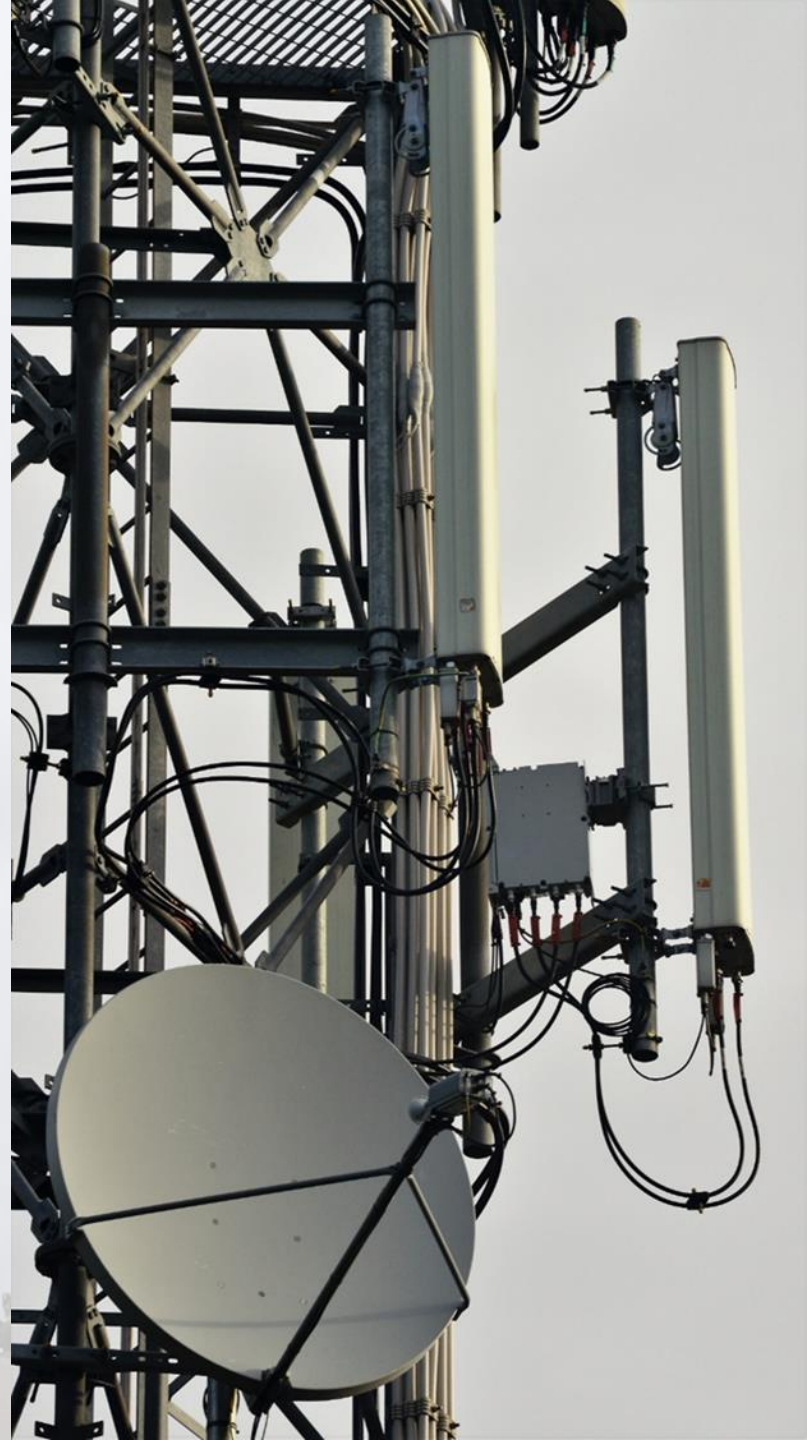
Commercial EMS Usage and optimisation

Maj Andy Sutton
SO2 Tech Futures
254 (SGIS) Signal Squadron

ROYAL SIGNALS INSTITUTION

Contents

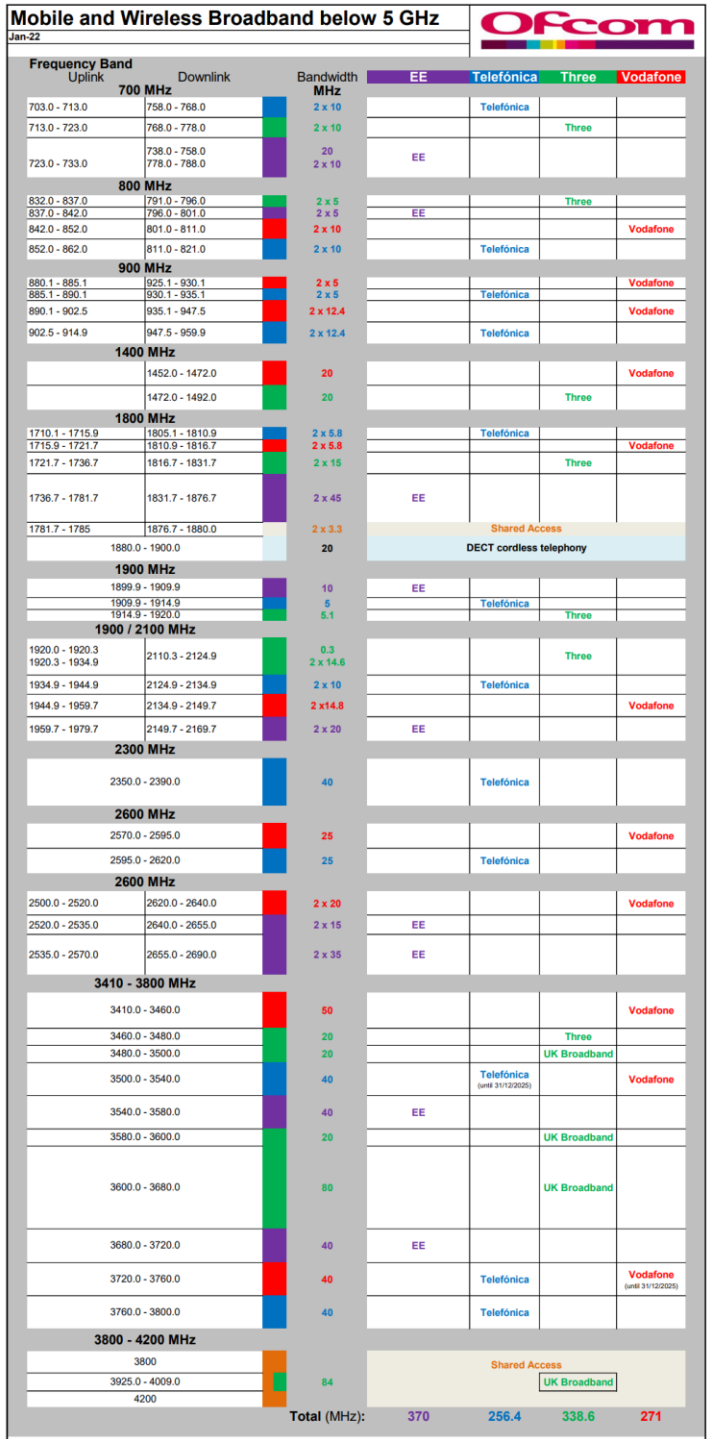
- Cellular (mobile) radio access networks
- Mobile frequency bands
- Mobile network engineering
- Radio coverage and propagation
  - Rural example
  - Urban example
  - Semi-rural example
- Spectrum for private 5G networks
- WiFi spectrum and evolution
- Satellite communications
- WiGig and V-band
- Deployable COTS based solutions
- Summary



Radio Access Network - RAN

- Radio base station known as a gNB
- UK public mobile network spectrum is available in the following frequency bands:
  - 700 MHz (FDD & SDL)
  - 800 MHz (FDD)
  - 900 MHz (FDD)
  - 1400 MHz (SDL)
  - 1800 MHz (FDD)
  - 2100 MHz (FDD)
  - 2300 MHz (TDD)
  - 2600 MHz (FDD & TDD)
  - 3600 MHz (TDD)
  - Future 26 GHz (TDD)
  - Future 40 GHz (TDD)
- A wide range of antenna systems are available, including massive MIMO

Mobile and Wireless Broadband below 5 GHz



Mobile and Wireless Broadband below 5 GHz

Jan-22

Ofcom

Frequency Band Uplink	Frequency Band Downlink	Bandwidth MHz	EE	Telefónica	Three	Vodafone
700 MHz						
703.0 - 713.0	758.0 - 768.0	2 x 10		Telefónica		
713.0 - 723.0	768.0 - 778.0	2 x 10			Three	
723.0 - 733.0	738.0 - 758.0 778.0 - 788.0	20 2 x 10	EE			
800 MHz						
832.0 - 837.0	791.0 - 796.0	2 x 5			Three	
837.0 - 842.0	796.0 - 801.0	2 x 5	EE			
842.0 - 852.0	801.0 - 811.0	2 x 10				Vodafone
852.0 - 862.0	811.0 - 821.0	2 x 10		Telefónica		
900 MHz						
880.1 - 885.1	925.1 - 930.1	2 x 5				Vodafone
885.1 - 890.1	930.1 - 935.1	2 x 5		Telefónica		
890.1 - 902.5	935.1 - 947.5	2 x 12.4				Vodafone
902.5 - 914.9	947.5 - 959.9	2 x 12.4		Telefónica		
1400 MHz						
	1452.0 - 1472.0	20				Vodafone
	1472.0 - 1492.0	20			Three	
1800 MHz						
1710.1 - 1715.9	1805.1 - 1810.9	2 x 5.8		Telefónica		
1715.9 - 1721.7	1810.9 - 1816.7	2 x 5.8				Vodafone
1721.7 - 1736.7	1816.7 - 1831.7	2 x 15			Three	
1736.7 - 1781.7	1831.7 - 1876.7	2 x 45	EE			
1781.7 - 1785	1876.7 - 1880.0	2 x 3.3	Shared Access			
1880.0 - 1900.0		20	DECT cordless telephony			
1900 MHz						
1899.9 - 1909.9		10	EE			
1909.9 - 1914.9		5		Telefónica		
1914.9 - 1920.0		5.1			Three	
1900 / 2100 MHz						
1920.0 - 1920.3 1920.3 - 1934.9	2110.3 - 2124.9	0.3 2 x 14.6			Three	
1934.9 - 1944.9	2124.9 - 2134.9	2 x 10		Telefónica		
1944.9 - 1959.7	2134.9 - 2149.7	2 x14.8				Vodafone
1959.7 - 1979.7	2149.7 - 2169.7	2 x 20	EE			
2300 MHz						
2350.0 - 2390.0		40		Telefónica		
2600 MHz						
2570.0 - 2595.0		25				Vodafone
2595.0 - 2620.0		25		Telefónica		
2600 MHz						
2500.0 - 2520.0	2620.0 - 2640.0	2 x 20				Vodafone
2520.0 - 2535.0	2640.0 - 2655.0	2 x 15	EE			
2535.0 - 2570.0	2655.0 - 2690.0	2 x 35	EE			
3410 - 3800 MHz						
3410.0 - 3460.0		50				Vodafone
3460.0 - 3480.0		20			Three	
3480.0 - 3500.0		20			UK Broadband	
3500.0 - 3540.0		40		Telefónica (until 31/12/2025)		Vodafone
3540.0 - 3580.0		40	EE			
3580.0 - 3600.0		20			UK Broadband	
3600.0 - 3680.0		80			UK Broadband	
3680.0 - 3720.0		40	EE			
3720.0 - 3760.0		40		Telefónica		Vodafone (until 31/12/2025)
3760.0 - 3800.0		40		Telefónica		
3800 - 4200 MHz						
3800			Shared Access			
3925.0 - 4009.0		84			UK Broadband	
4200						
		Total (MHz):	370	256.4	338.6	271

Source: Ofcom

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3800 3925.0 - 4009.0 4200		84	Shared Access		UK Broadband	
Total (MHz):			370	256.4	338.6	271

Source: Ofcom

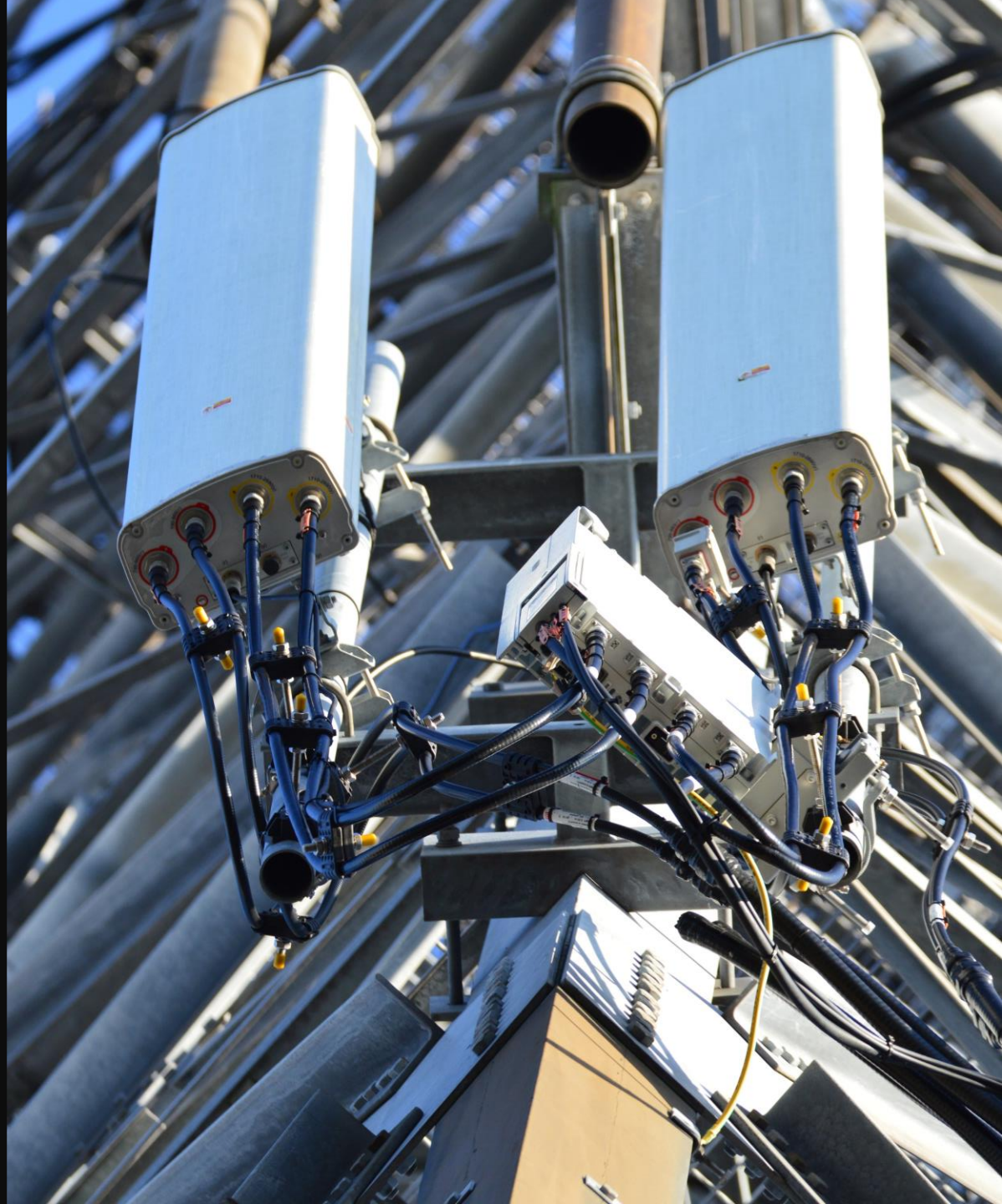
Cellular (mobile) radio interface - air interface

- The connection between the network and your device is known as the downlink
- The connection between your device and the network is known as the uplink

- The duplex mode of transmission and reception are:

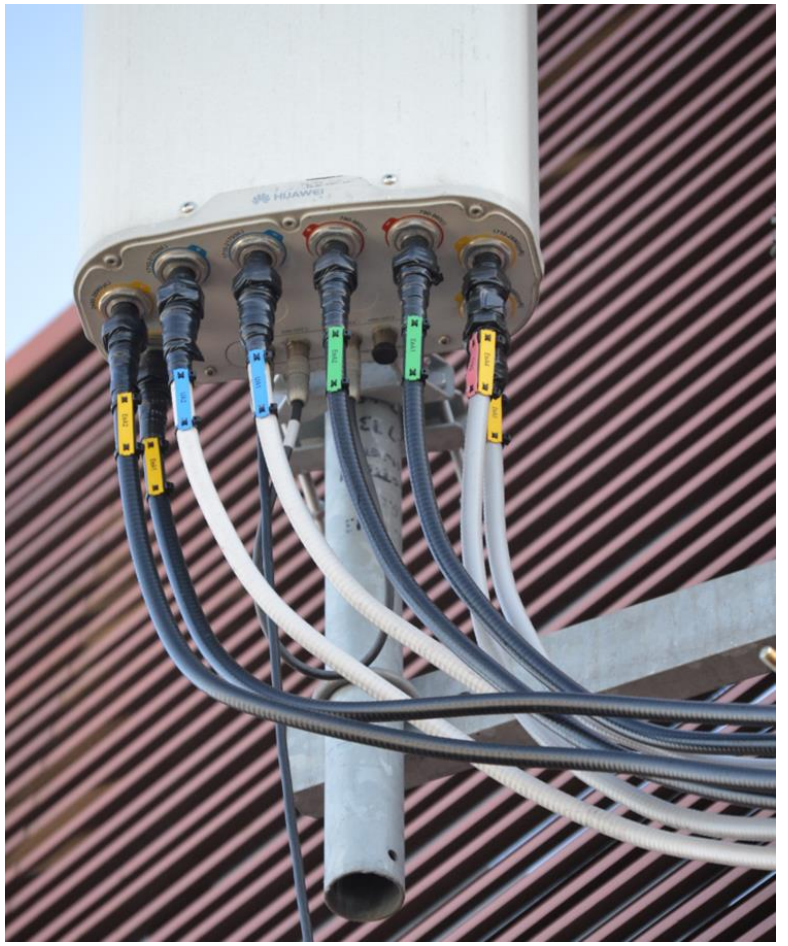
  - Frequency Division Multiplexing (FDD)
  - Time Division Multiplexing (TDD)

- Carrier Aggregation enables a device to connect to multiple RF carriers simultaneously for enhanced throughput and performance



Multi-radio access technology RF site design

- Cell sites support multiple radio access technologies across multiple frequency bands
- There are many complex antenna and transmission line arrangements
- A range of combiners/diplexers and mast head low noise amplifiers are deployed
- The majority of antennas are cross-polarised, +/- 45°slant polarised arrays
- Radios can be ground mounted or remote radio units which are located closer to the antenna, active antennas are available too
- Coaxial cables, fibre optic cables and DC power cabling required on the structure



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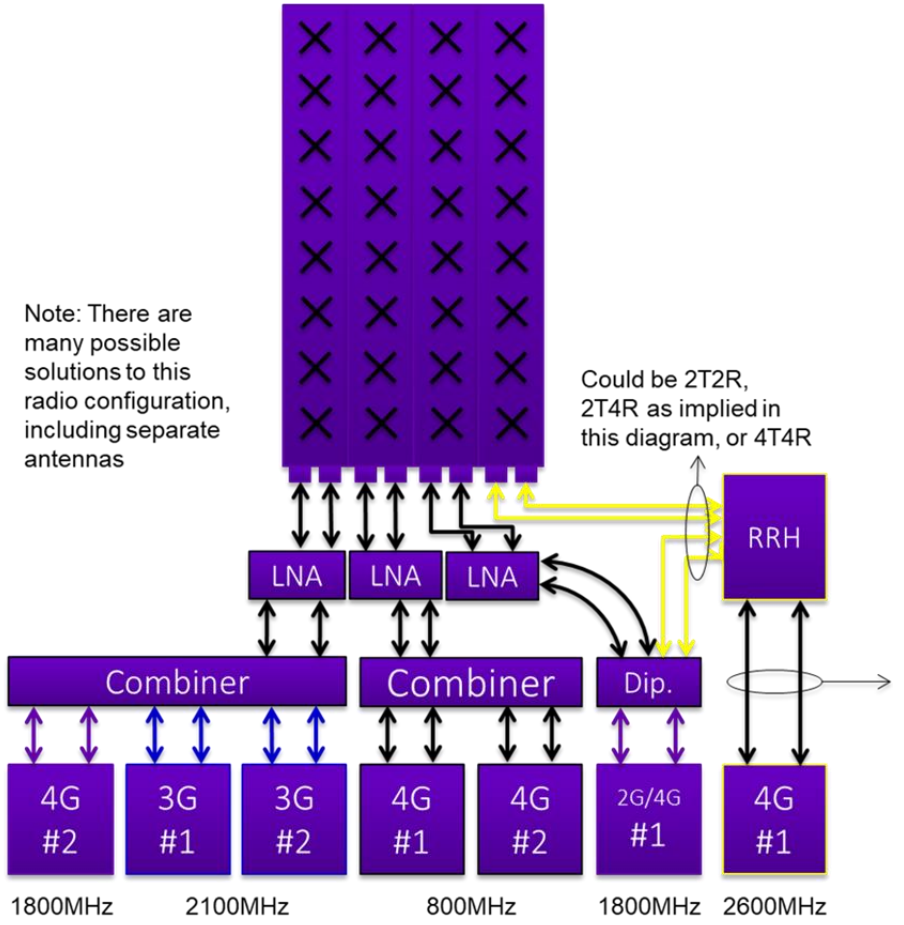
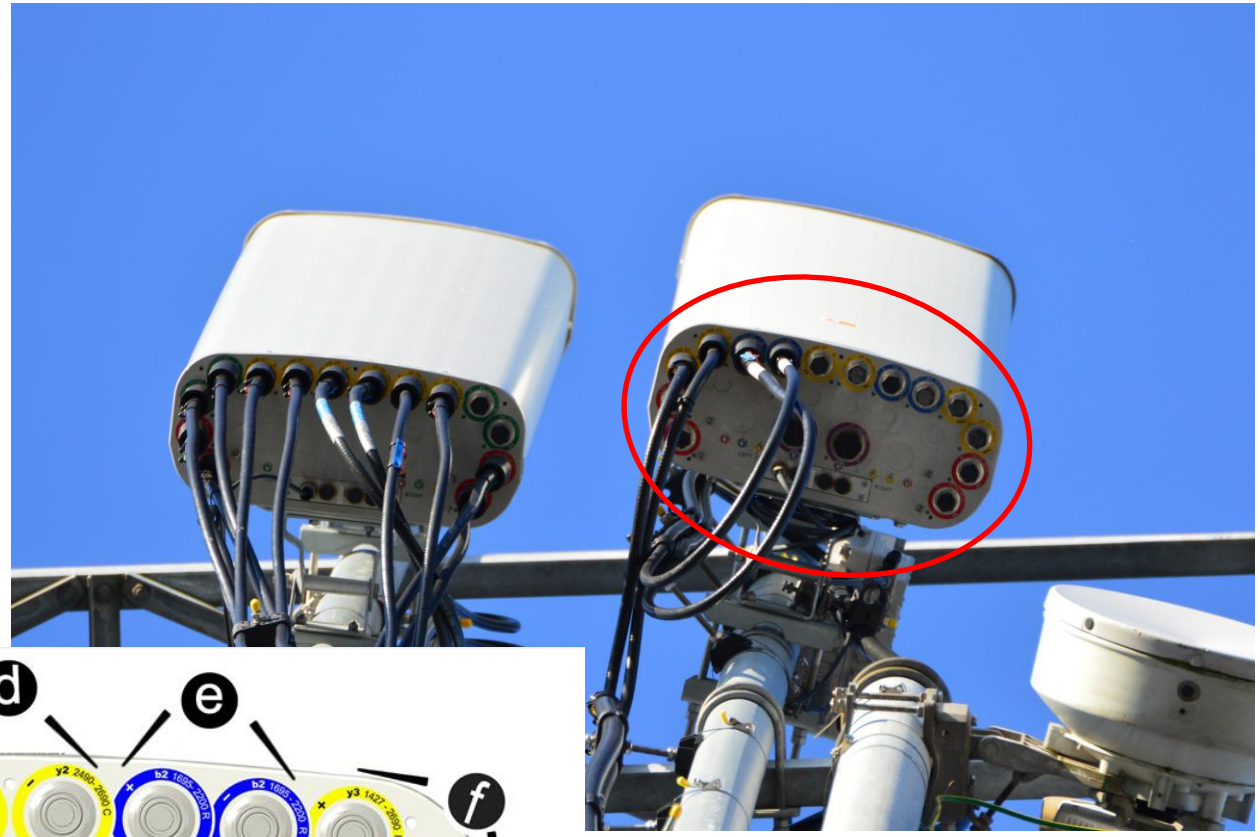
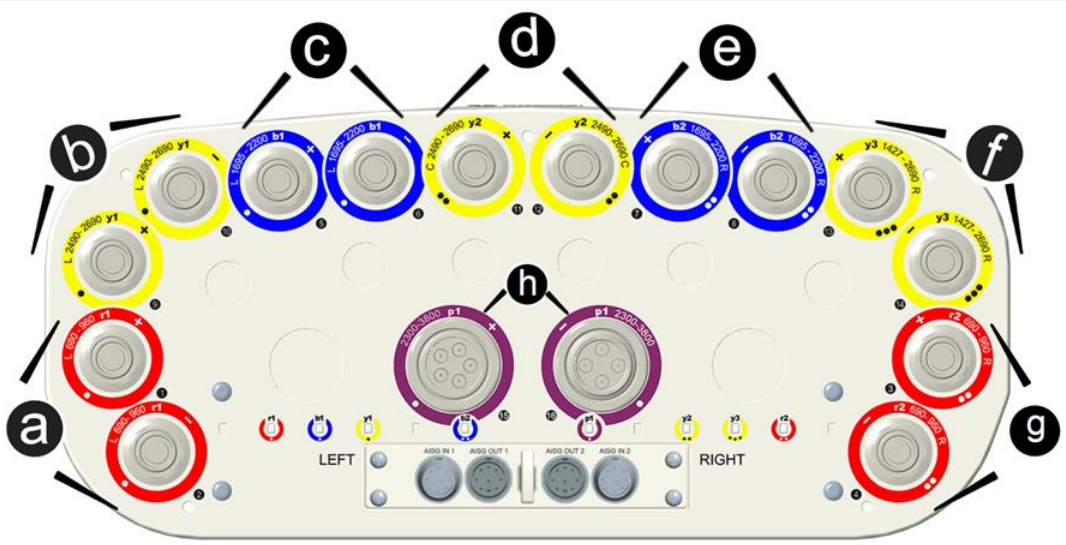


