vs Real World Measurements
High clutter environment - George Square
AW3828/AW3923 antenna
gNodeBike EIRP 27dBm

George Square City Centre

RF Model 1 metre Lidar Model

Takeaway 1:

Know variability, performance, sensitivity, & parameters of:

- Radio front-end and antenna beam patterns
- 5G SA Radio Dynamic range on Tx and Rx
- Radio filtering stages (both analogue and SDR digital)
- RF Planning tools – use appropriate verifiable terrain models
- UE and modem performance varies
- Calibration is challenging - so many variables!

Takeaway 2:

Operable in High Power High Tower (HPHT) Environments

- Front end filtering and radio design will improve n77, less saturation
- Within a ‘few 100m’ 27dBm n77 operate effectively (power level dependent
- Front end filtering/screening will greatly enhance performance
- Different uplink/downlink (U/L) ratios – this is OK – engineer it!
- Unsynchronised – this is OK – engineer it!
- Synchronised TDD will always help, but not always essential

Takeaway 3:

Knowing performance: improve SAL & increase P5G use

- n77 complementary to public/MNO networks
- If MNO HPHT ‘nearby’, we can engineer networks to work
- n77 ‘whisper networks’ dont interfere with MNOs (by our measurements!)
- n77 networks can be more densely packed than currently
- In-band on-air spectrum monitoring is operable – bring on the AI.
- CEPT and their n77 mandate – don’t lose the UK lead in SAL!

Where is it all going?

Sprint test activity was to augment DSIT Sandboxes (Queen Mary, Durham, Real Wireless)

- **Adjacent channel n77 channel operation?** - *Yes, with think great options open*
- **Neighbouring cells on same n77 channel?** - *Yes, understanding options now*
- **Operating in presence of high-power/high-tower MNOs n78 -** *Excellent learnings*
- **For n77 managed sharing?** – *we think we need 'type approved' radios (ACLR etc).*
- **For rapid licensing, popup requests?** *Spectrum monitoring will be key.*
- **Filtering is important** – fixed deployments? Get that right and know the issues.
- **Whats next?** Ideally more extensive tests, integrate spectrum monitoring.
- **More when we have it!** - Continued testing in Extension period, April to June 2025


Thank You
Please join us on the Glasgow Testbed!
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Neutral Wireless
spectrum. unleashed.

ON SIDE

6GHz ‘Sharing’