Multi-band antenna system

- Support for the following bands:

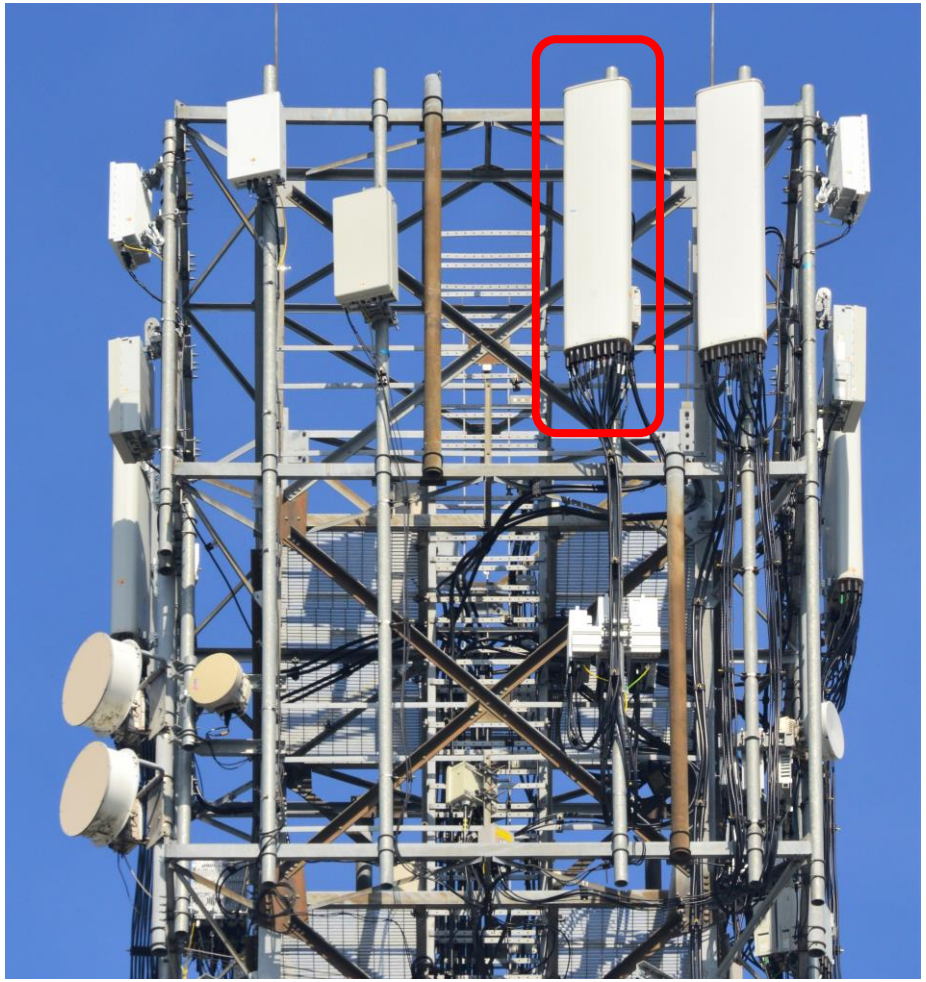
- 700 MHz
- 800 MHZ
- 900 MHz
- 1400 MHz
- 1800 MHz
- 2100 MHz
- 2300 MHz
- 2600 MHz
- 3500 MHz*
- 3700 MHz*

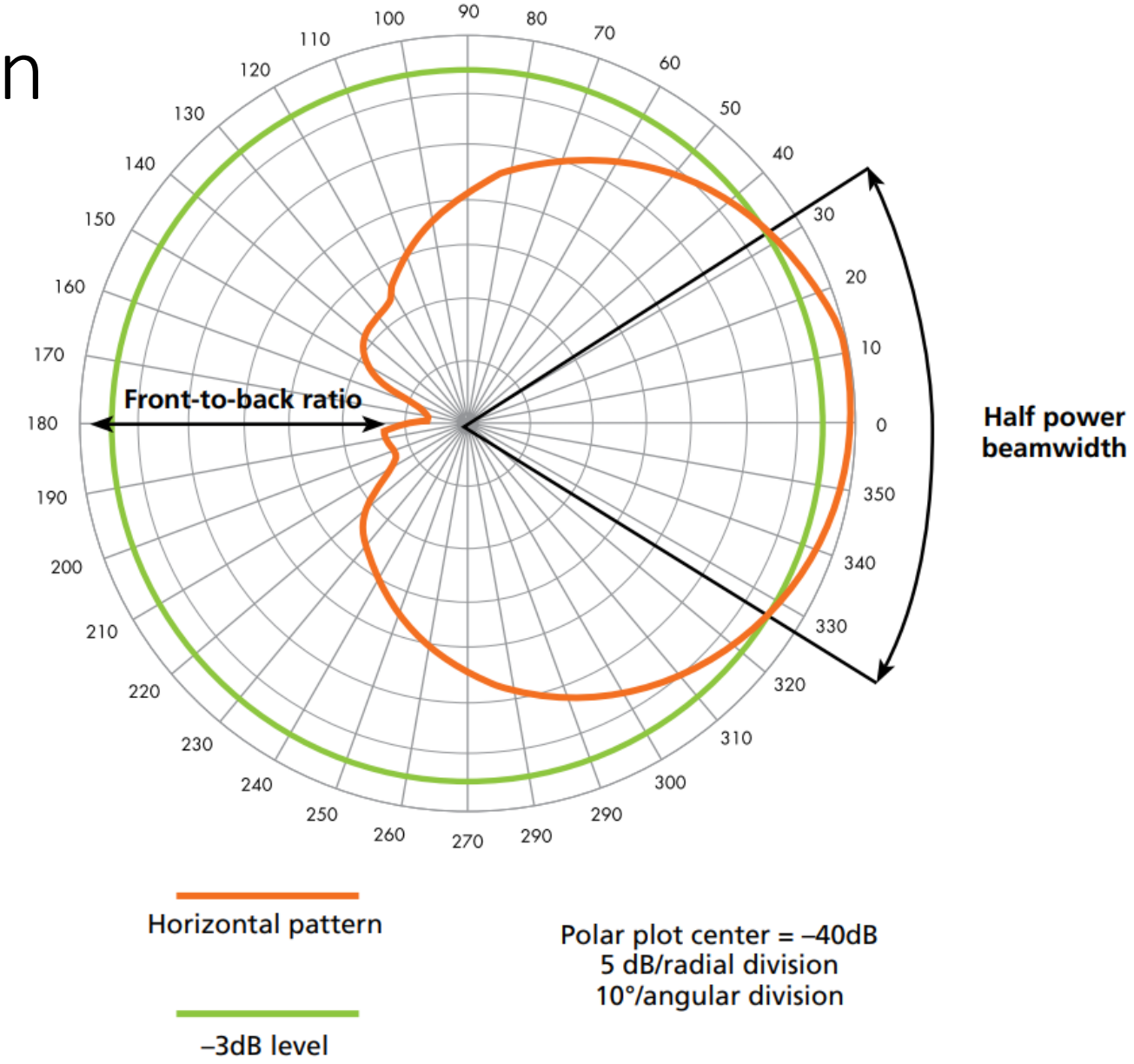




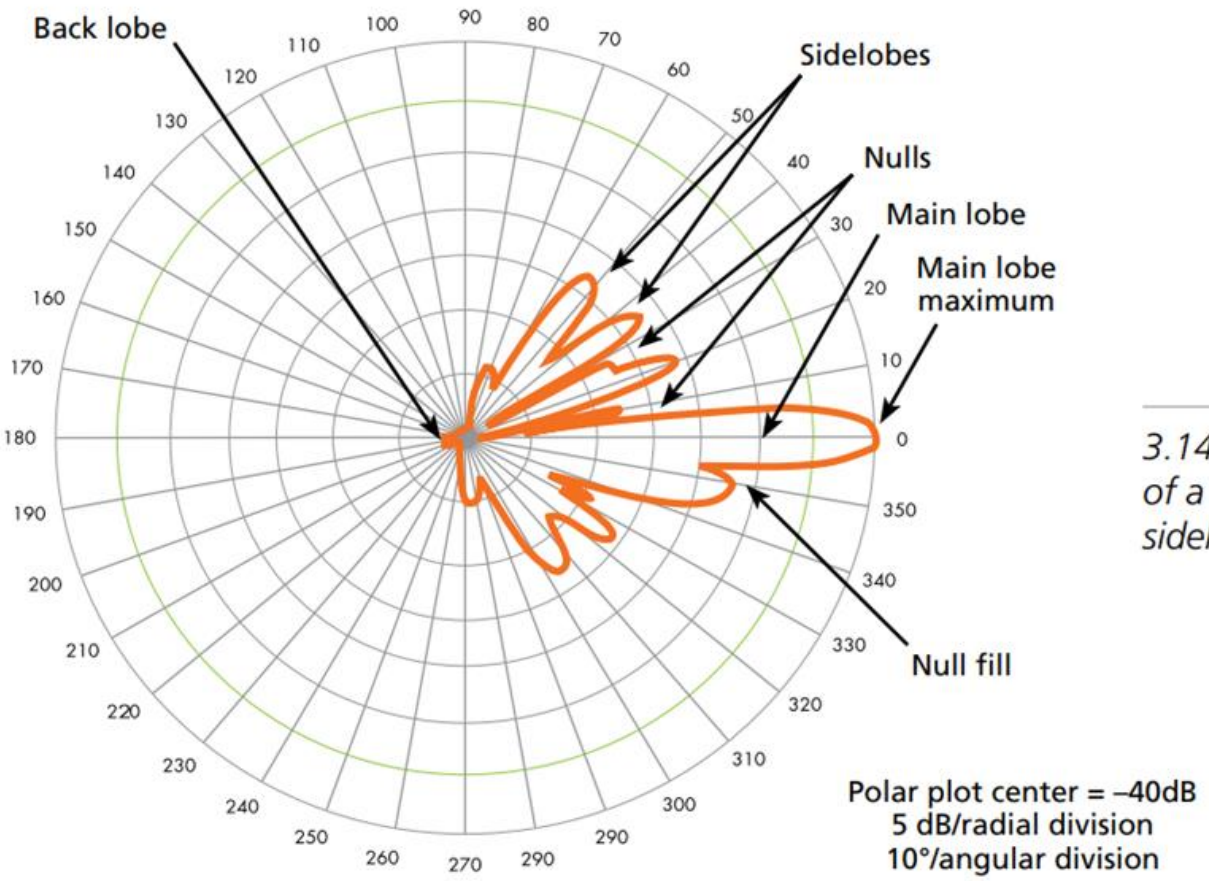
*despite the separate auctions, these 2 blocks collectively are known as the 3600 MHz band (3GPP 5G n78)

Typical cellular sector antenna - horizontal radiation pattern

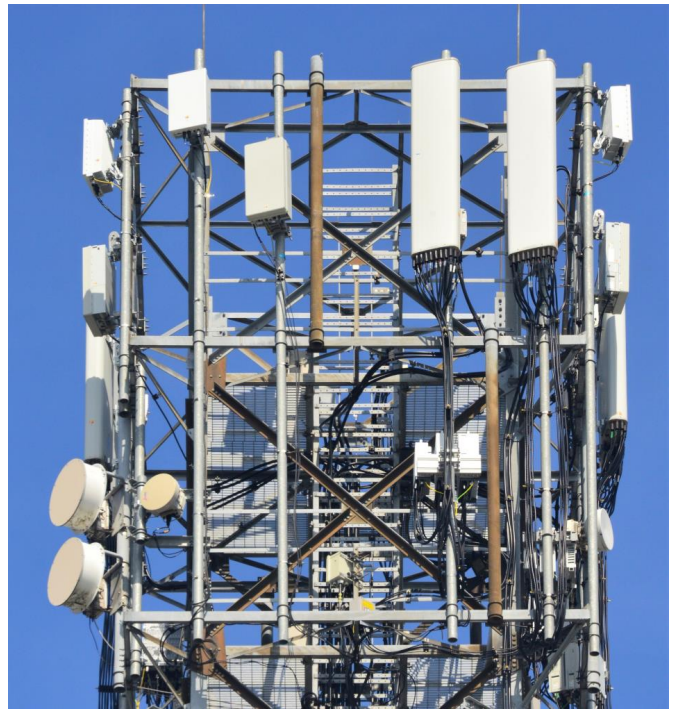




Typical cellular sector antenna - vertical radiation pattern

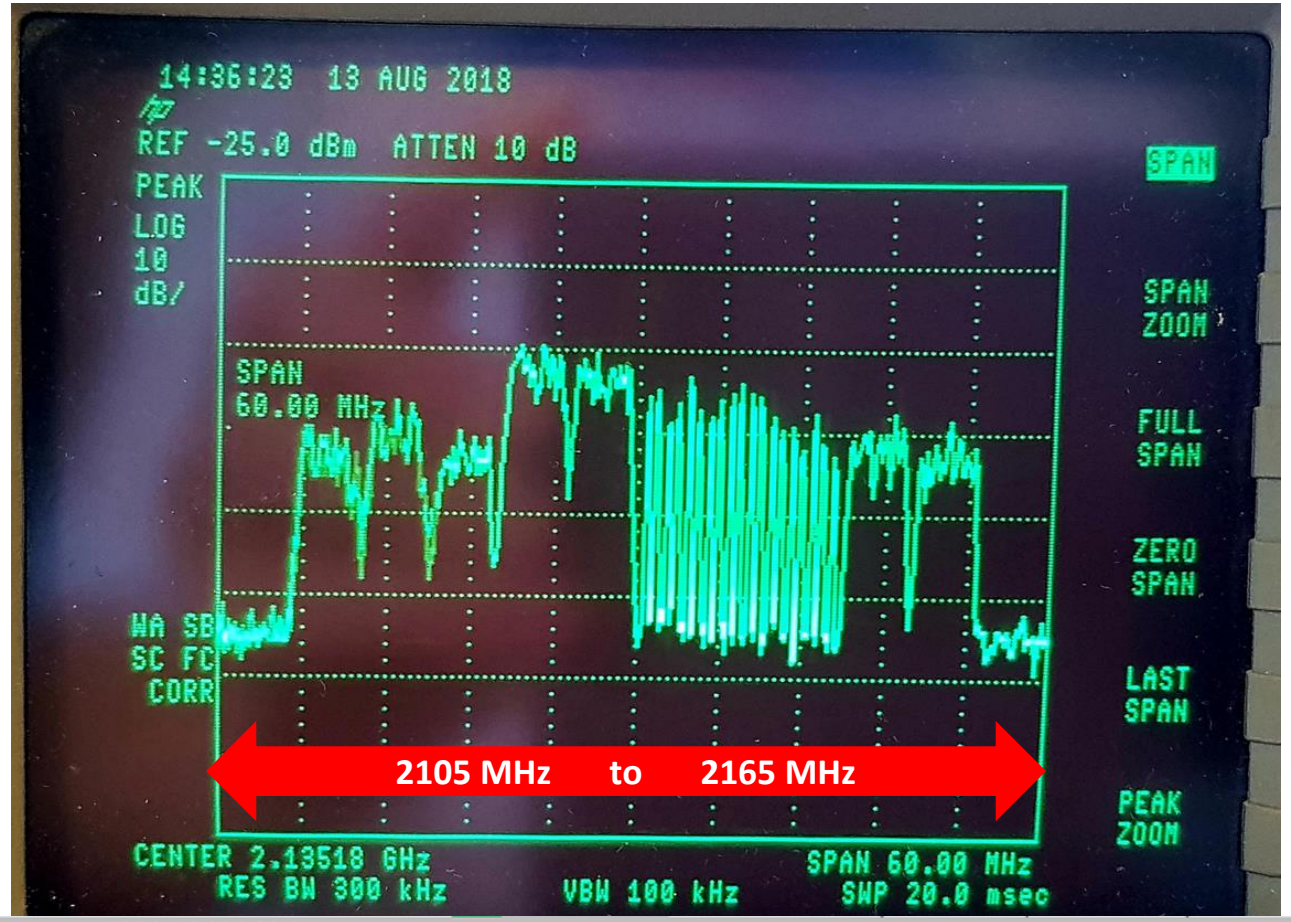


3.14: A polar representation of a vertical pattern including sidelobes and nulls



900 MHz band supporting 2G & 3G

2100 MHz spectrum utilisation for 3G & 4G



1900 / 2100 MHz

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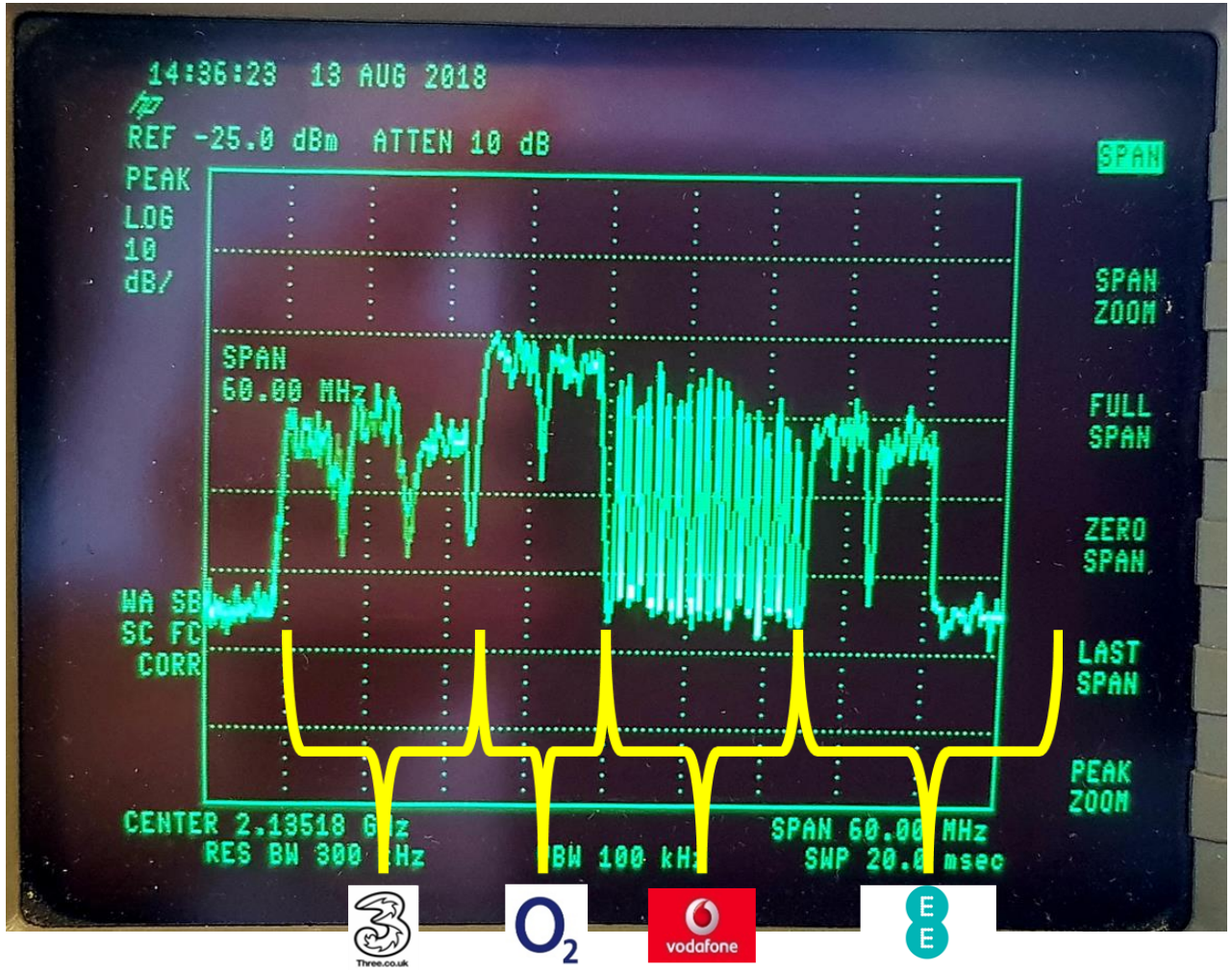
2100 MHz spectrum utilisation for 3G & 4G