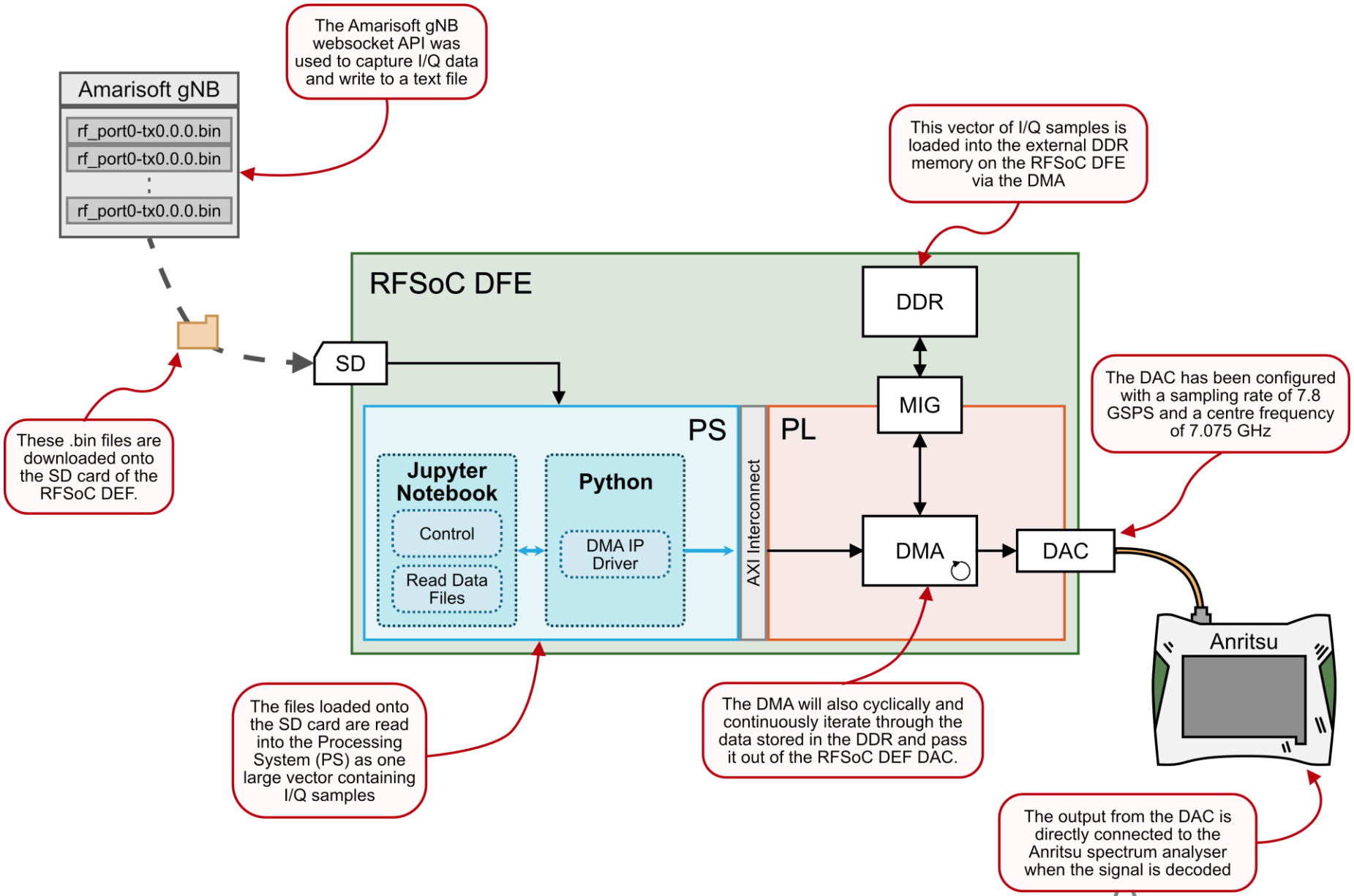
Building a 5G SA Testrig on AMD RFSoC

Developing the 6GHz Ecosystem - Overview

The aim of this 6GHz work was to determine if the RFSoC DFE board was able to transmit a 5G downlink signal in the 6GHz band and it be decoded by an Anritsu Spectrum Analyser.

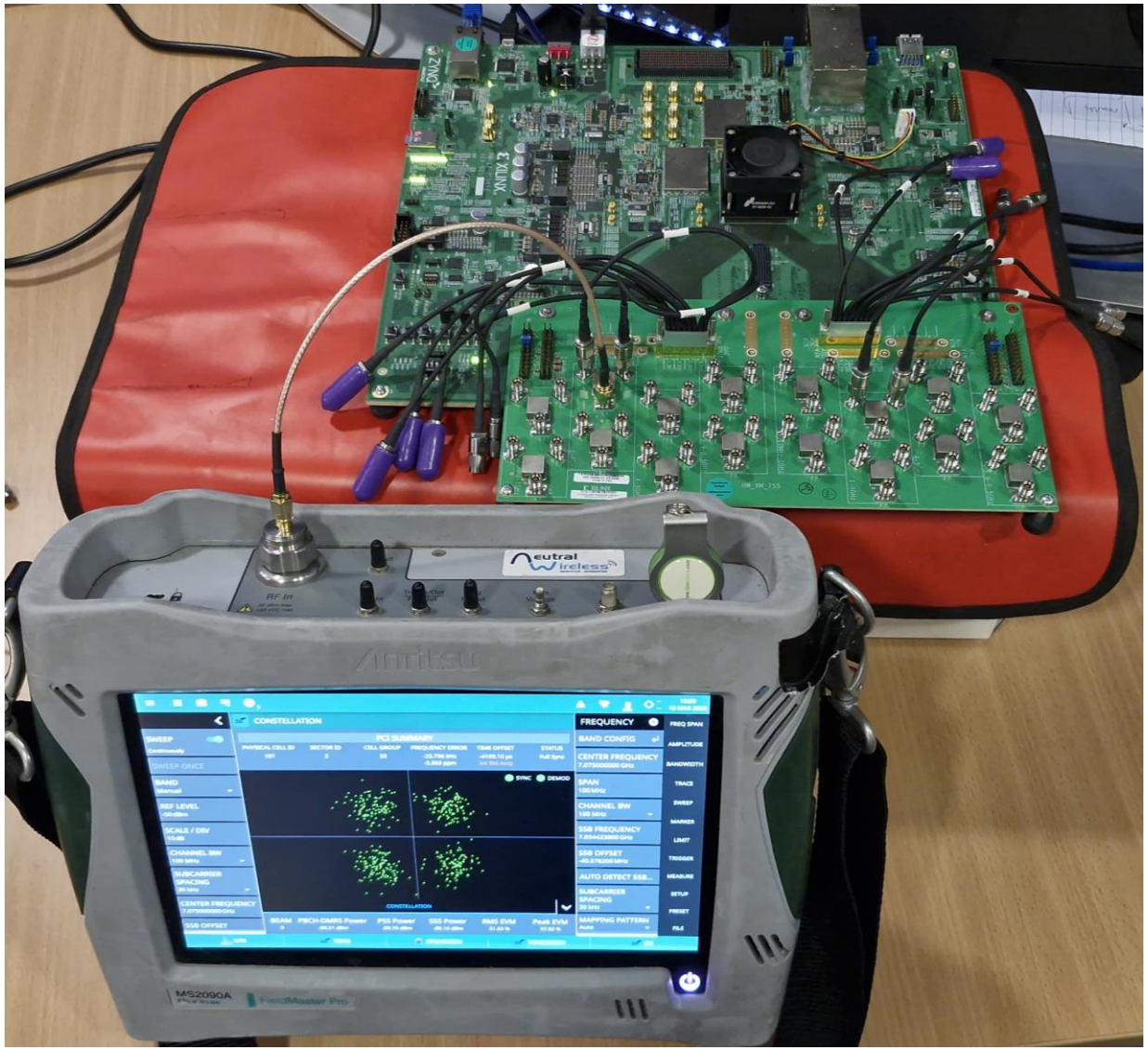
- Using the gNB websocket API, two frames of a 5G downlink signal were written to text files.
- These signals contained the SSB and the SIB1.
- These files were downloaded onto the RFSoC DFE board and stored onto the DDR memory.
- This data was then continuously looped out of the RFSoC DFE DAC.
- The DAC was sampled at 7.8 GSPS with a centre frequency of 7.075 GHz.
- The output of the DAC was then connected to the Anritsu Spectrum Analyser.
- The Anritsu was able to sync to the 5G signal and produce a constellation diagram.