Note: 3G has been switched off in some areas since this plot was captured - 2100 MHz will be refarmed to 4G/5G

Providers are switching off their 3G networks at different times

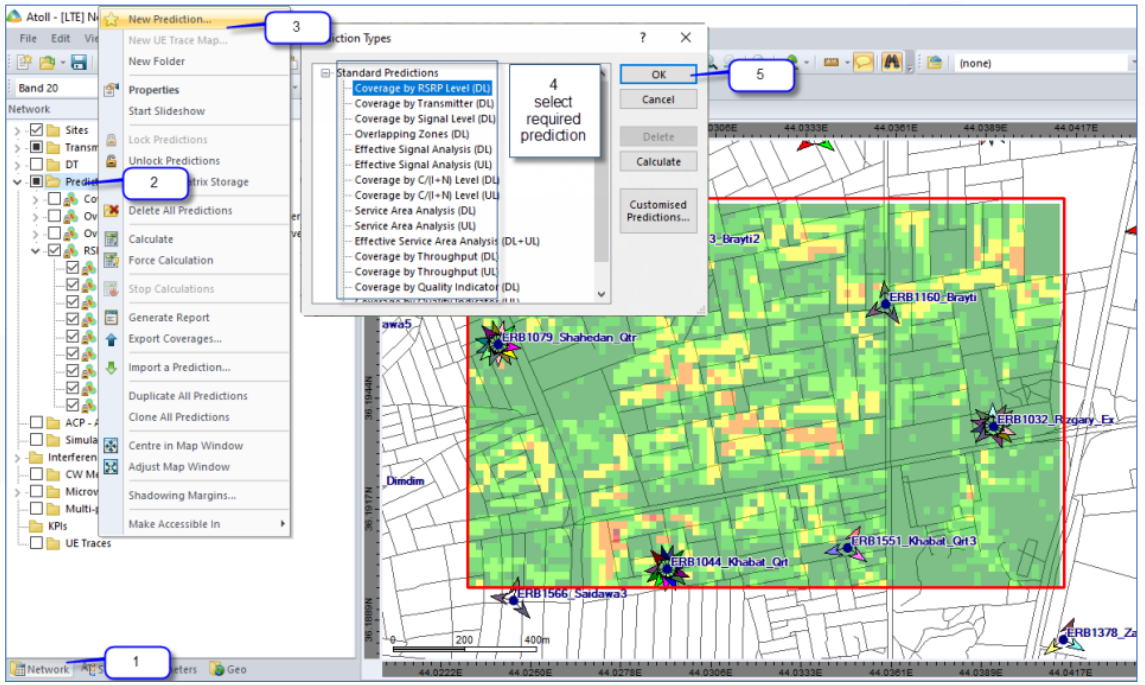
- Each mobile provider is setting its own timetable for its 3G network switch-off
- These timings might change, and you should check your mobile provider's website for the latest update:

- Vodafone is planning to complete its switch-off in early 2024
- EE plans to switch-off in early 2024, starting January
- Three expects to switch-off by the end of 2024
- O2 is planning to switch-off in 2025

Source: https://www.ofcom.org.uk/phones-telecoms-and-internet/advice-for-consumers/advice/3g-switch-off

Radio network planning tools

- Multi-RAT RAN Modelling
- 4G & 5G Network Design
- Prediction and Measurement-based Planning and Optimisation
- High Performance GIS
- In-built Customisation Capabilities

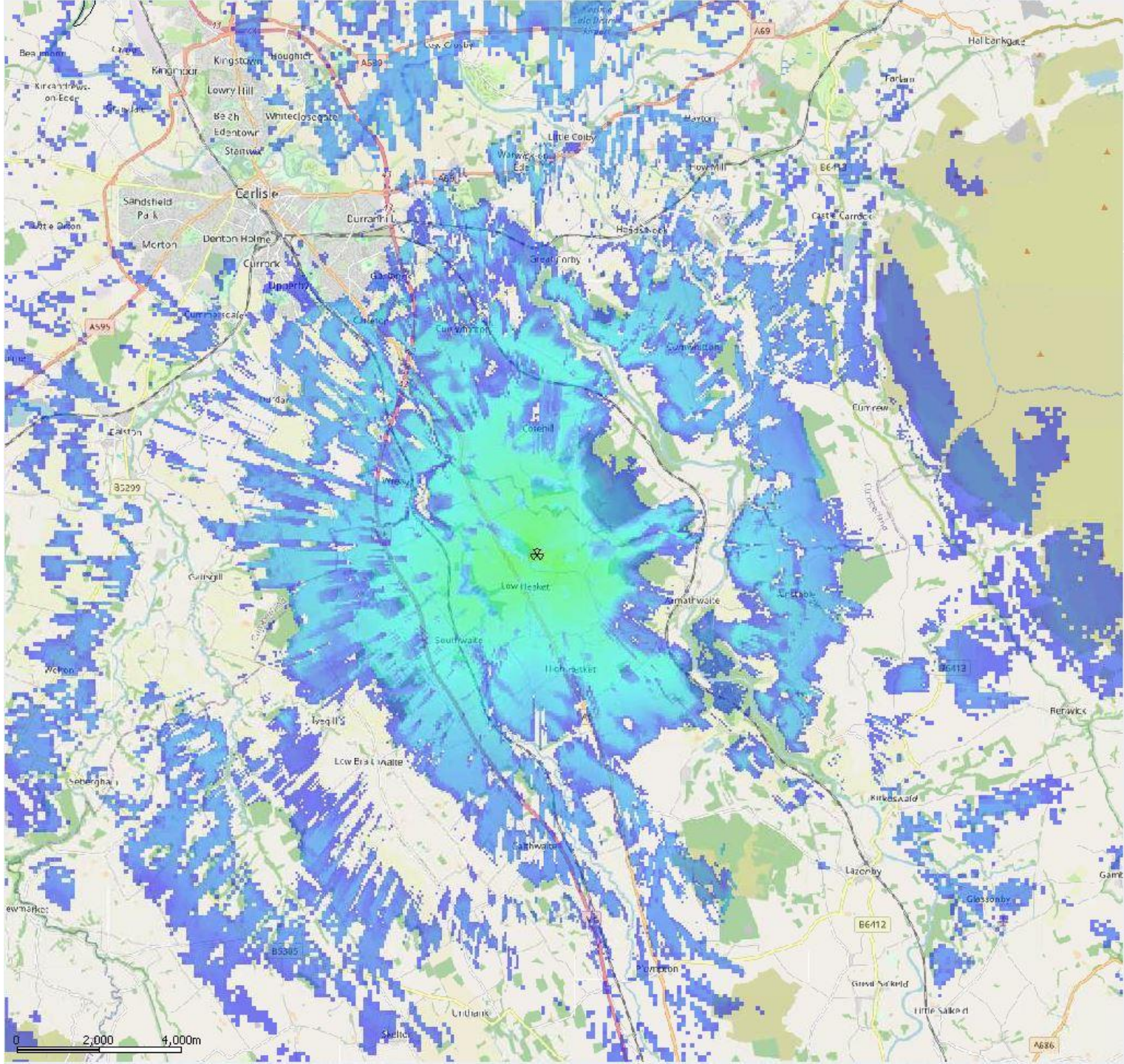


Penrith Beacon
Rural lattice tower site in Cumbria

Penrith - all layers down to -124dBm

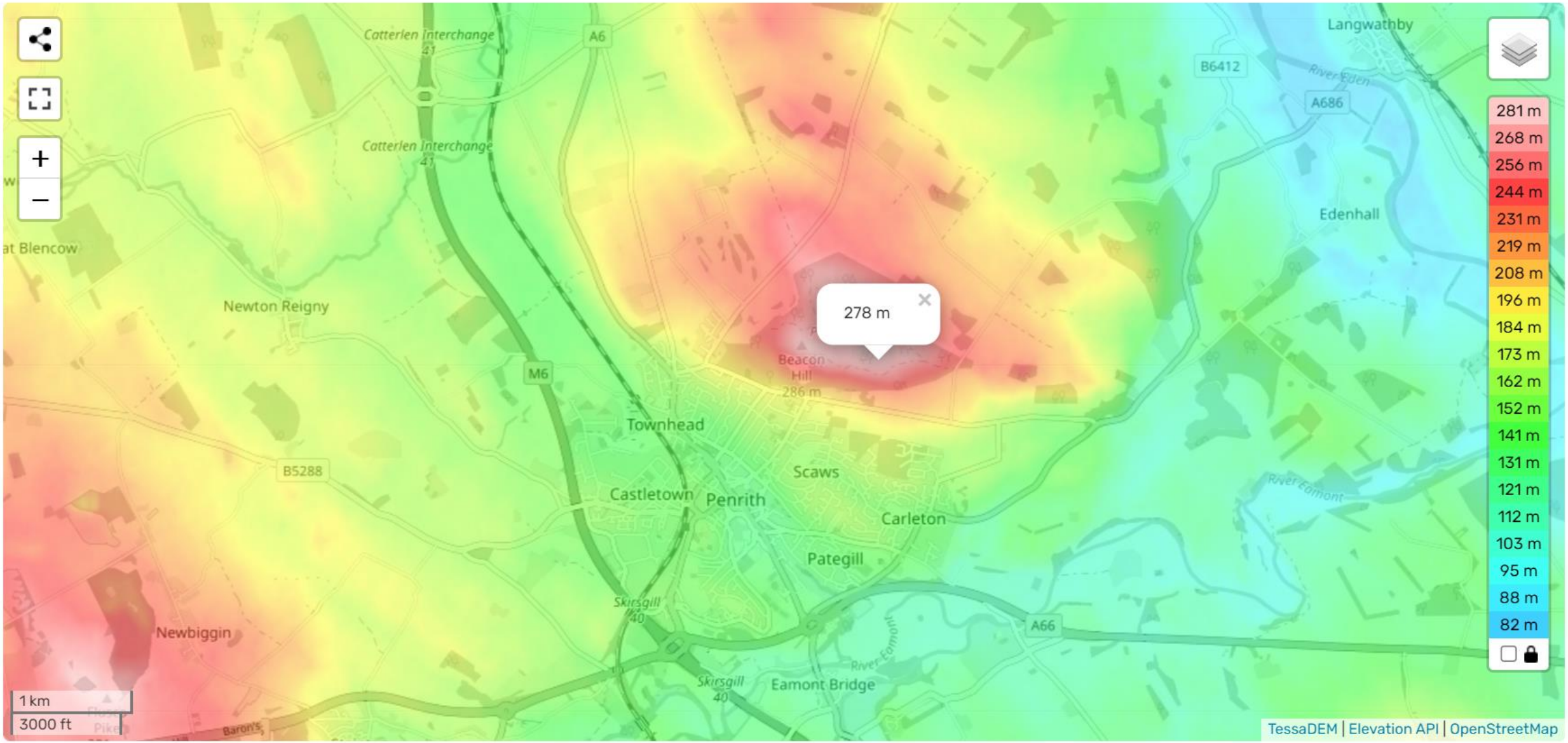
- Site supports 2G, 3G & 4G RATs
- 2G Transceivers - 1800 MHz
- 3G Carrier - 2100 MHz
- 4G Carriers - 800 MHz & 1800 MHz

- Site is connected by a point-to-point microwave radio link which has a maximum capacity of 682Mbps
- Microwave radio link connects to an adjacent site with a 1Gbps optical fibre connection to the mobile core network



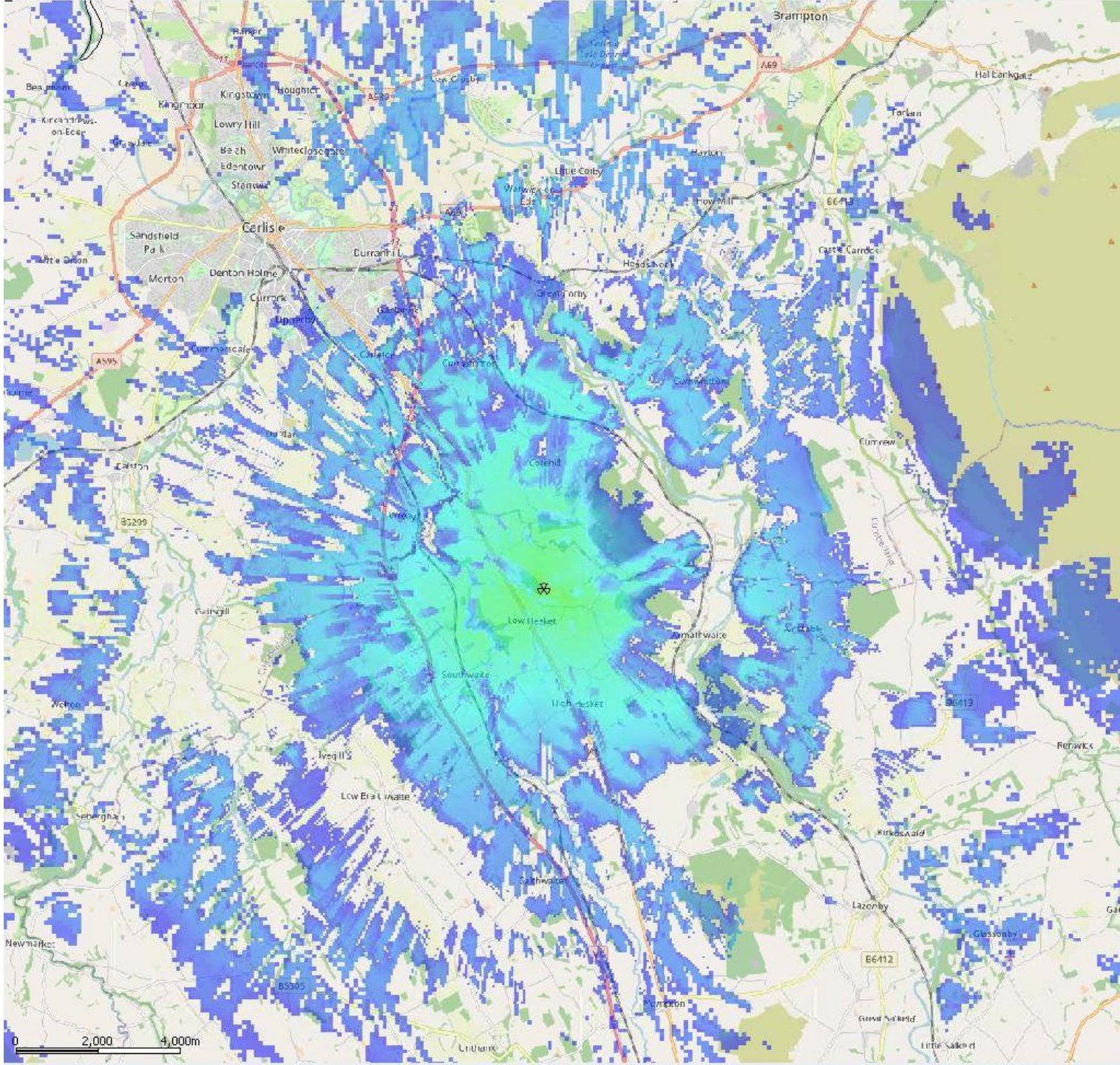
Brecon Beacons National Park topographic map

Click on the **map** to display **elevation**.

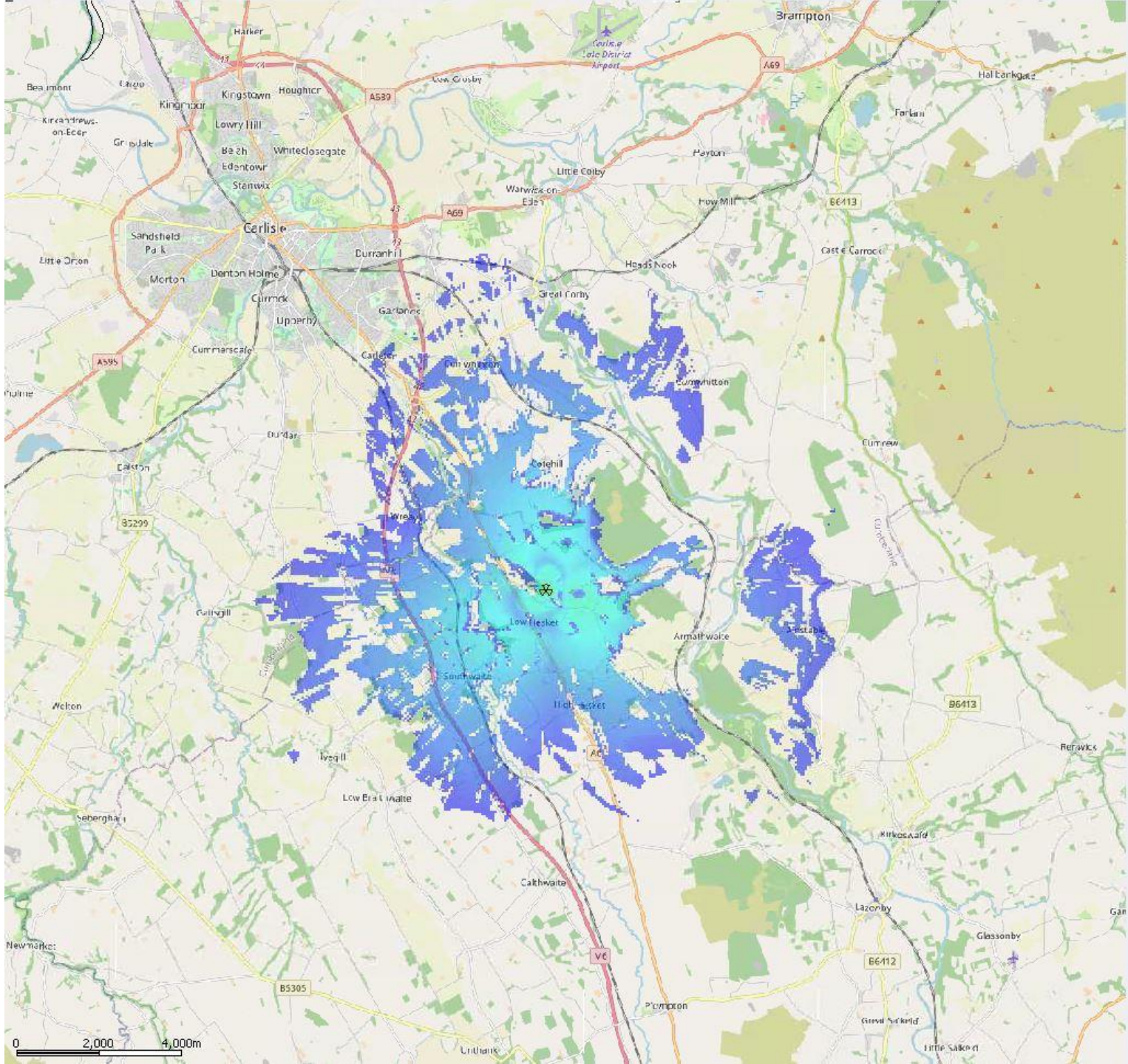


Source: https://en-gb.topographic-map.com/map-txm18/Brecon-Beacons-National-Park/?center=54.6733%2C-2.74613&zoom=13&popup=54.67406%2C-2.734

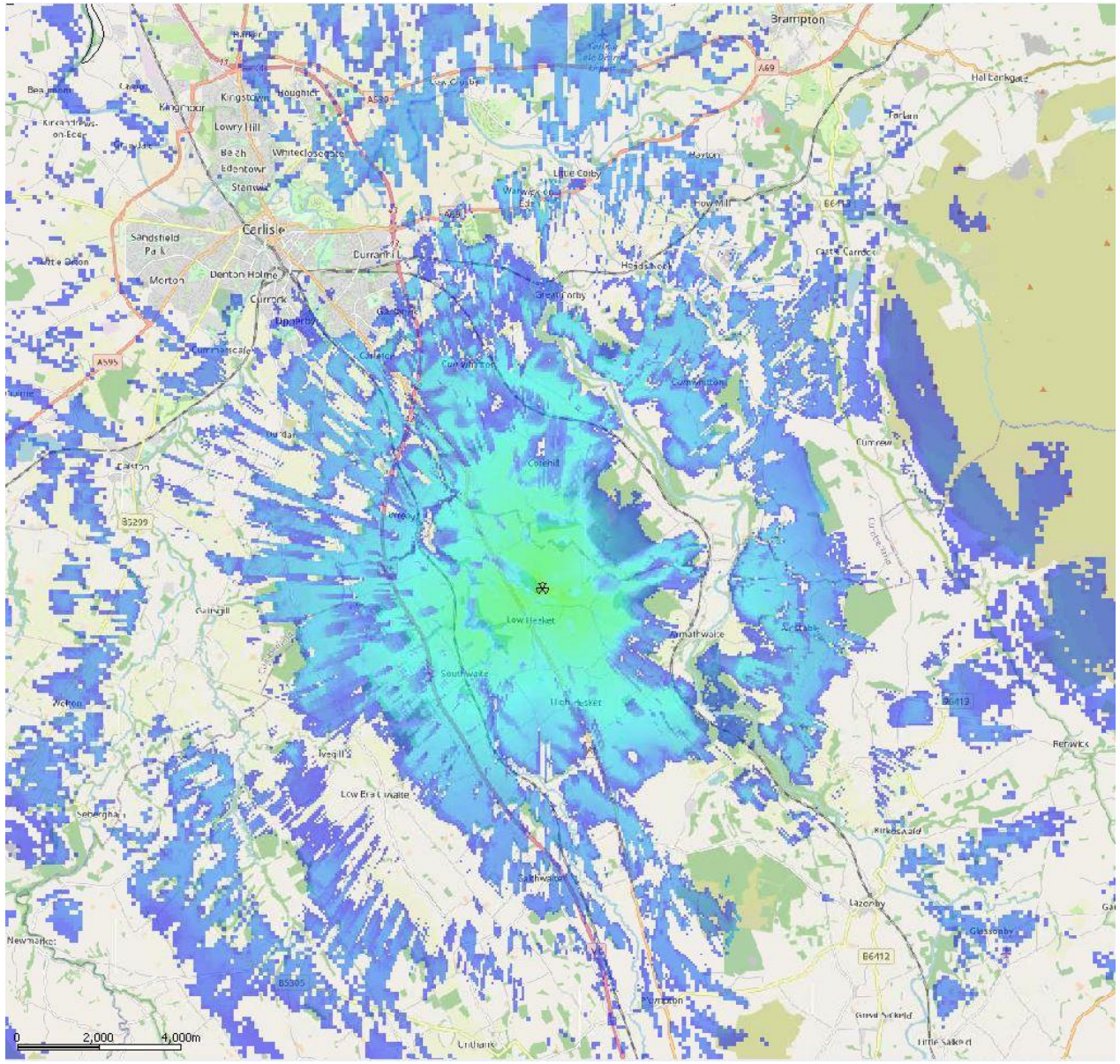
Penrith - LTE800

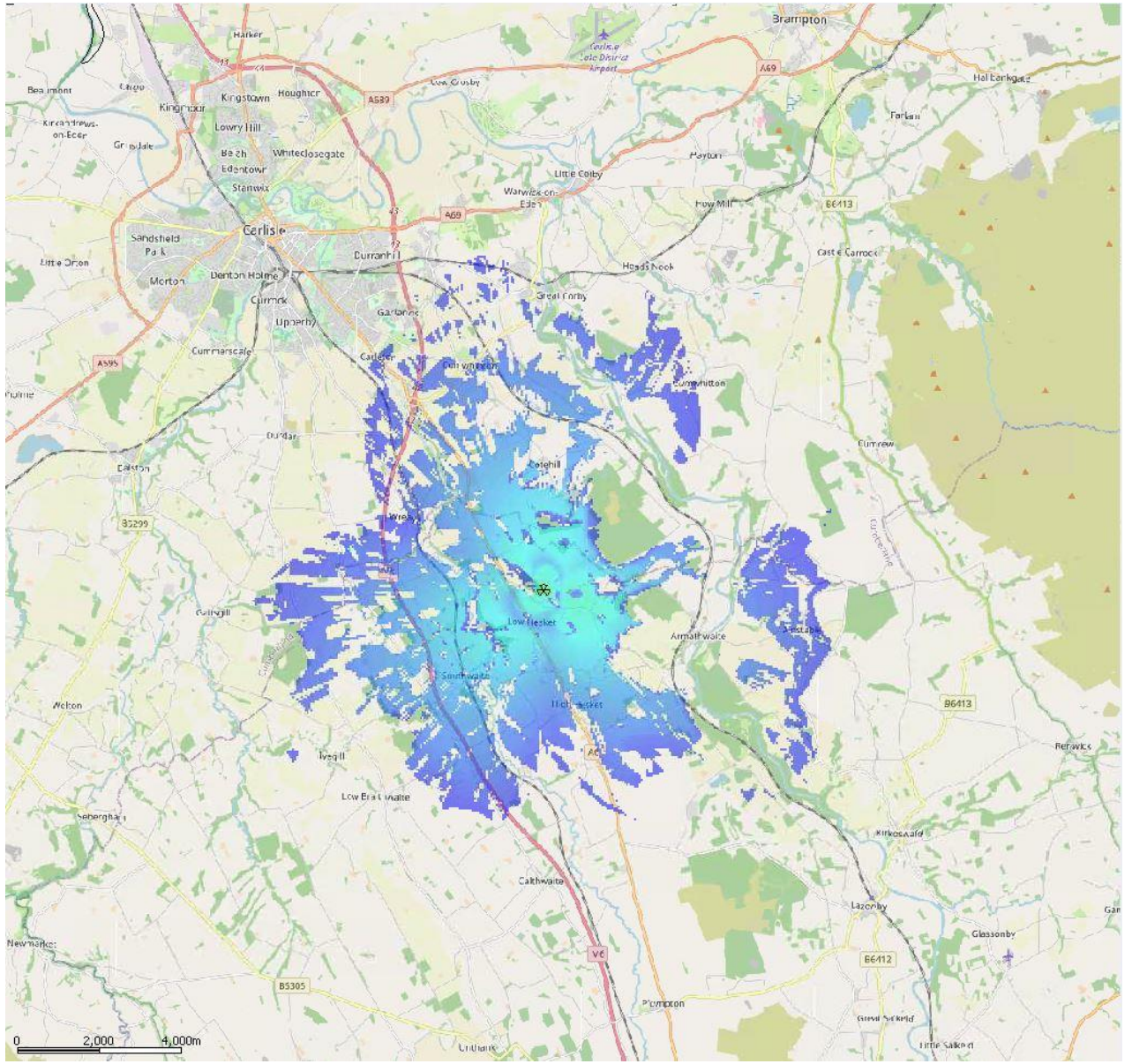


Penrith - LTE1800



Penrith, Cumbria - comparison of LTE 800 & LTE1800 coverage



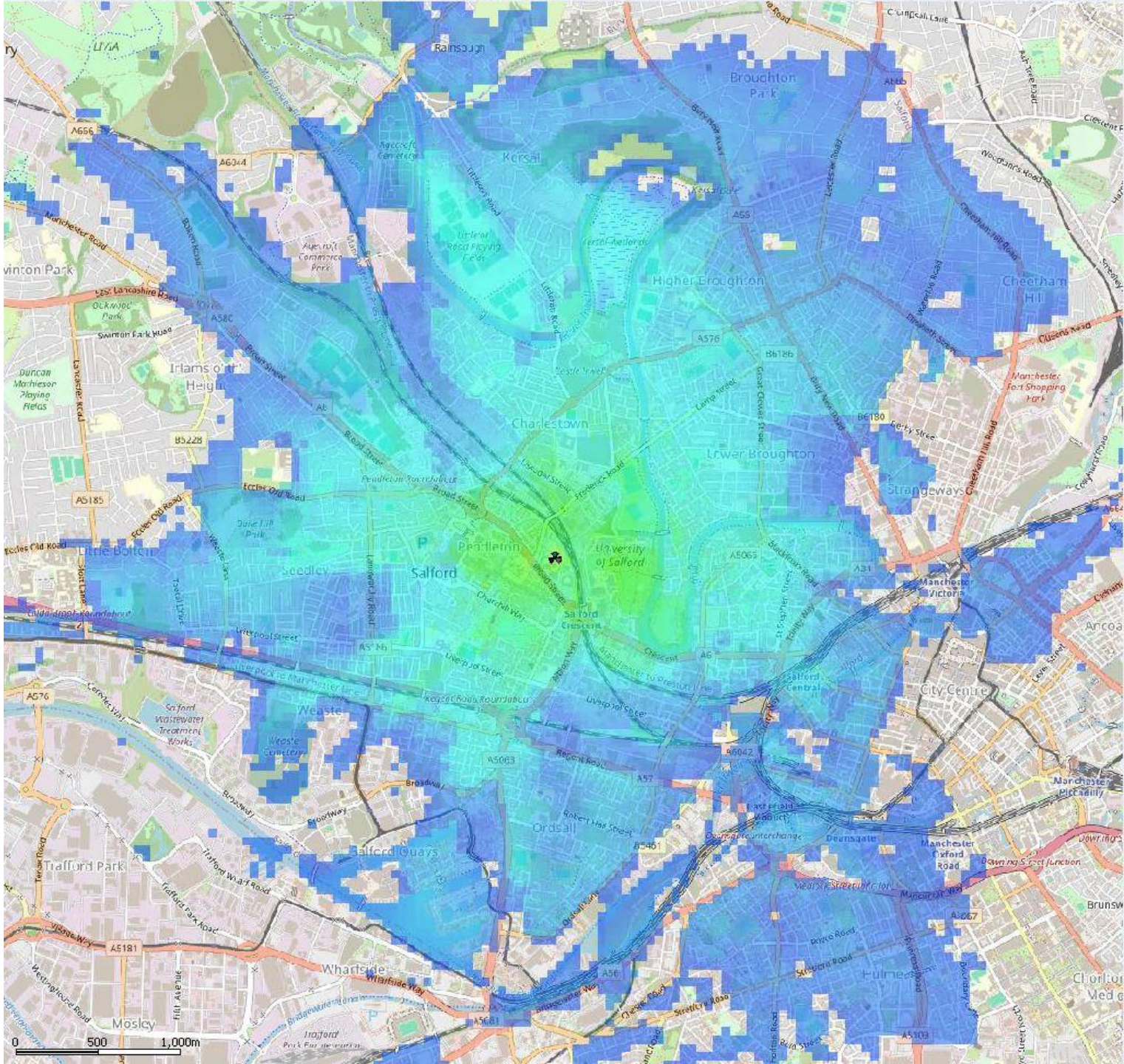


University of Salford
Urban rooftop site in Salford, Greater Manchester

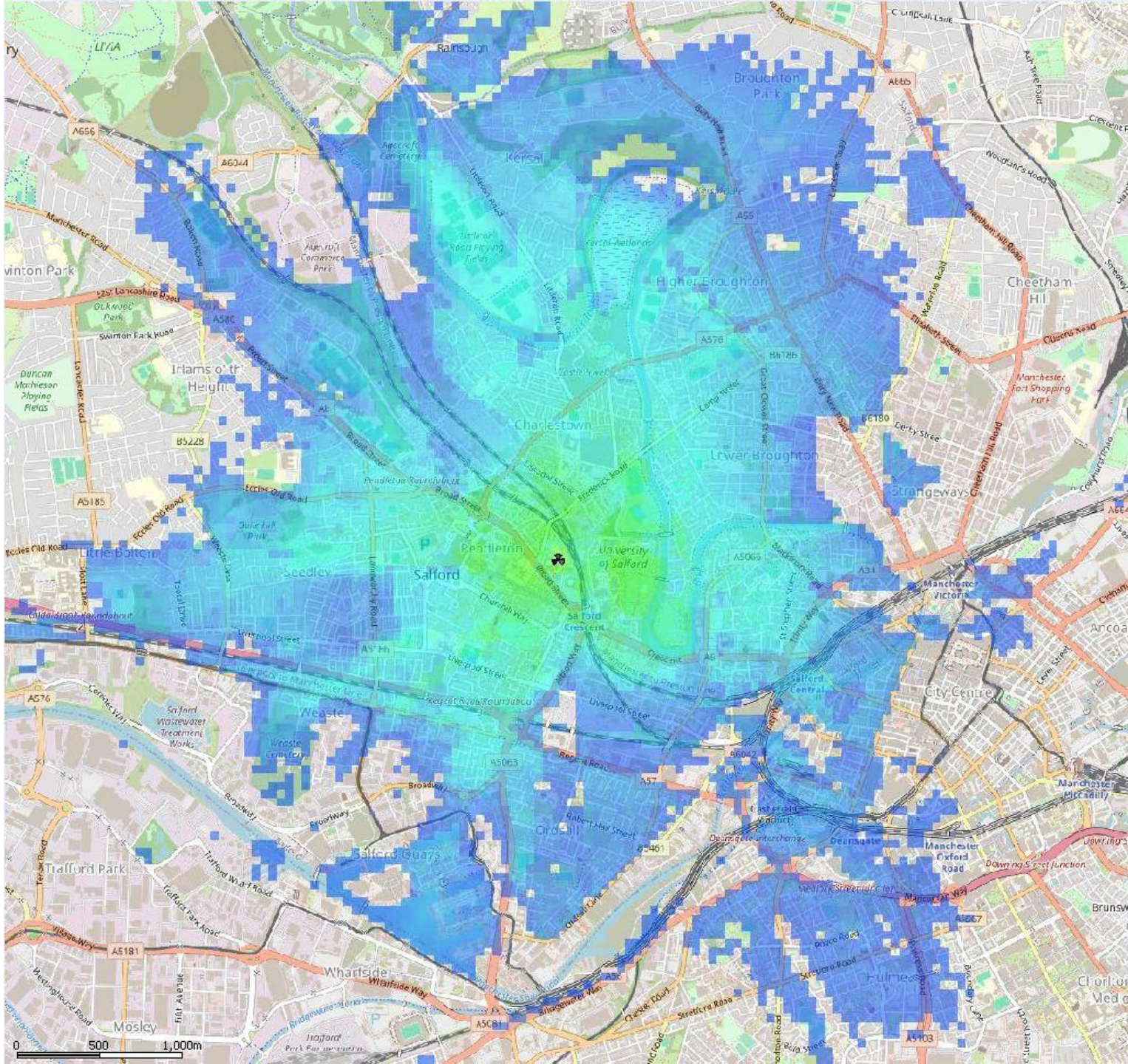
Macro cell site

University of Salford - all layers down to -124dBm

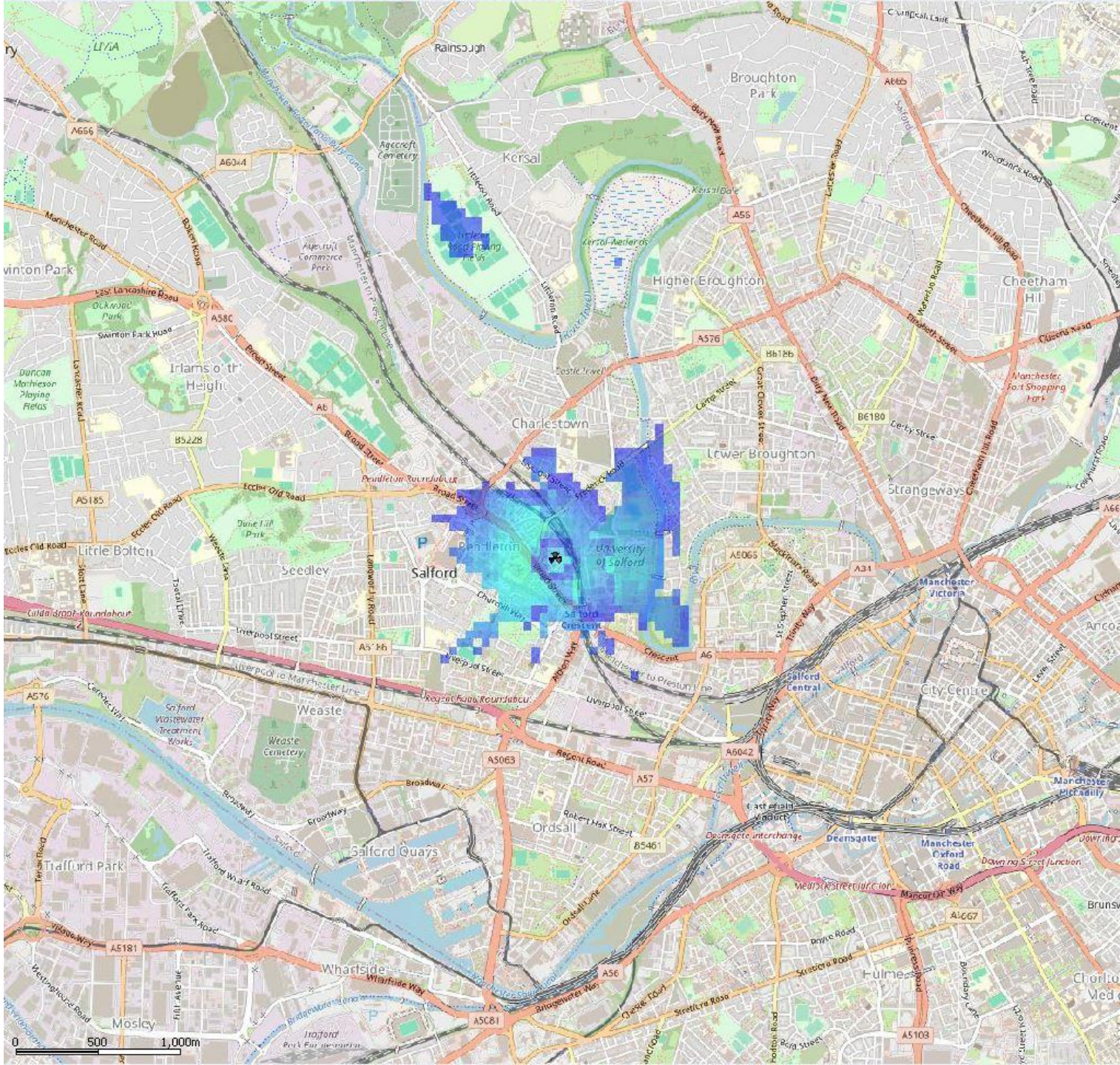
- Site supports 2G, 3G, 4G & 5G RATs
- 2G Transceivers - 1800 MHz
- 3G Carrier - 2100 MHz
- 4G Carriers - 800 MHz, 1800 MHz, 2100 MHz & 2600 MHz
- 5G Carriers - 700 MHz, 1800 MHz, 2100 MHz, 2600 MHz & 3400 MHz
- Site is an optical fibre hub with access DWDM connectivity – the first channel provides backhaul of 10 Gbps
- Fibre backhaul solution is single fibre working so 2 x λ per channel