6GHz Block Diagram



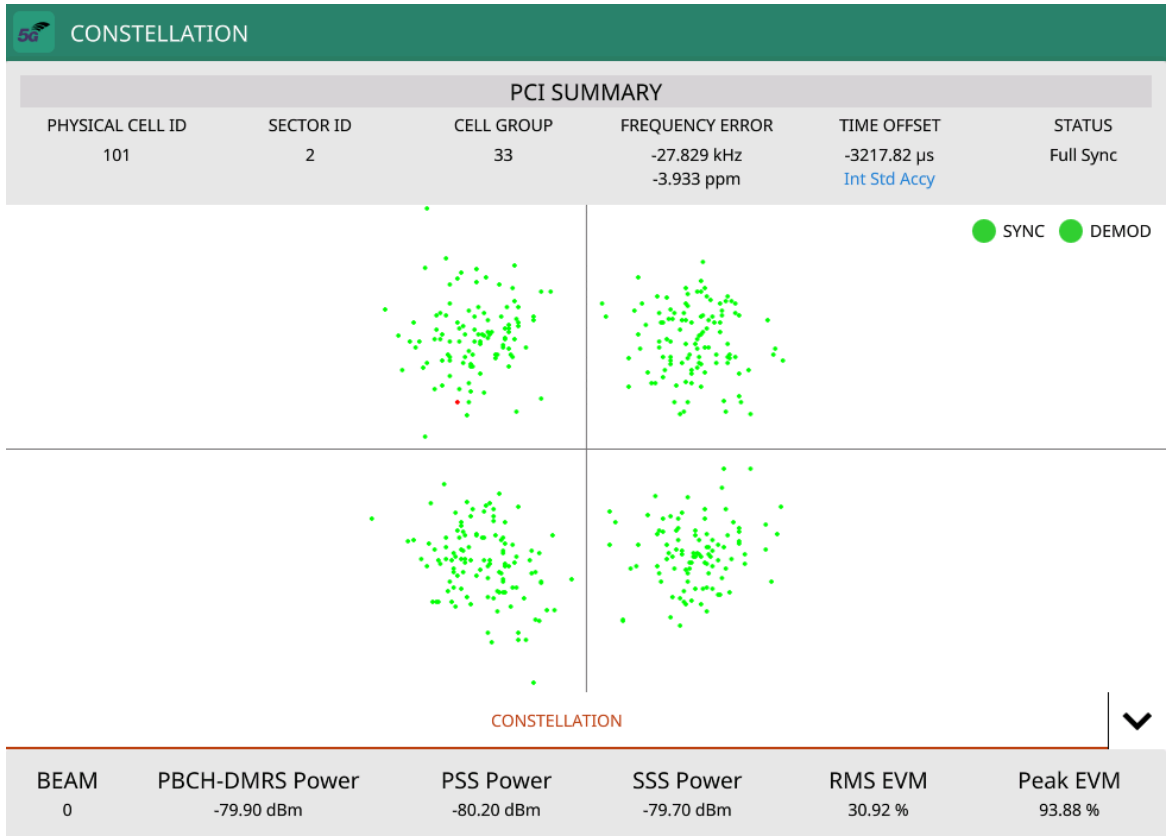
6GHz Practical Setup

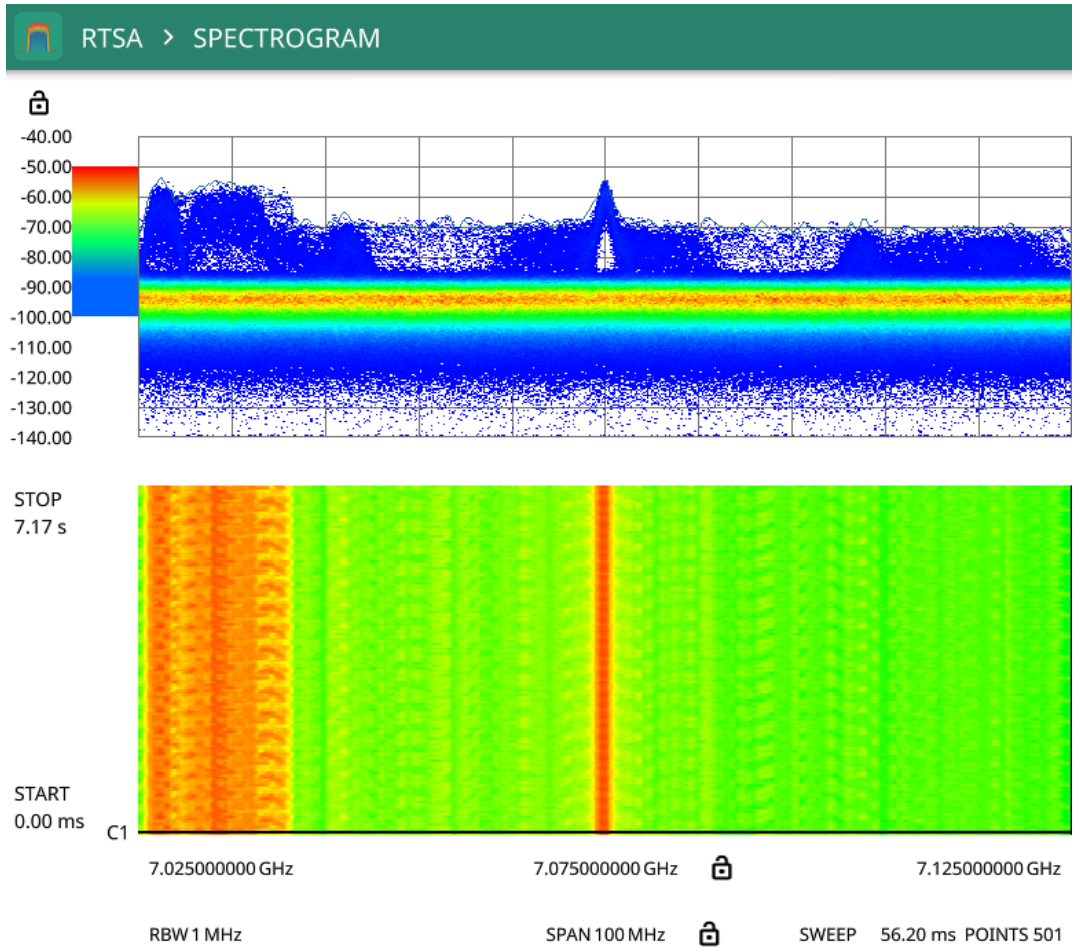
- This image shows the RFSoC DFE board connected to the Anritsu Spectrum Analyser via an SMA cable.
- The RFSoC DFE is looping through 2 frames of a 5G downlink signal generated from an Amarisoft gNB.
- The RF DAC is centred at 7.075GHz.
- The 5G downlink signal is a 100 MHz signal which is sitting at the upper most end of the 6G band.
- The Anritsu is able to lock onto the SSB of the 5G signal and produce a constellation diagram.



6GHz Anritsu Sync

The Anritsu was able to sync to the 5G downlink signal output from the RFSoC DFE with a centre frequency of 7.075 GHz and produce a constellation diagram.





Outline Agenda: n77 Private 5G (P5G) Networks

- **The Background** stages to be ready for n77 Testing/Sandbox
  - Operative, Performative, Qualitative to Quantitative (Sandbox)
- **Validation** of RF Modelling with Real-World Measurements
- **Live n77 testing** and analysis with Onside
- Distances: **Frequency reuse** and interference
- P5G operation with **Adjacent Operating Channels**
- P5G operation when close to n78 **MNO Neighbours**
- **Preliminary Conclusions** (Takeaways!)
- Developing the **6 GHz Ecosystem** (slides only)