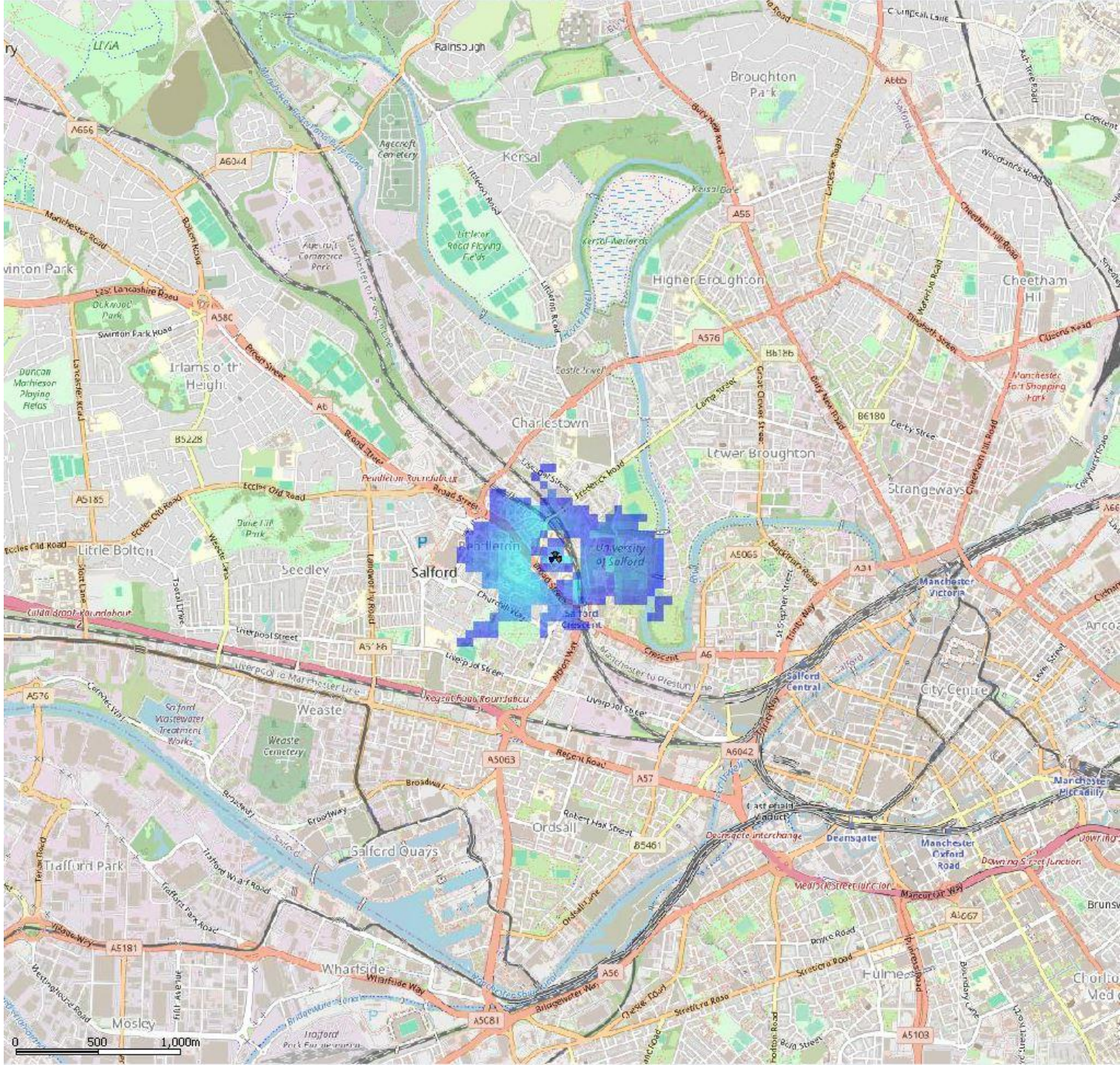
University of Salford - LTE 800



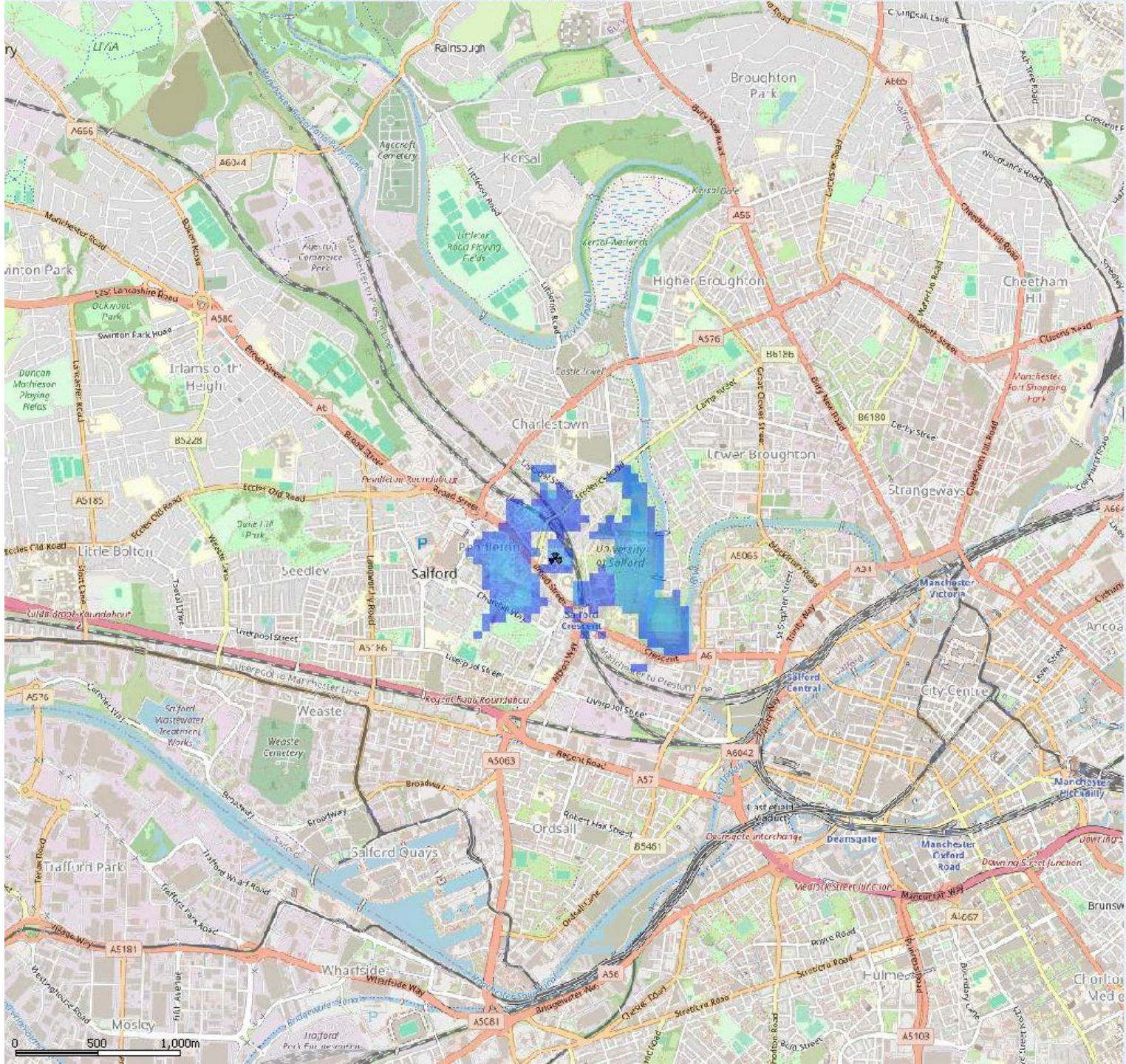
University of Salford - LTE1800



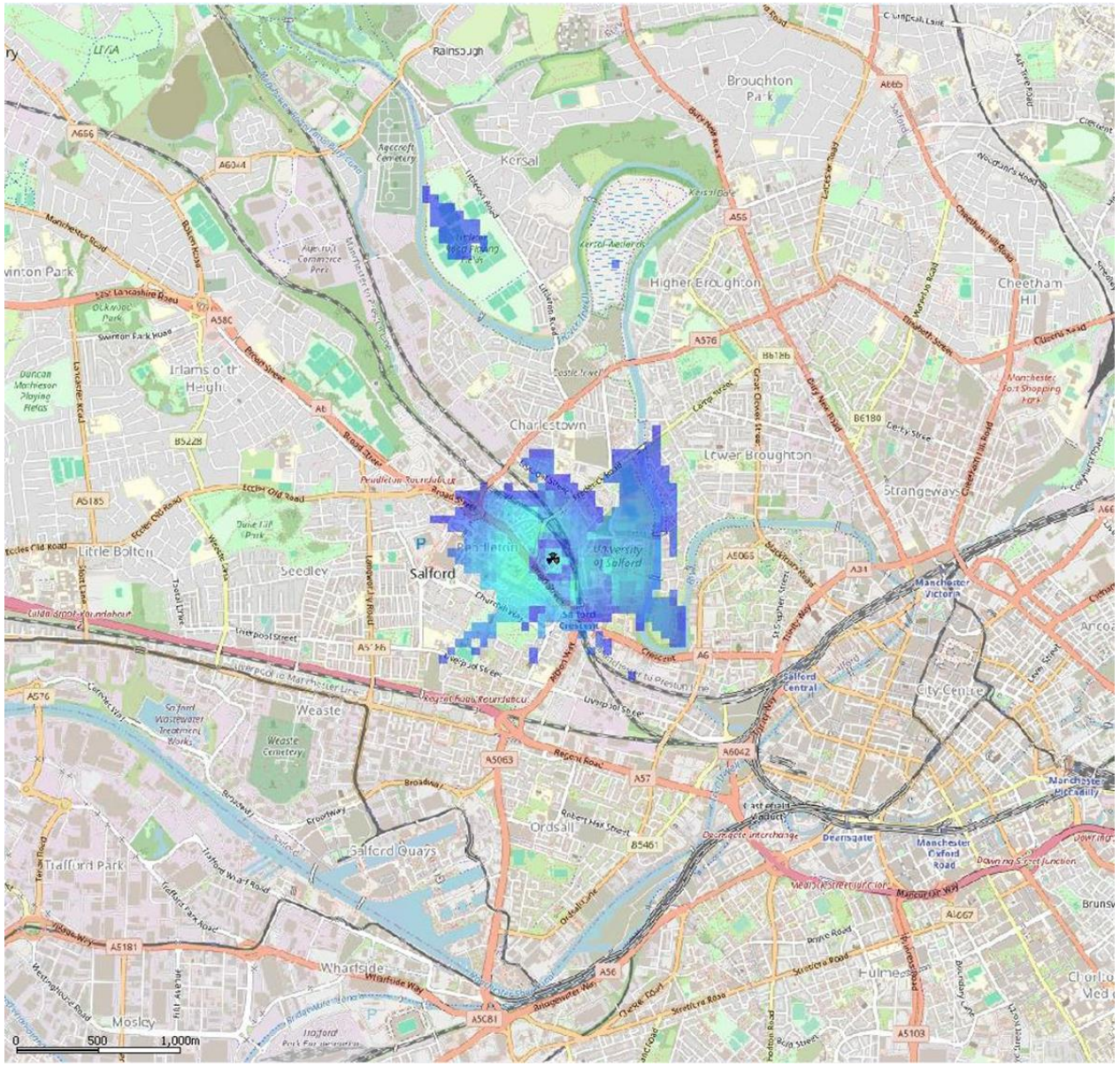
University of Salford - LTE2100

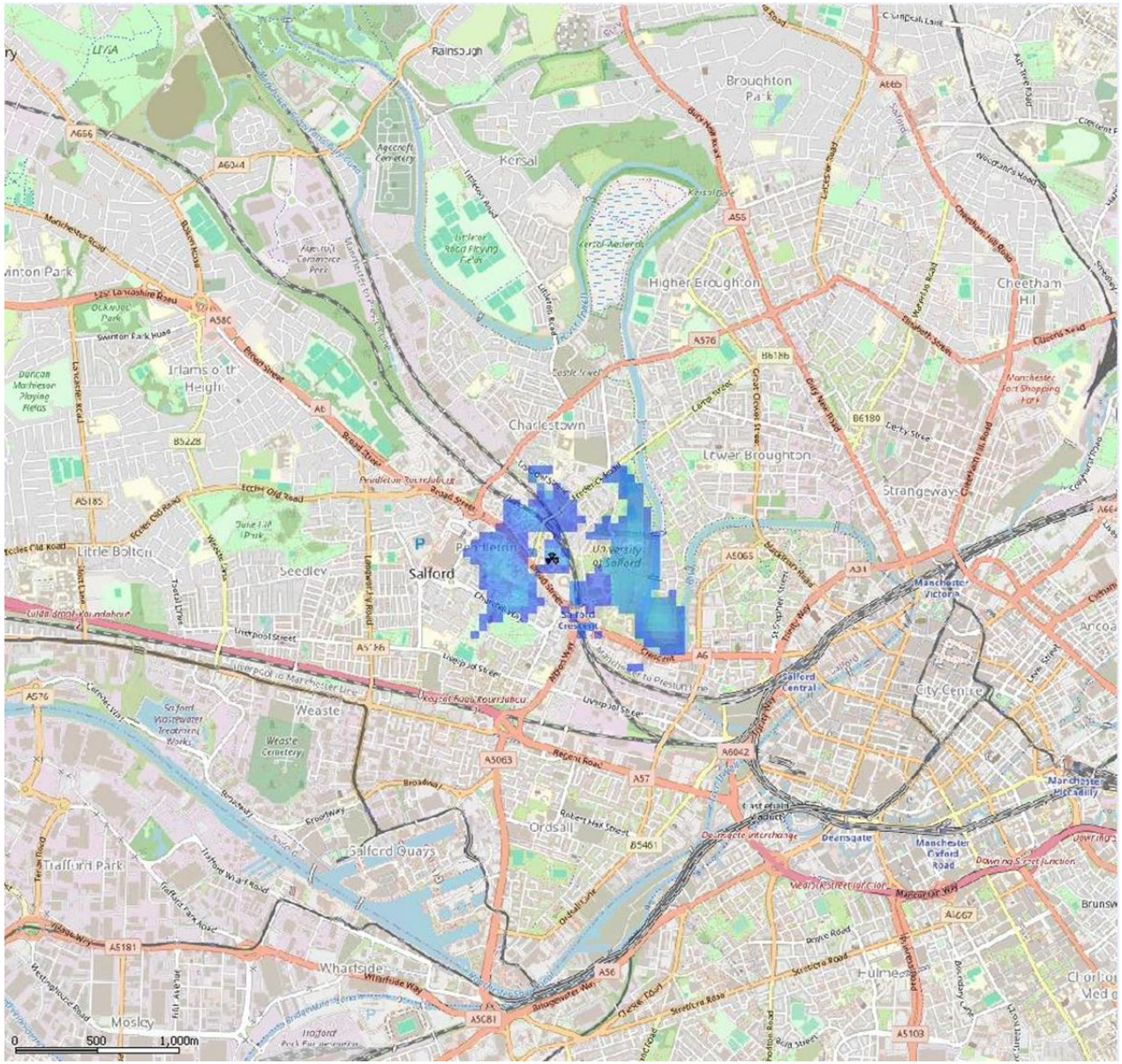


University of Salford - LTE2600

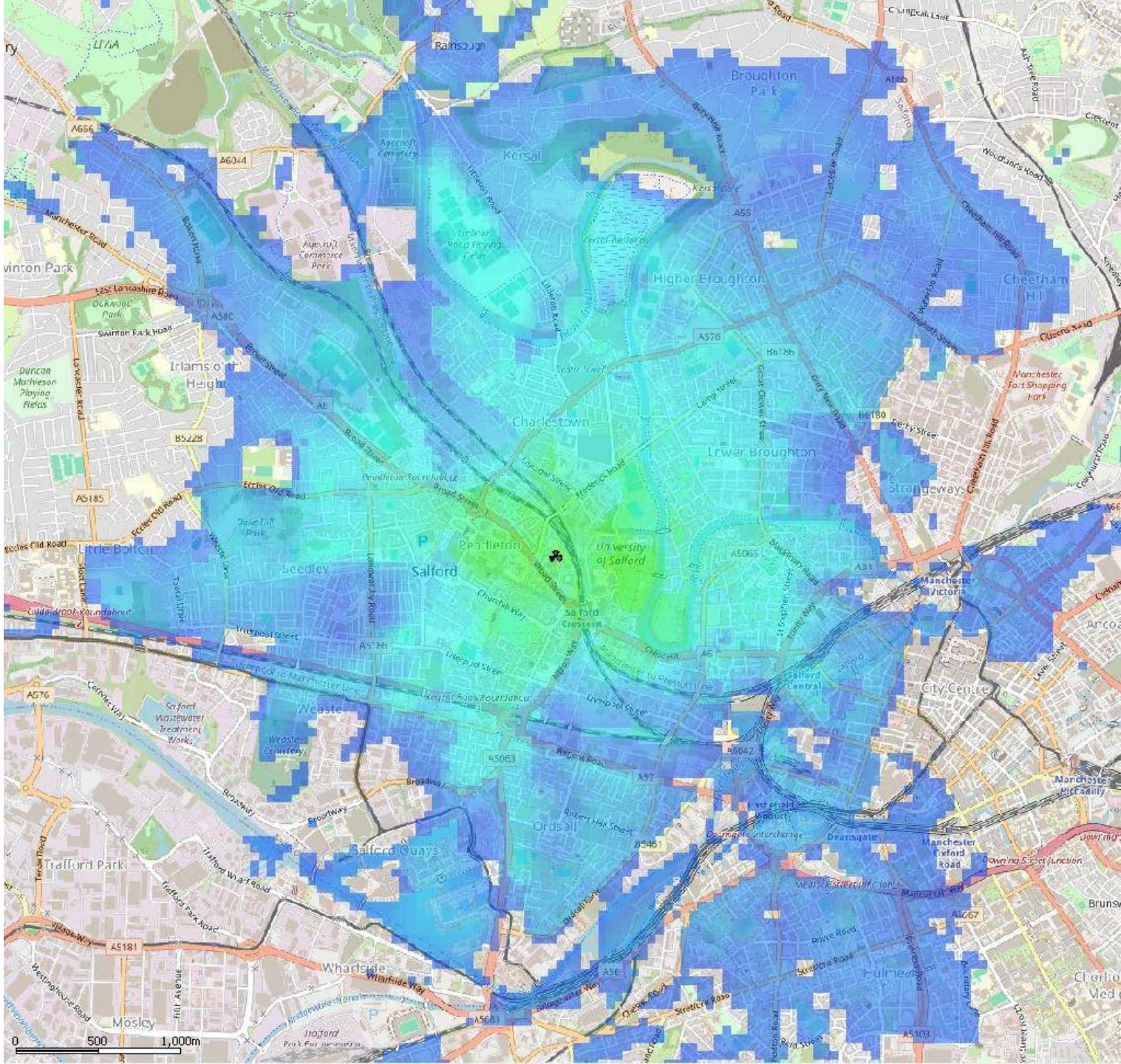


Salford, Gtr Mcr - comparison of LTE1800 & LTE2600 coverage

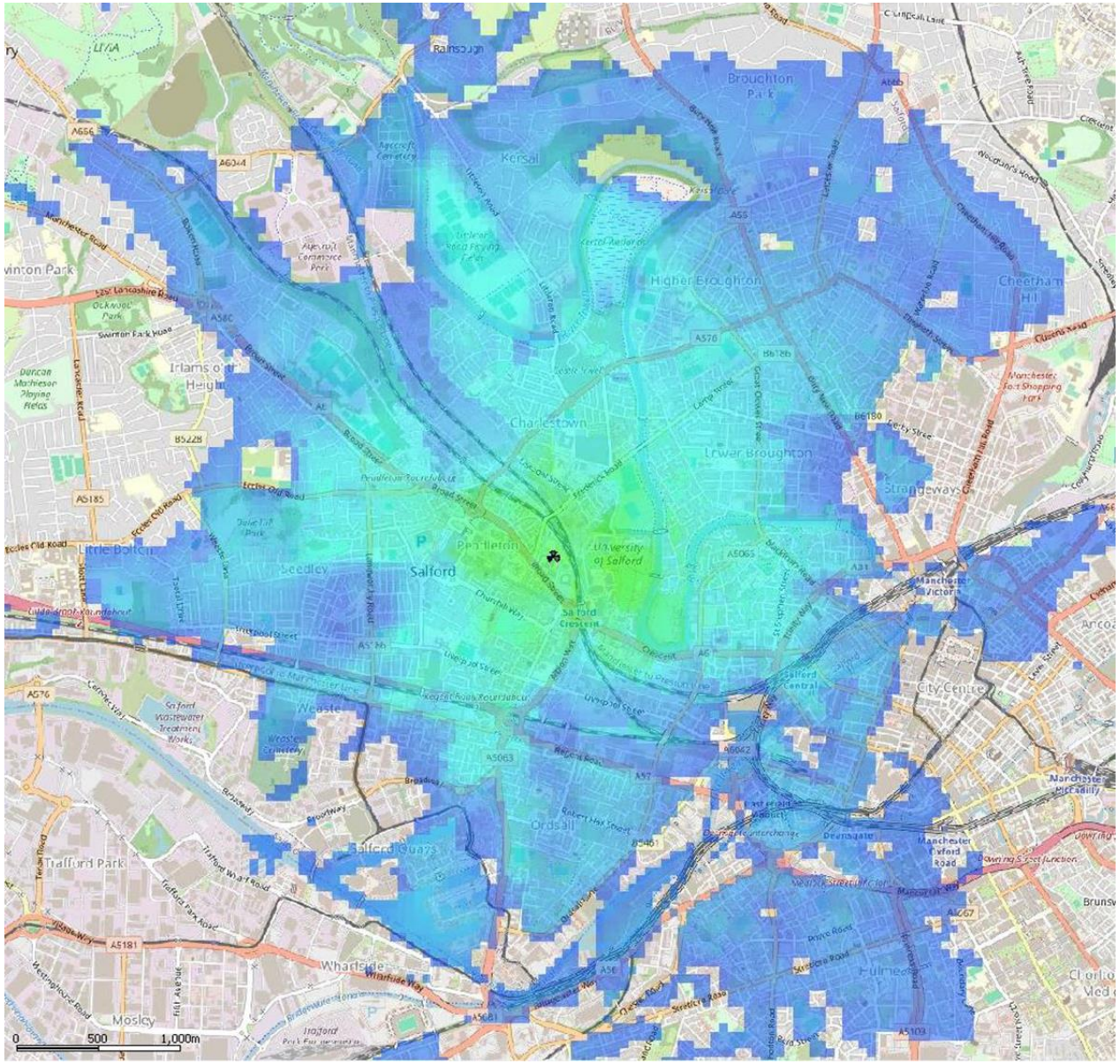


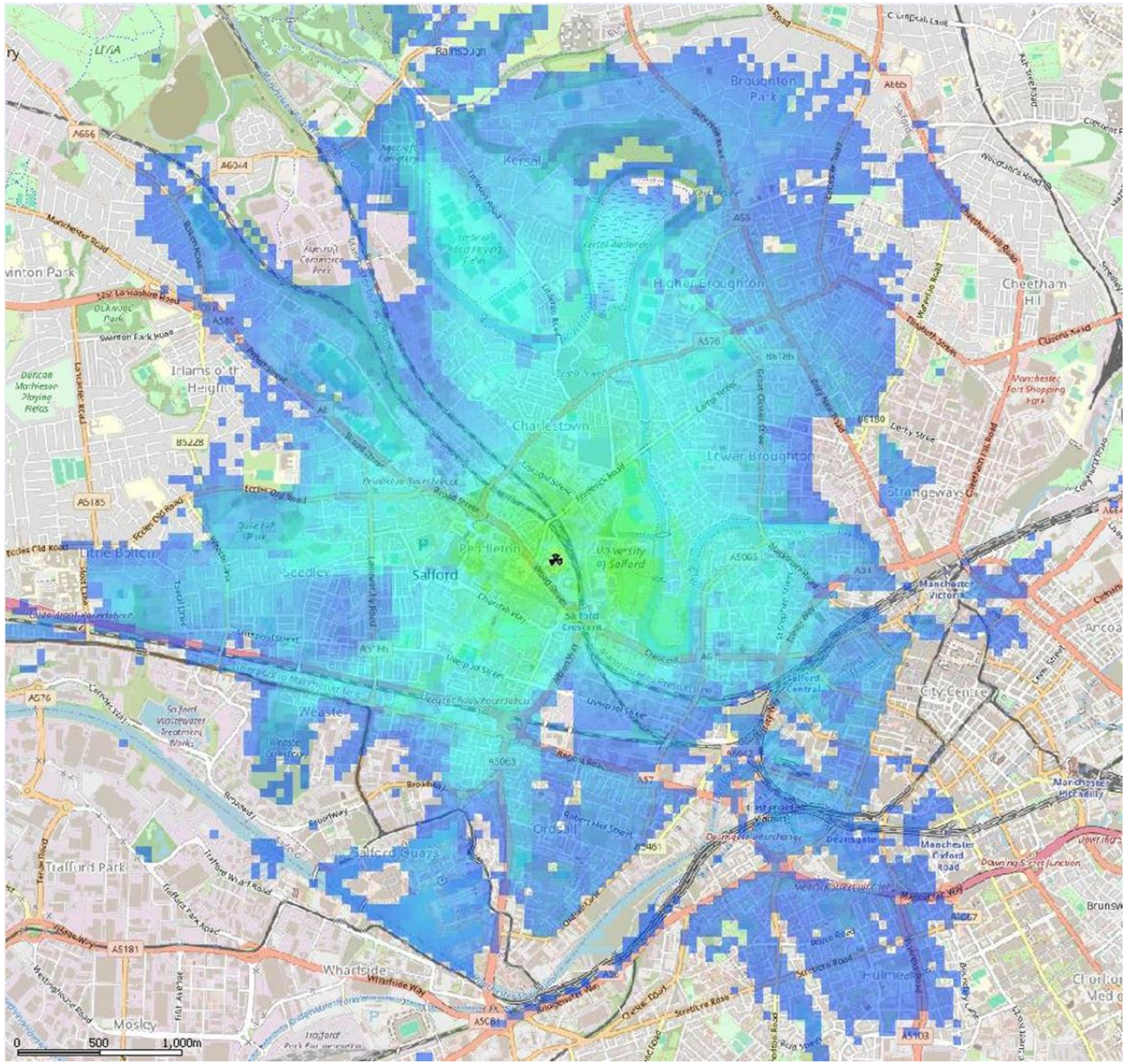


University of Salford - NR700



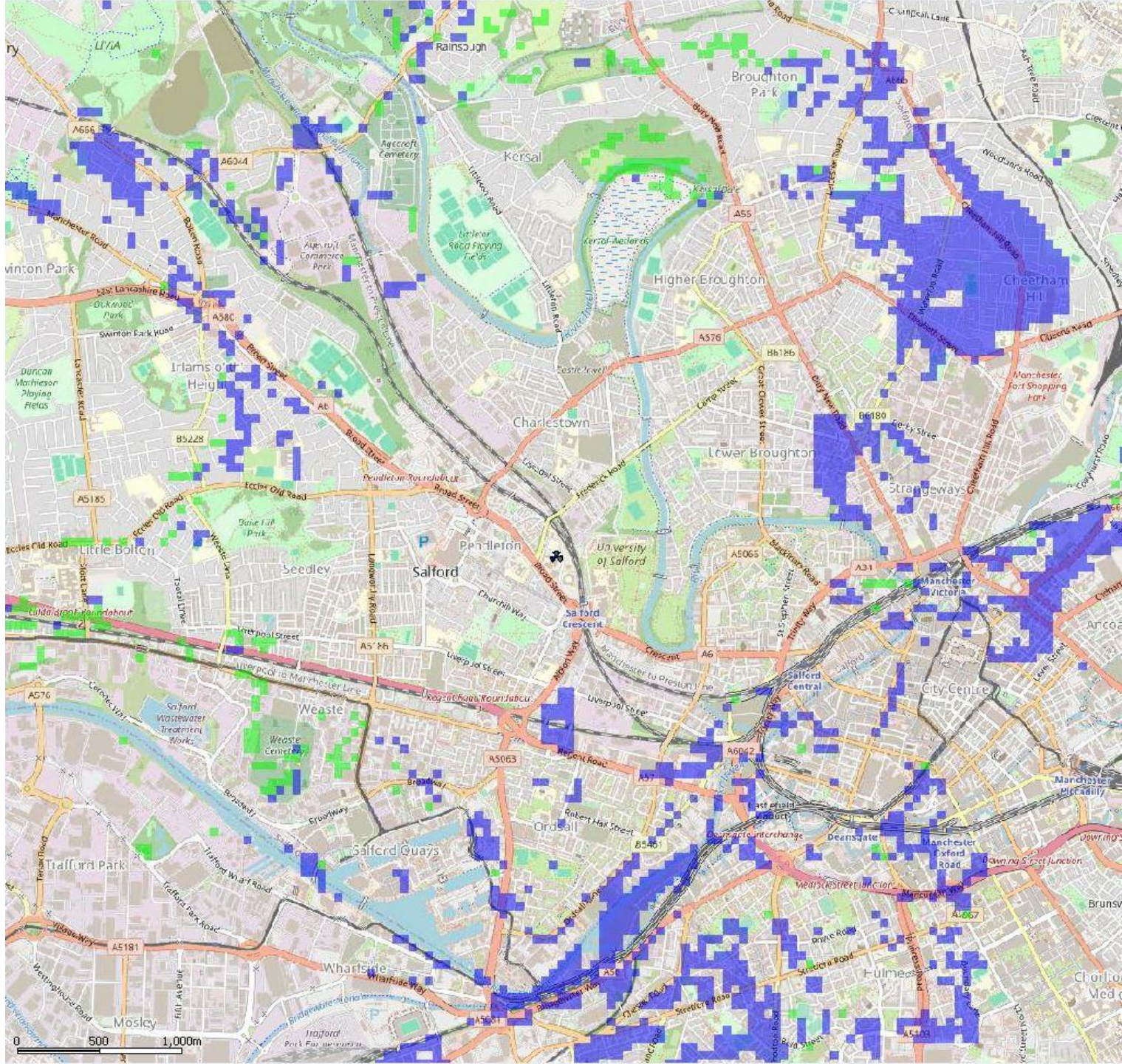
Salford, Gtr Mcr - comparison of NR700 & LTE800 coverage



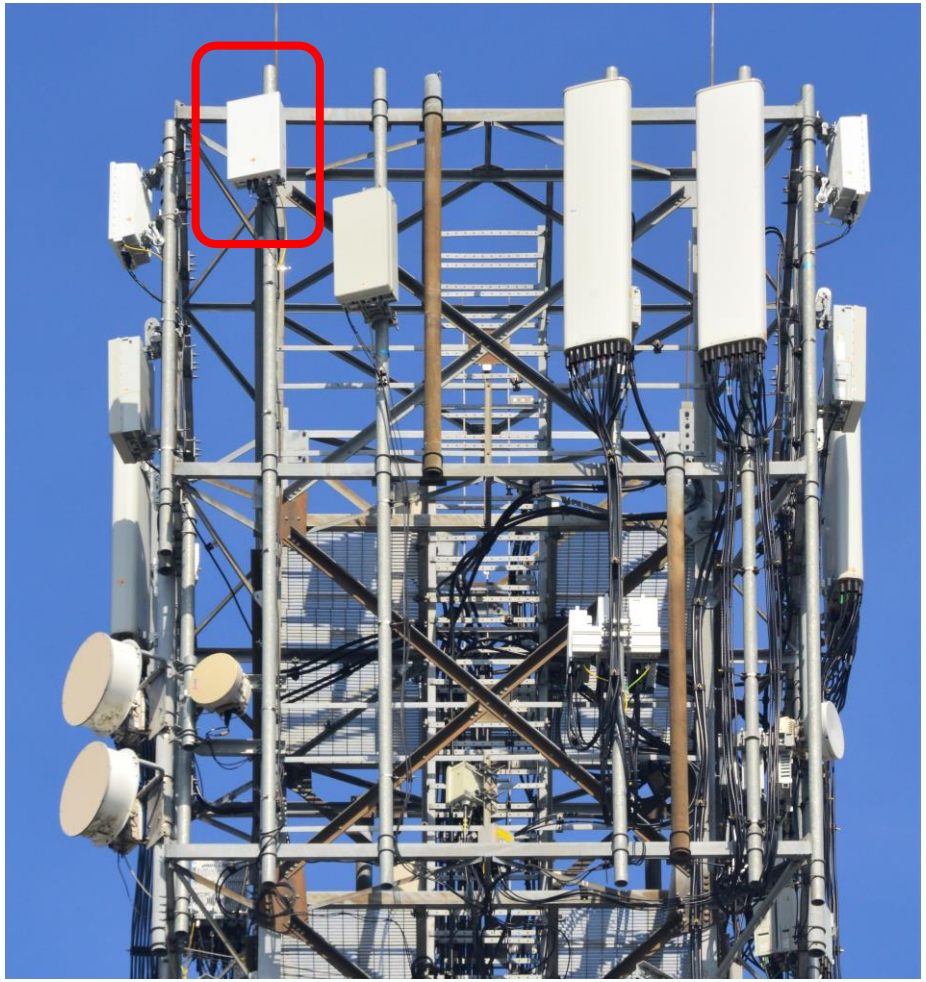


University of Salford - NR700

- Coverage beyond that delivered by LTE800



Typical cellular mMIMO antenna - horizontal radiation pattern - beam forming



Comparing a conventional antenna with a Mmimo antenna system (active phased array antenna)

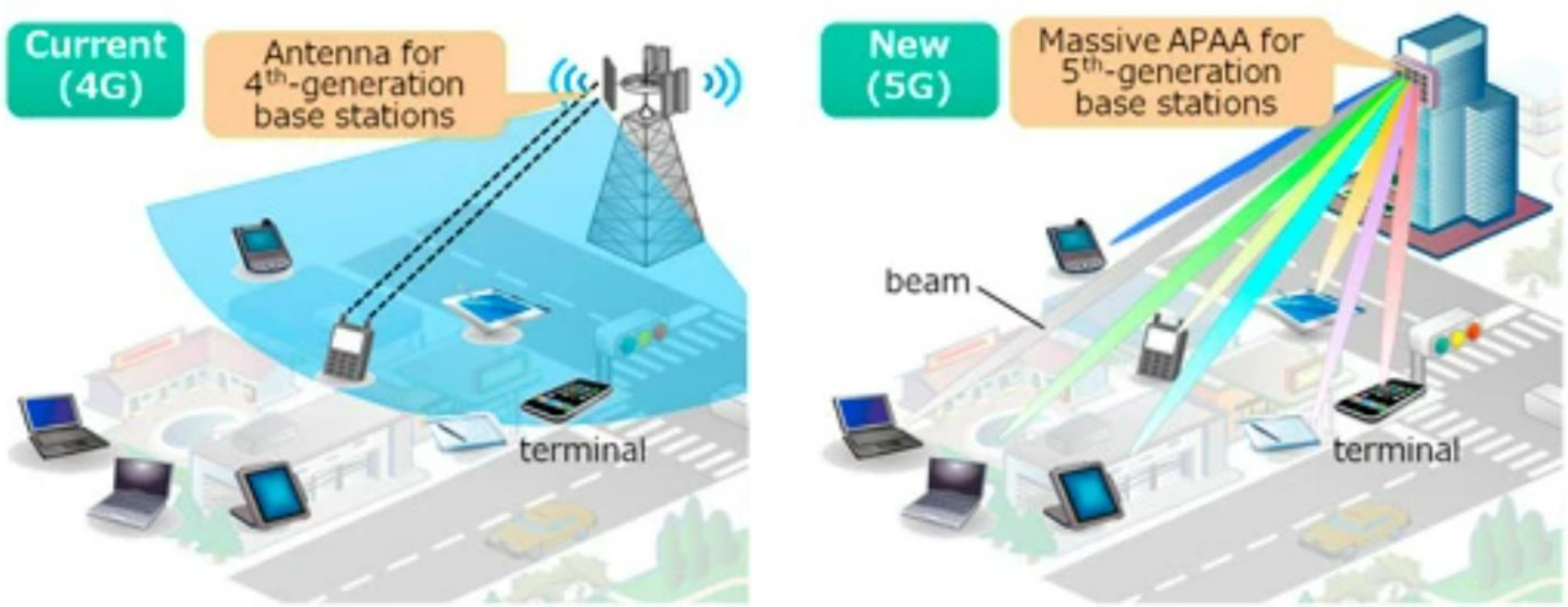
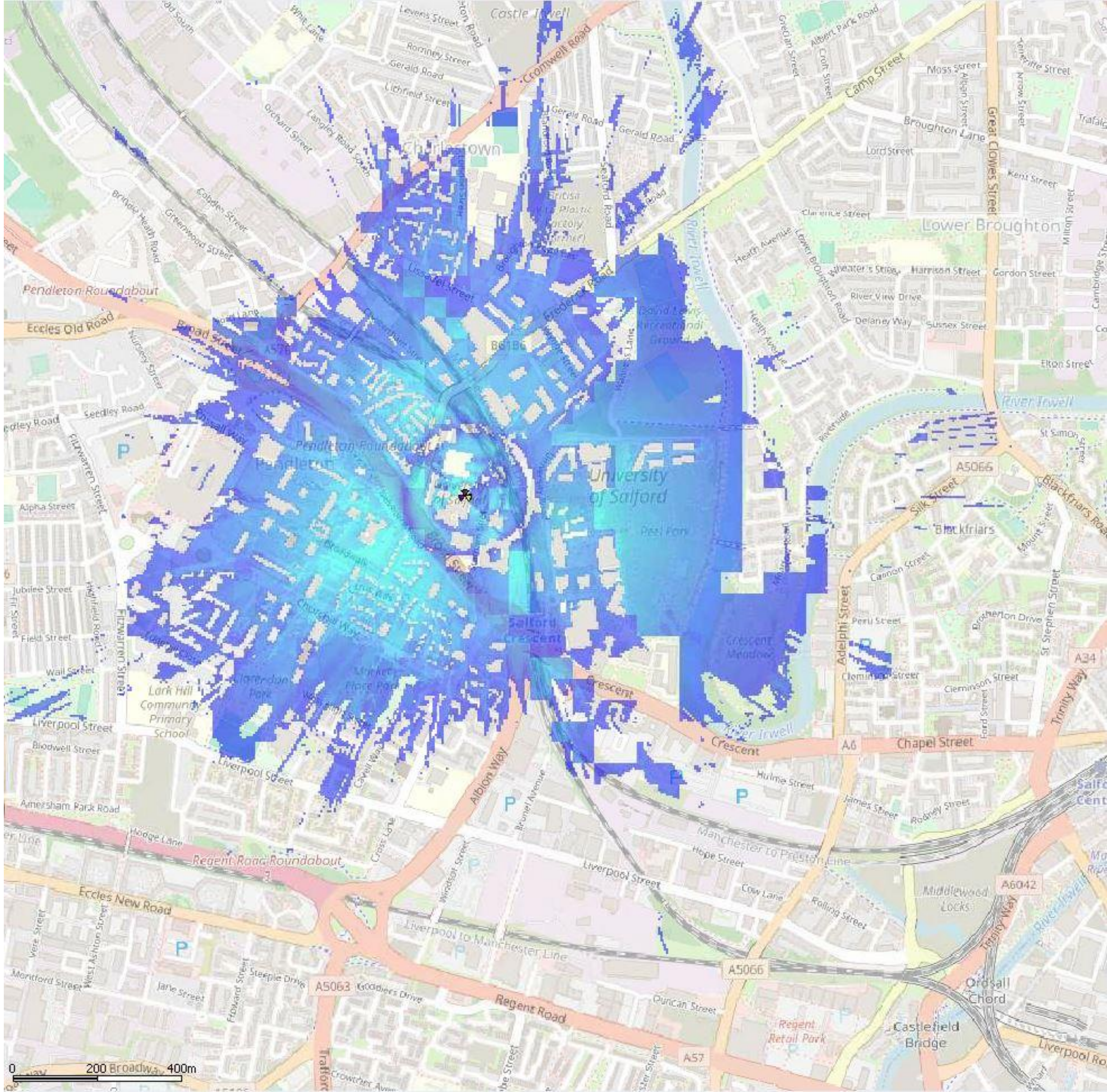


Image source: https://www.ni.com/en/shop/wireless-design-test/what-is-the-mimo-prototyping-system/5g-massive-mimo-testbed--from-theory-to-reality--.html

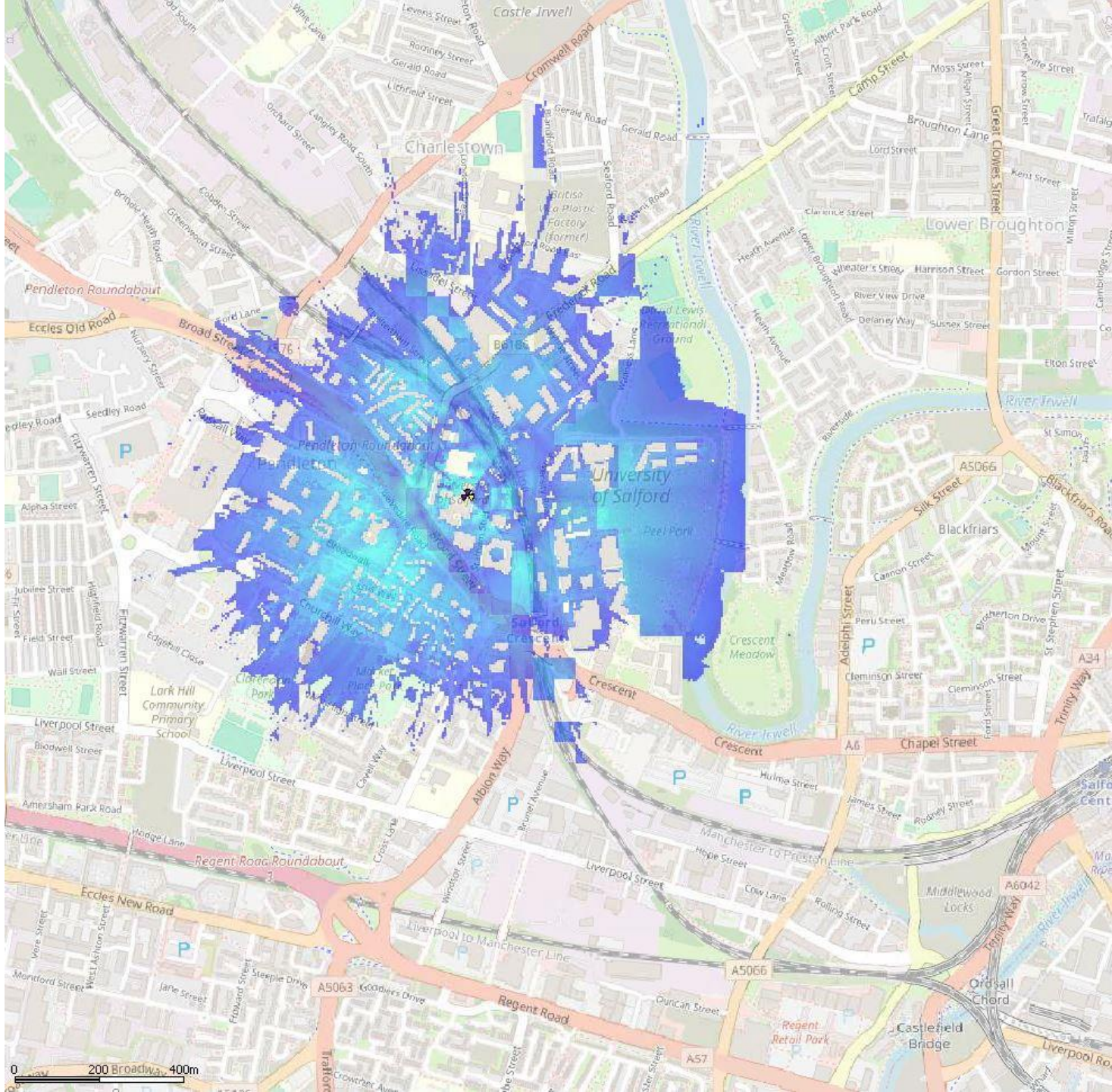
University of Salford - NR3500

- 32T32R massive MIMO antenna system

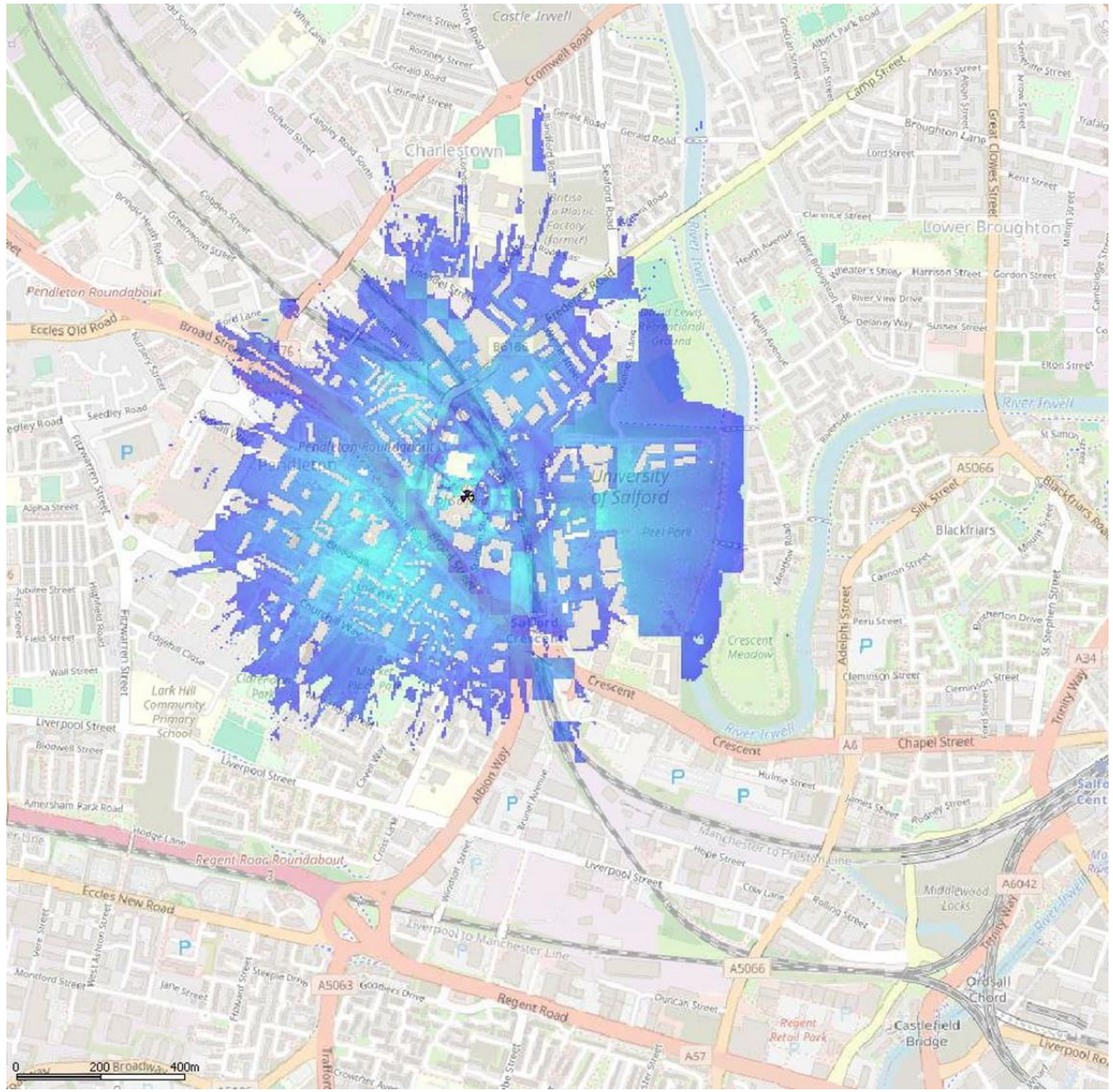


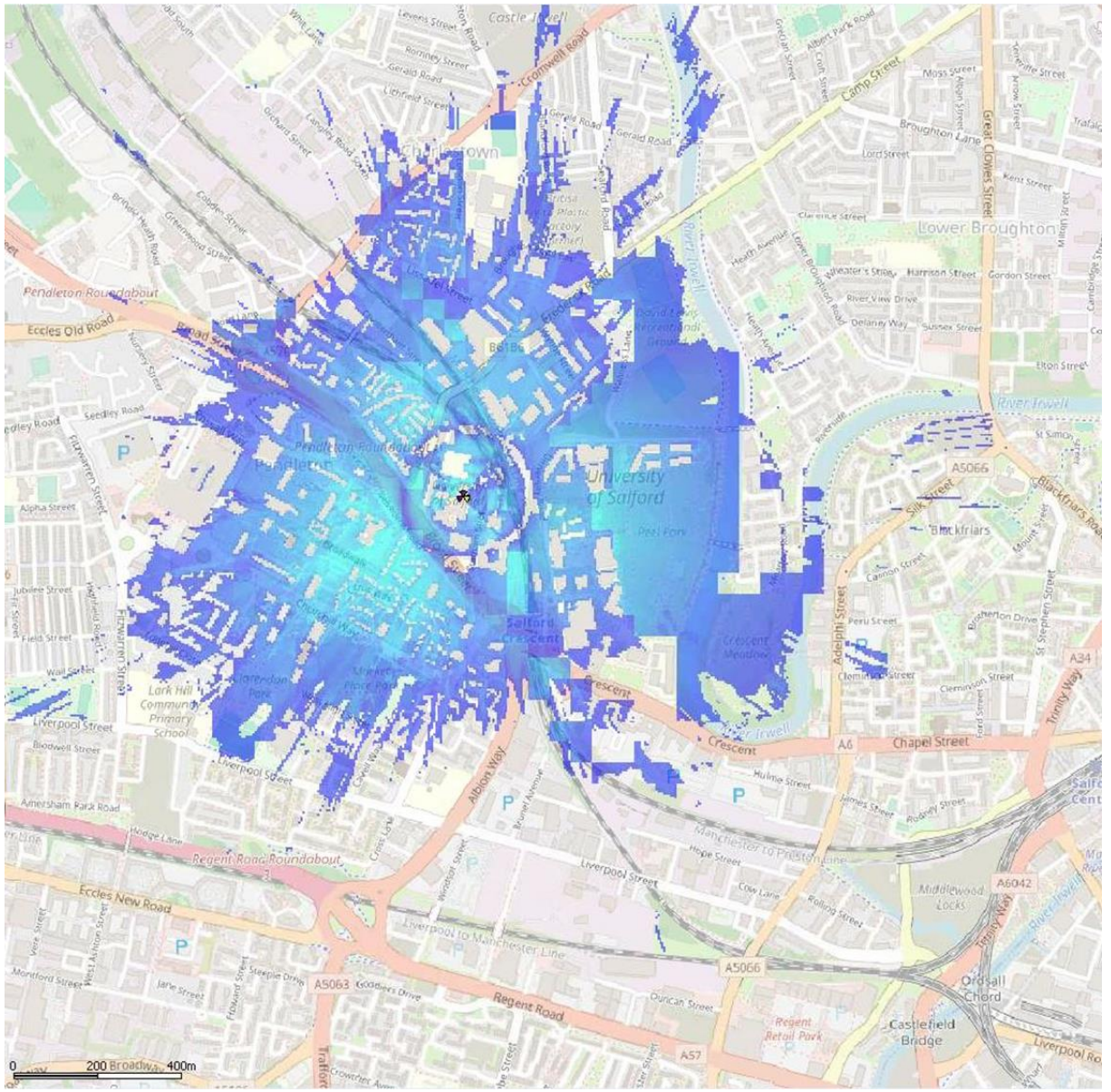
University of Salford - NR3500

- 8T8R massive MIMO antenna system



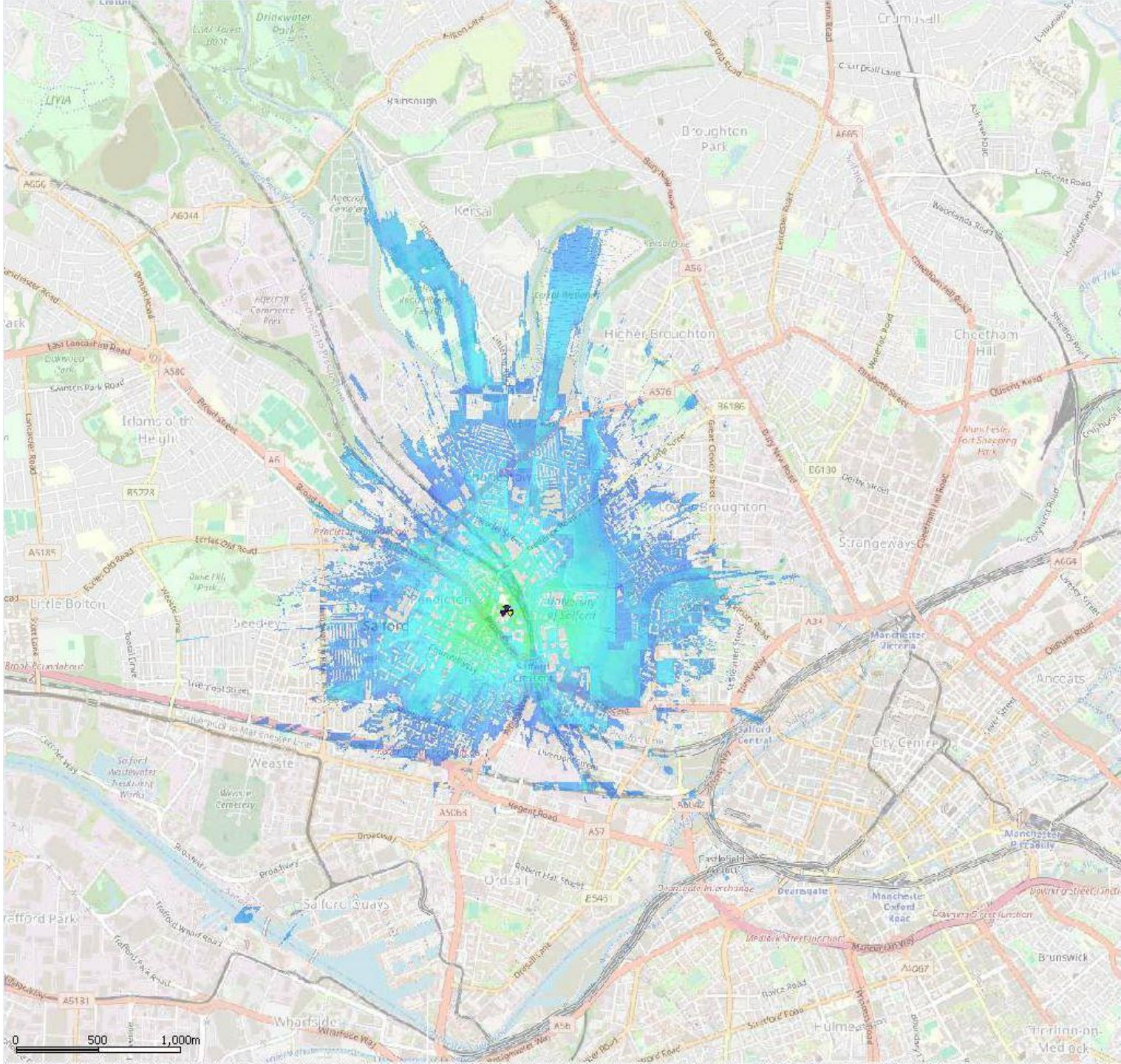
Comparison of NR3500 DL coverage with 8T8R & 32T32R Ae





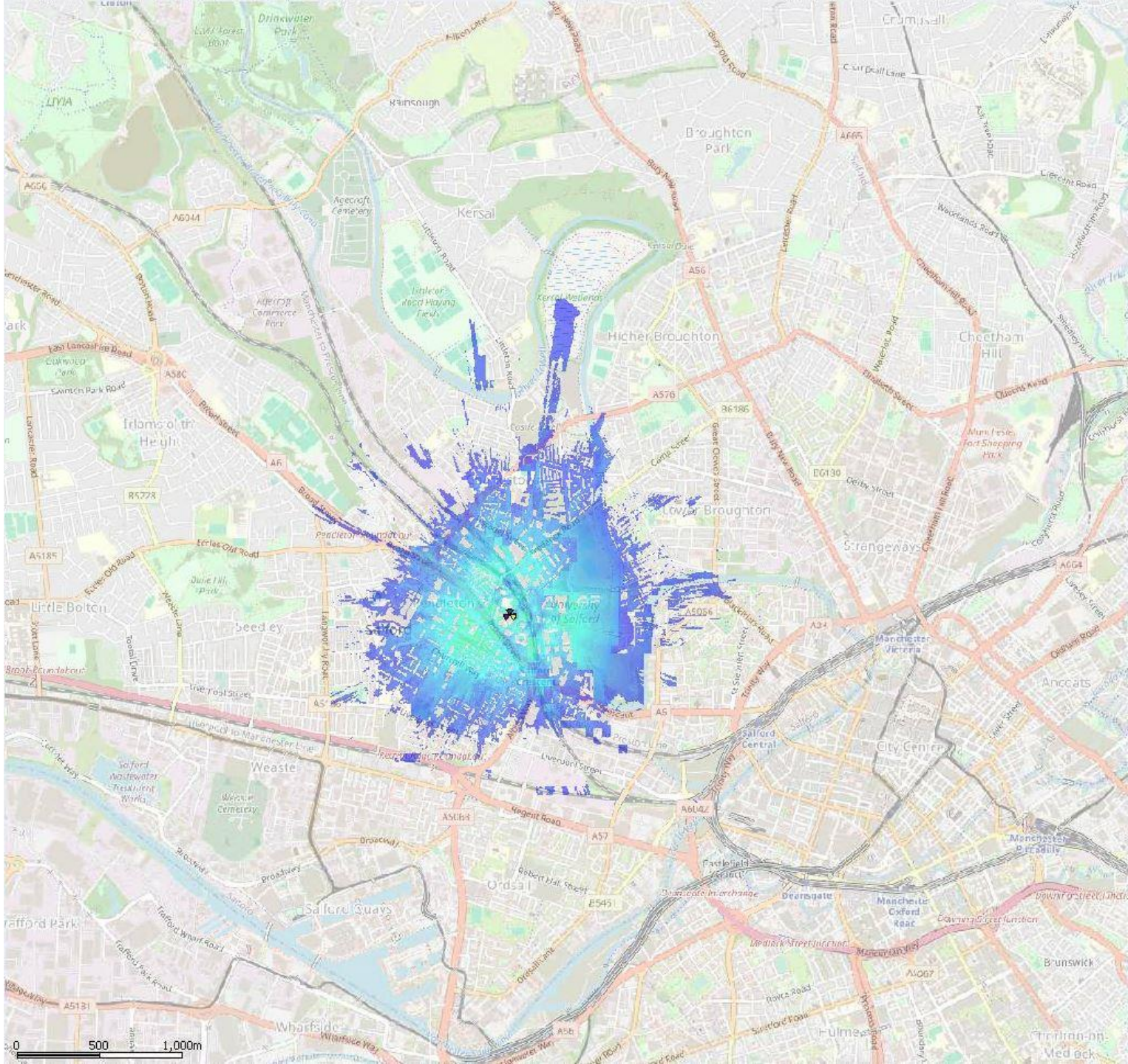
University of Salford - NR3500

- 32T32R massive MIMO antenna system
- Uplink

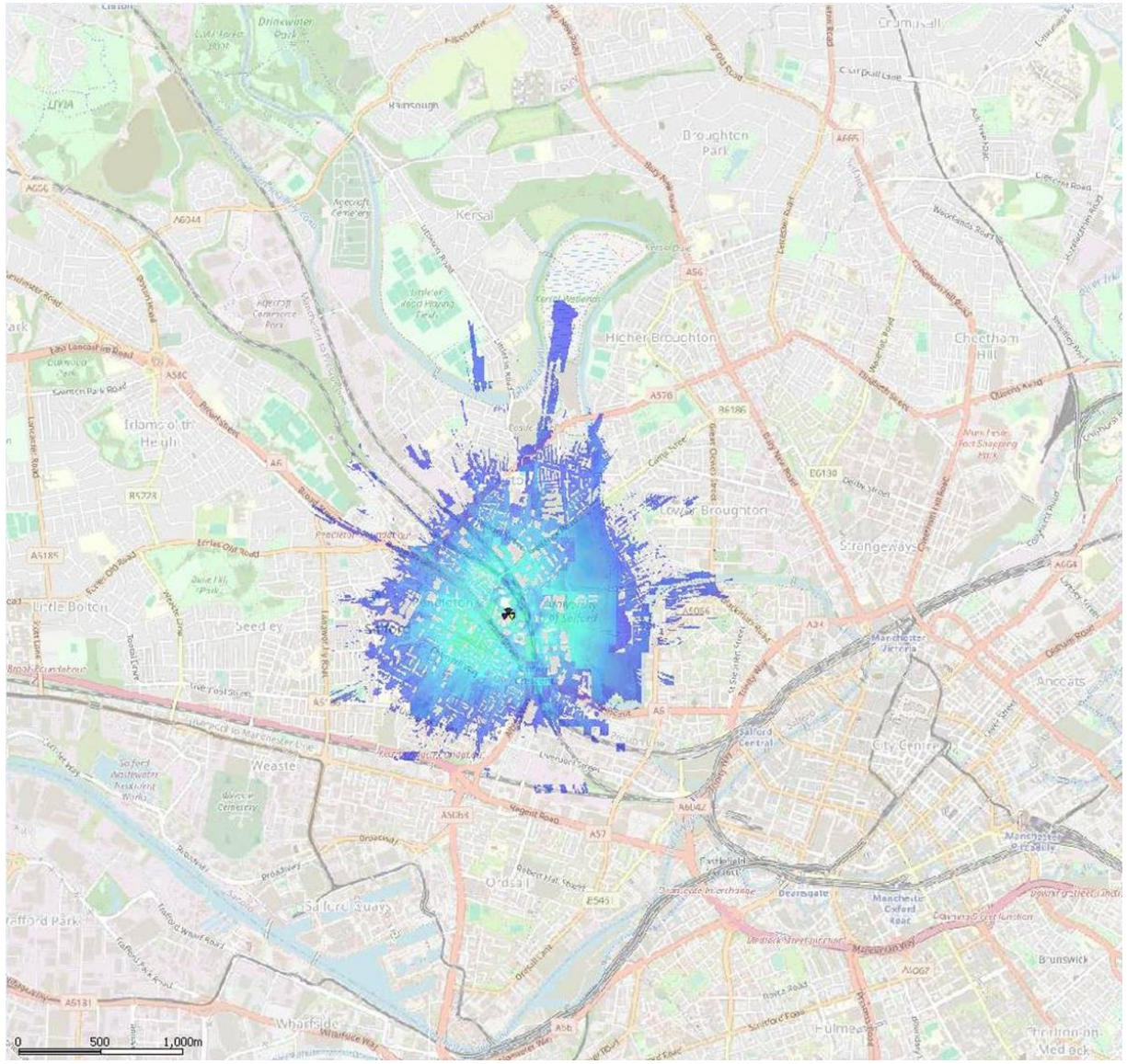


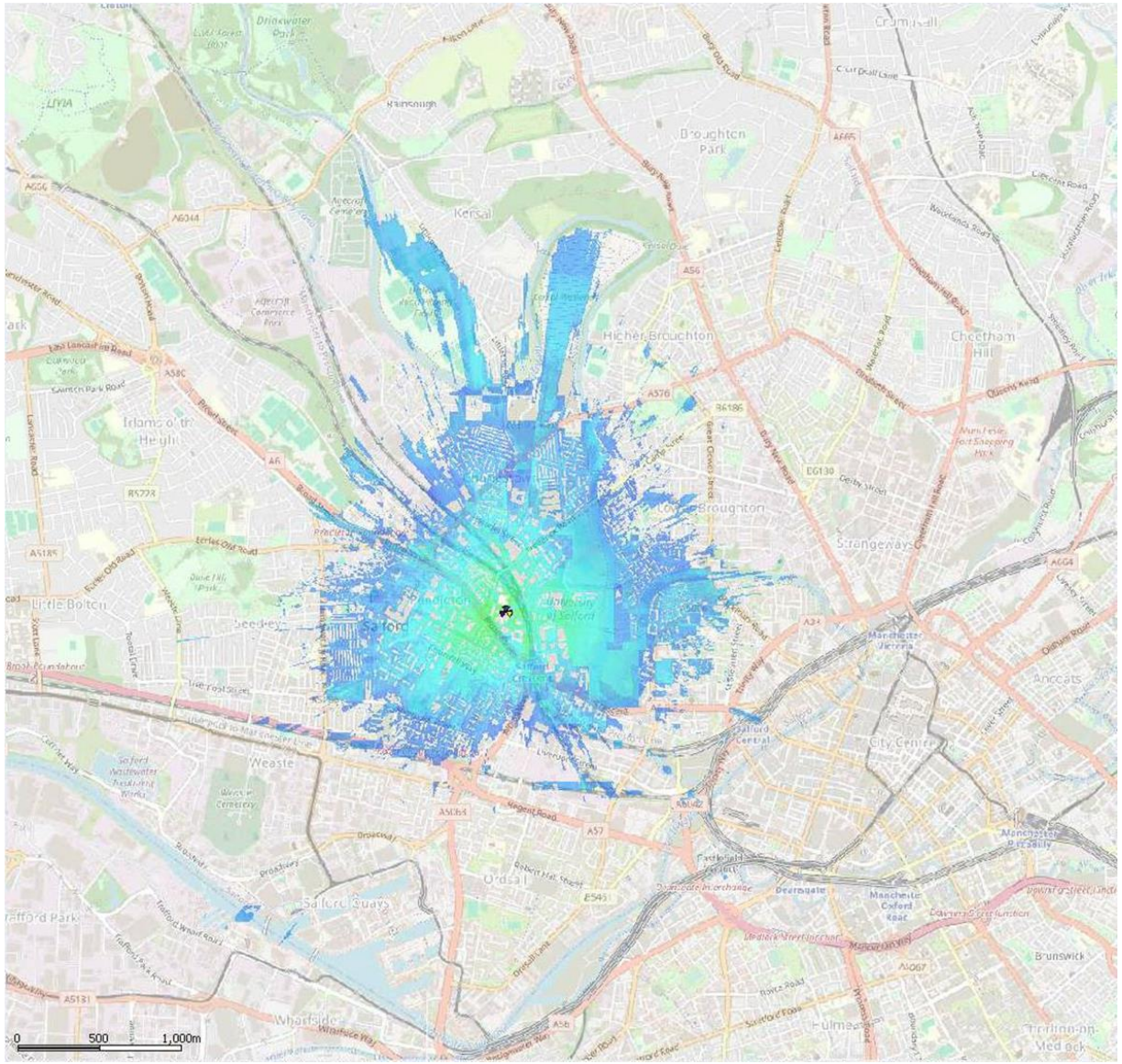
University of Salford - NR3500

- 8T8R massive MIMO antenna system
- Uplink



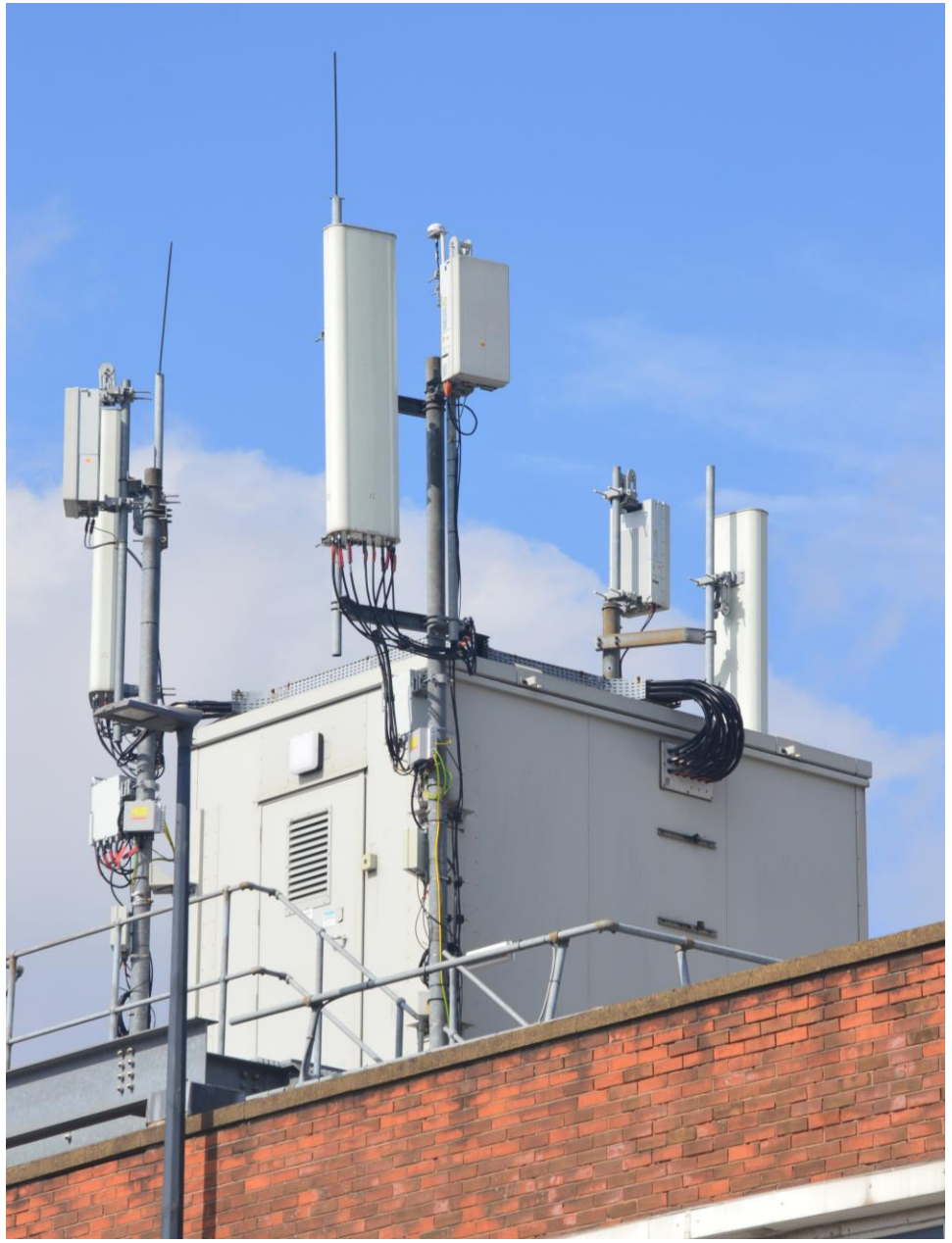
Comparison of NR3500 UL coverage with 8T8R & 32T32R Ae



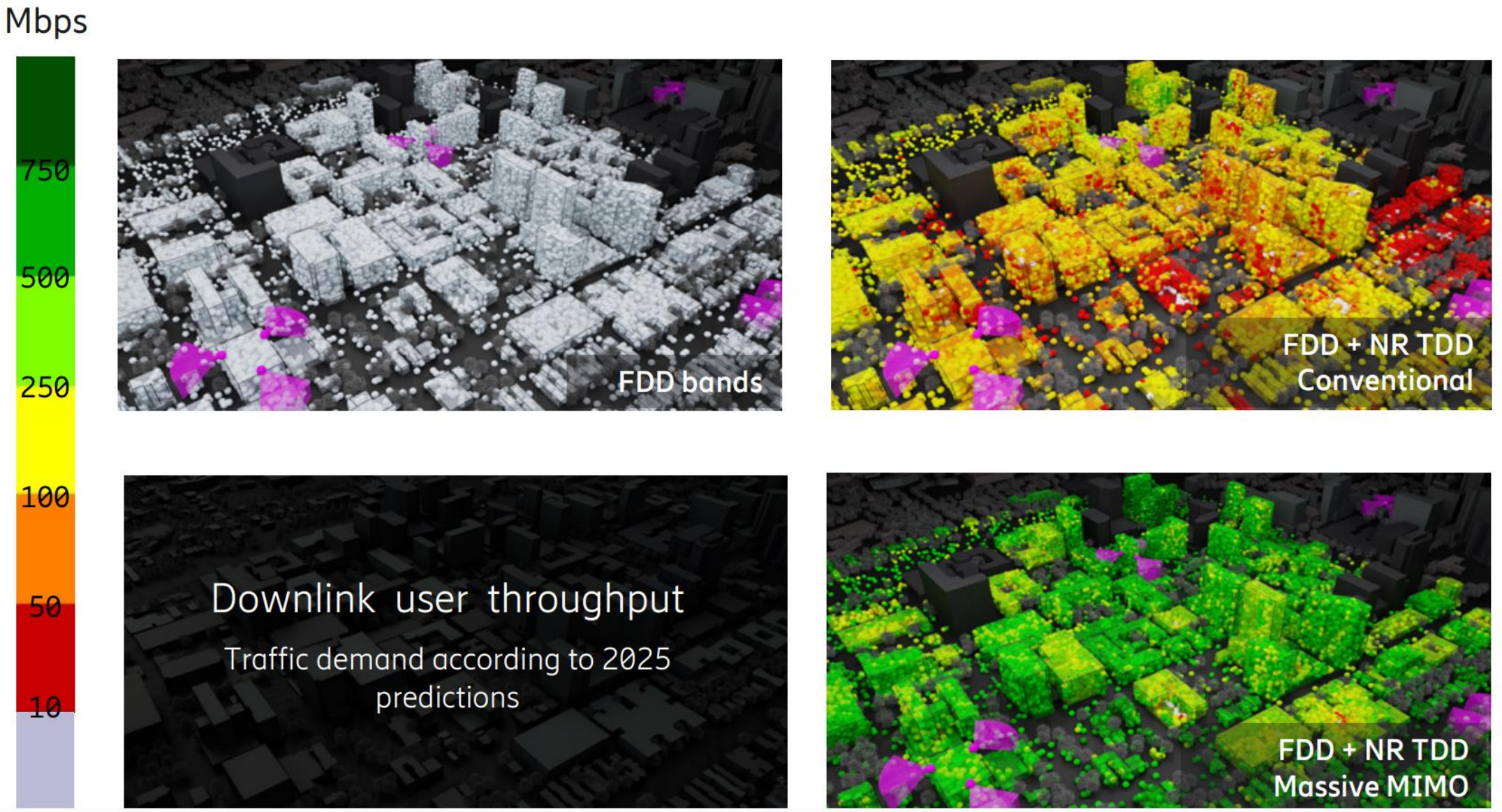


mMIMO

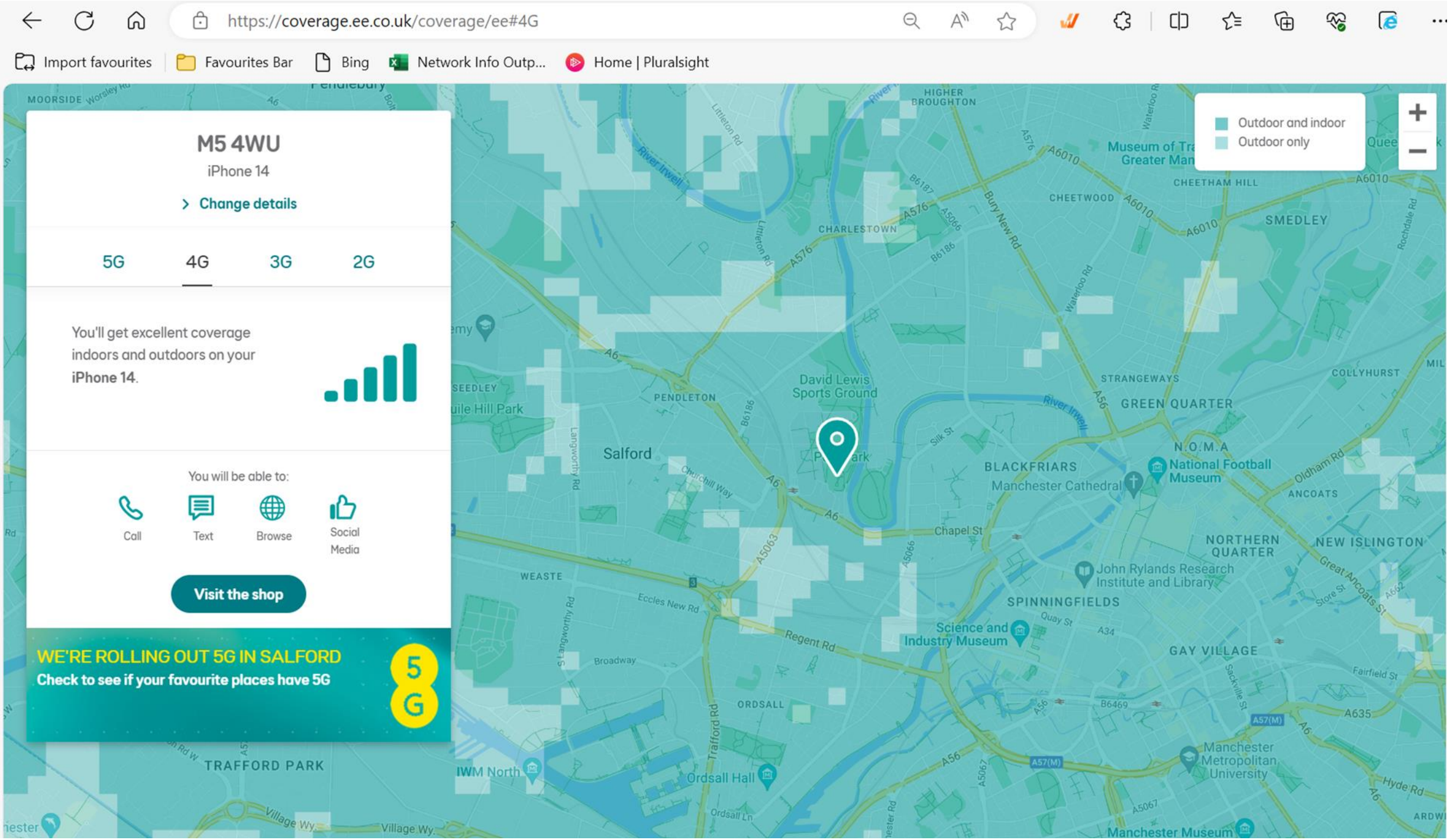
- Massive MIMO technology improves network performance by making use of spatial properties of the radio channel and antenna array capabilities
- 5G networks require cost-efficient solutions that provide significantly improved coverage, capacity, and user throughput to support higher capacity and enhanced user experience
- All sites are unique with different performance requirements and deployment related constraints
- Massive MIMO can effectively provide the required increase of coverage, capacity and user throughput



Benefits of mMIMO



Source: Ericsson


https://coverage.ee.co.uk/coverage/ee#4G
Import favourites
Favourites Bar
Bing
Network Info Outp...
Home | Pluralsight
M5 4WU
iPhone 14
Change details
5G
4G
3G
2G
You'll get excellent coverage indoors and outdoors on your iPhone 14.
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Text
Browse
Social Media
Visit the shop
WE'RE ROLLING OUT 5G IN SALFORD
Check to see if your favourite places have 5G
5G
Outdoor and indoor
Outdoor only
Salford
PENDLETON
David Lewis Sports Ground
CHARLESTOWN
HIGHER BROUGHTON
CHEETHAM HILL
CHEETWOOD
SMEDLEY
STRANGEWAYS
GREEN QUARTER
COLLYHURST
BLACKFRIARS
Manchester Cathedral
N.O.M.A
National Football Museum
ANCOATS
NORTHERN QUARTER
NEW ISLINGTON
John Rylands Research Institute and Library
SPINNINGFIELDS
Science and Industry Museum
GAY VILLAGE
WEASTE
ORDSALL
TRAFFORD PARK
IWM North
Ordsall Hall
Manchester Metropolitan University
Manchester Museum
Chapel St
Regent Rd
Eccles New Rd
Broadway
Trafford Rd
Langworthy Rd
Churchill Way
Silk St
Oldham Rd
Great Ancoats St
Fairfield St
Sackville St
Quay St
Store St
Hyde Rd
Village Wy
Ordsall Ln
River Irwell
Littleton Rd
Bury New Rd
Waterloo Rd
Rochdale Rd
A6
A56
A57(M)
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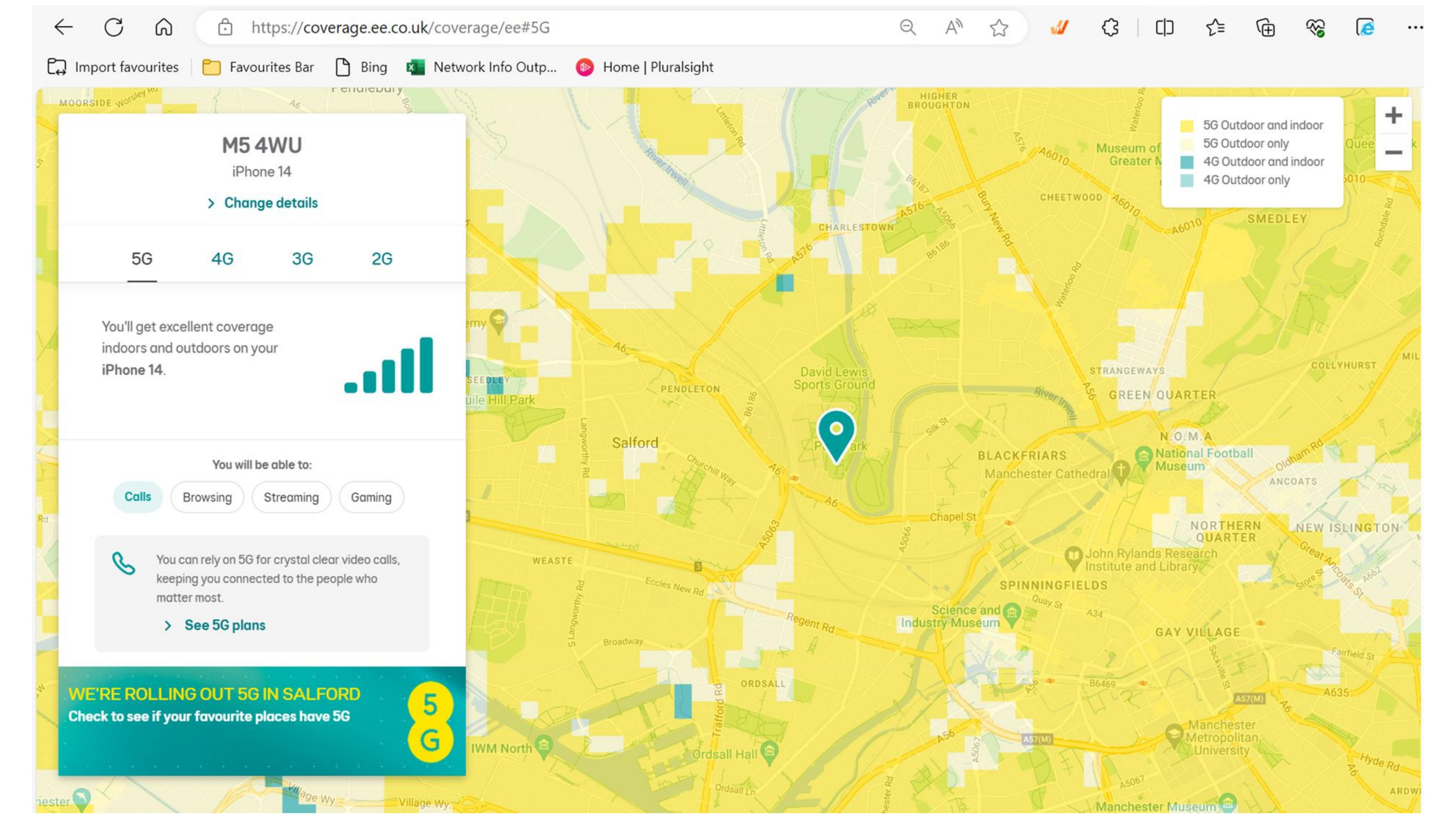
https://coverage.ee.co.uk/coverage/ee#5G
Import favourites
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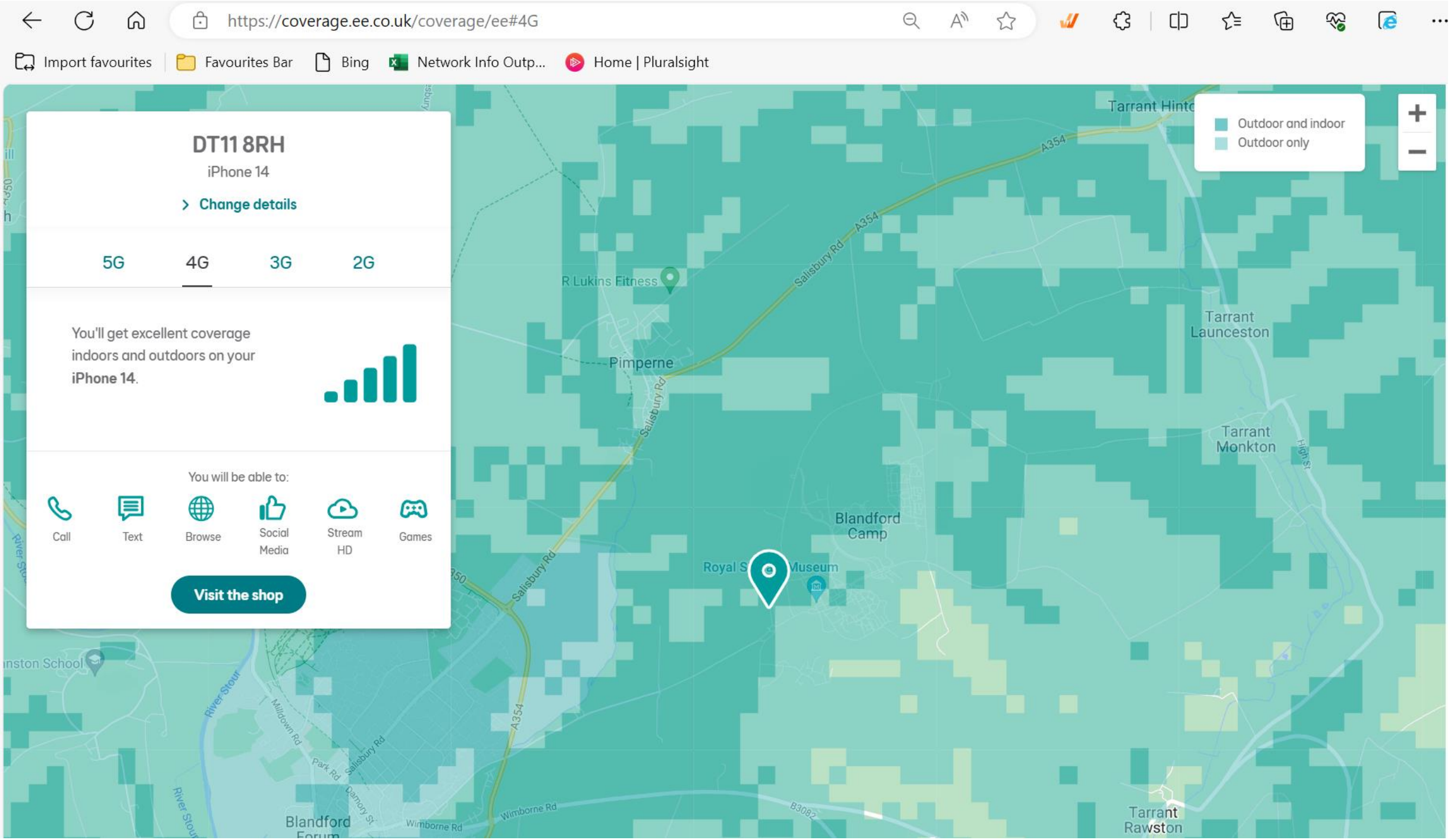
Chapel St
Eccles New Rd
Regent Rd
Broadway
Oldham Rd
Great Ancoats St
Fairfield St
Hyde Rd
Village Wy

Blandford Camp
Rural column site in Dorset


https://coverage.ee.co.uk/coverage/ee#4G
Import favourites
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iPhone 14
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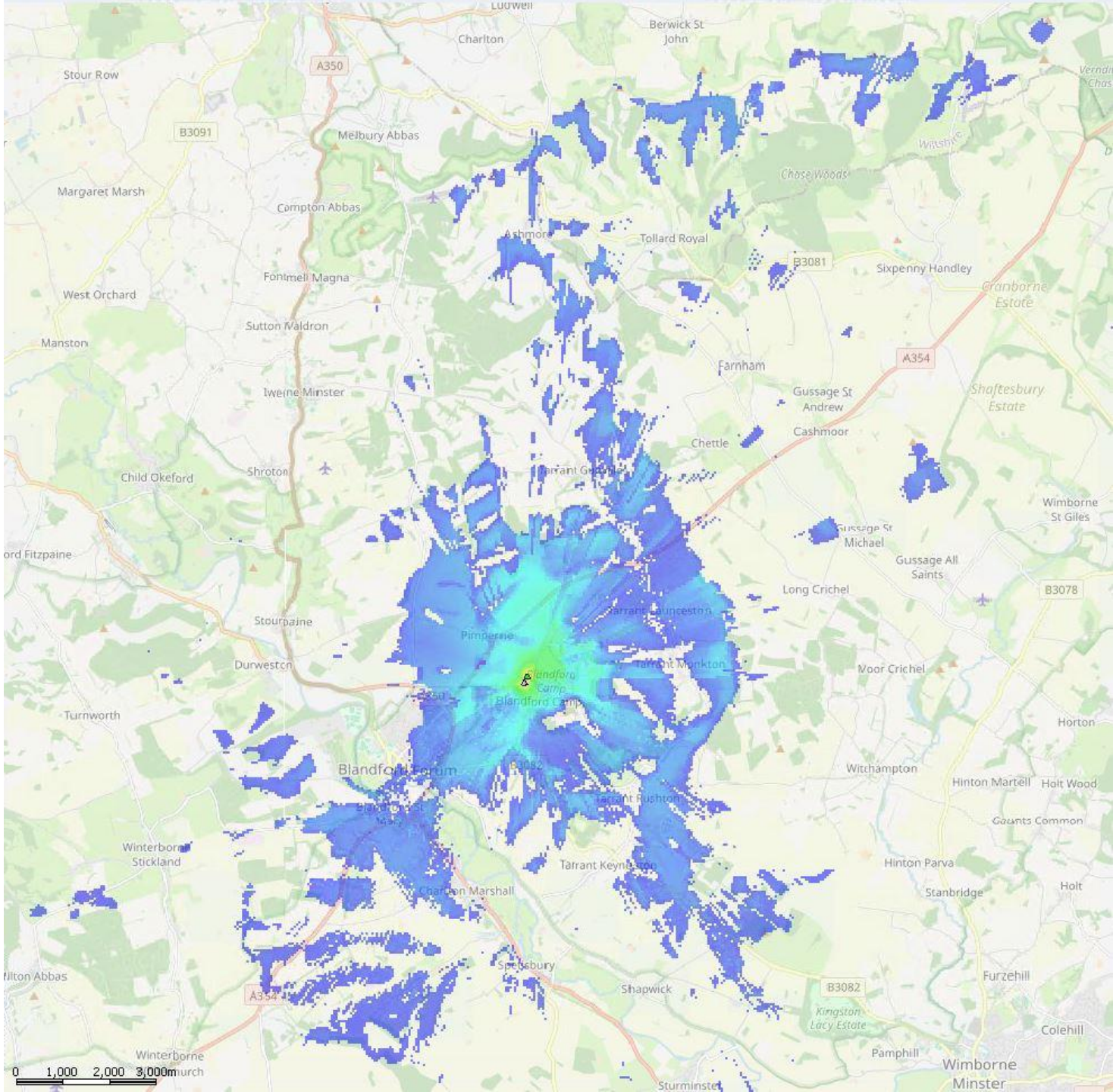
Stream HD
Games
Visit the shop
Outdoor and indoor
Outdoor only
Tarrant Hinto
A354
Salisbury Rd
R Lukins Fitness
Pimperne
Tarrant Launceston
Tarrant Monkton
High St
Blandford Camp
Museum
Royal S
Salisbury Rd
A354
River Stour
Milldown Rd
Park Rd
Salisbury Rd
Damory St
Wimborne Rd
B3082
Blandford Forum
Tarrant Rawston

Blandford Camp

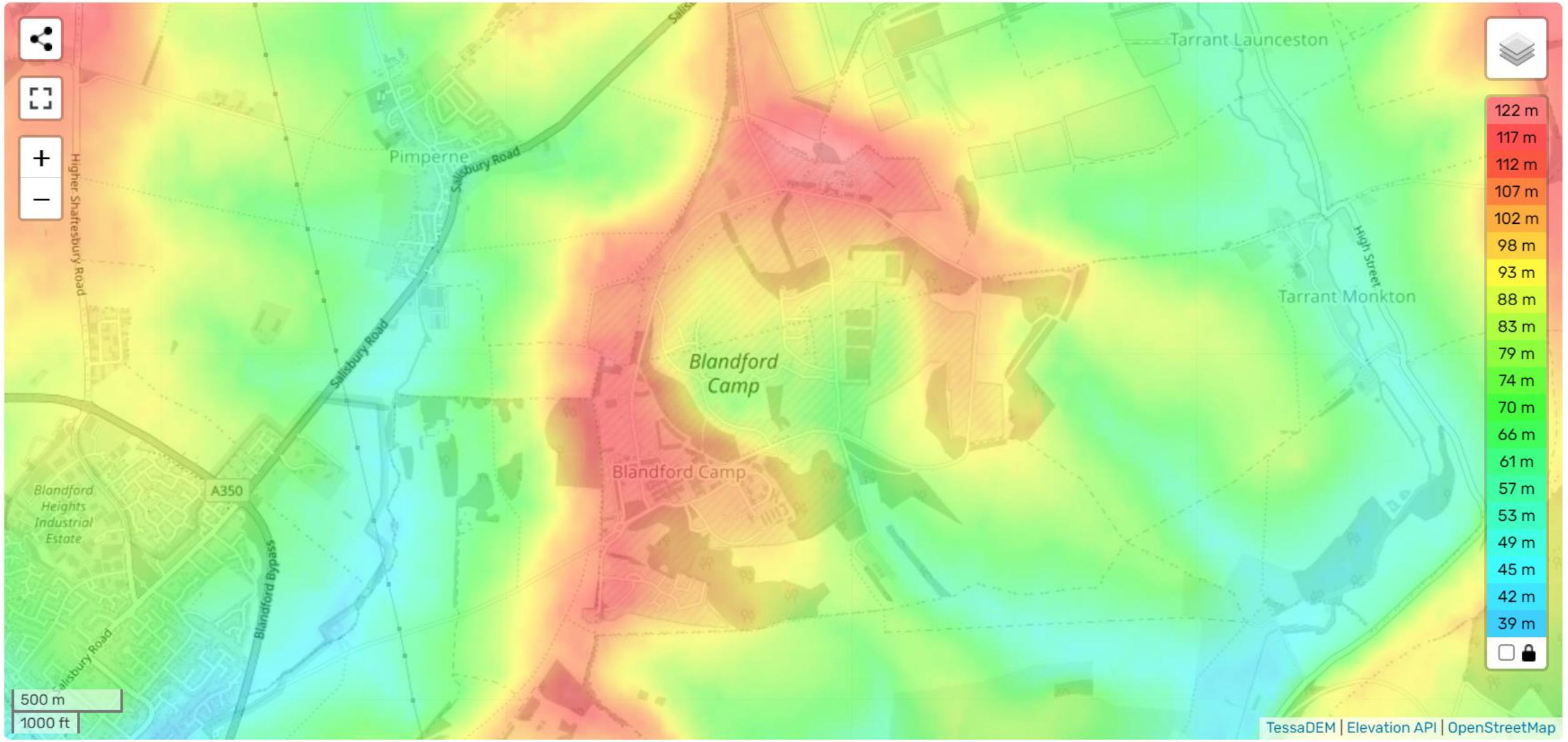
all layers down to -124dBm

- Site supports 2G, 3G & 4G RATs
- 2G Transceivers - 1800 MHz
- 3G Carrier - 2100 MHz
- 4G Carriers - 800 MHz & 1800 MHz

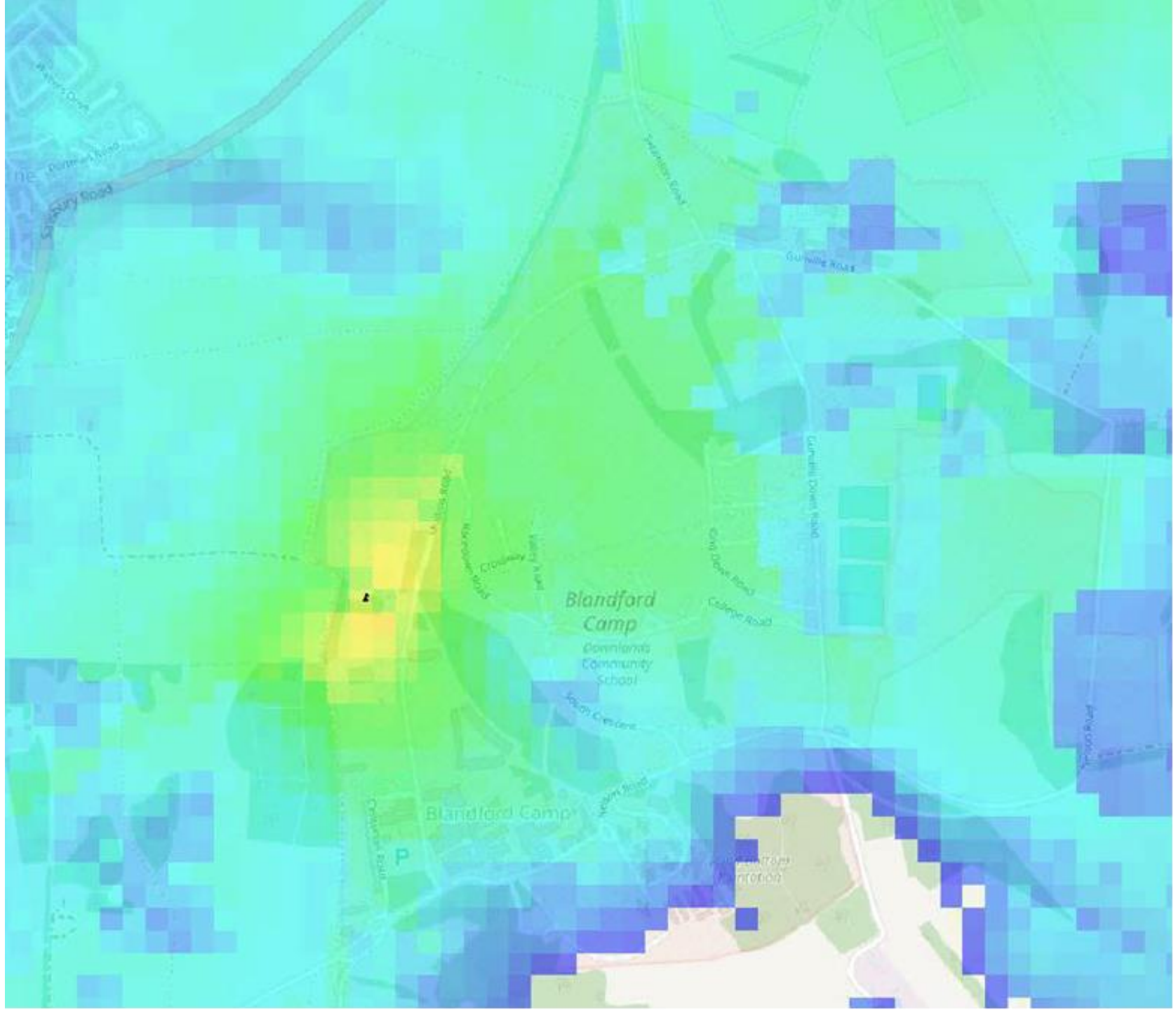
- Site is connected by a 1Gbps optical fibre circuits and supports sub-tended sites via point-to-point microwave radio links

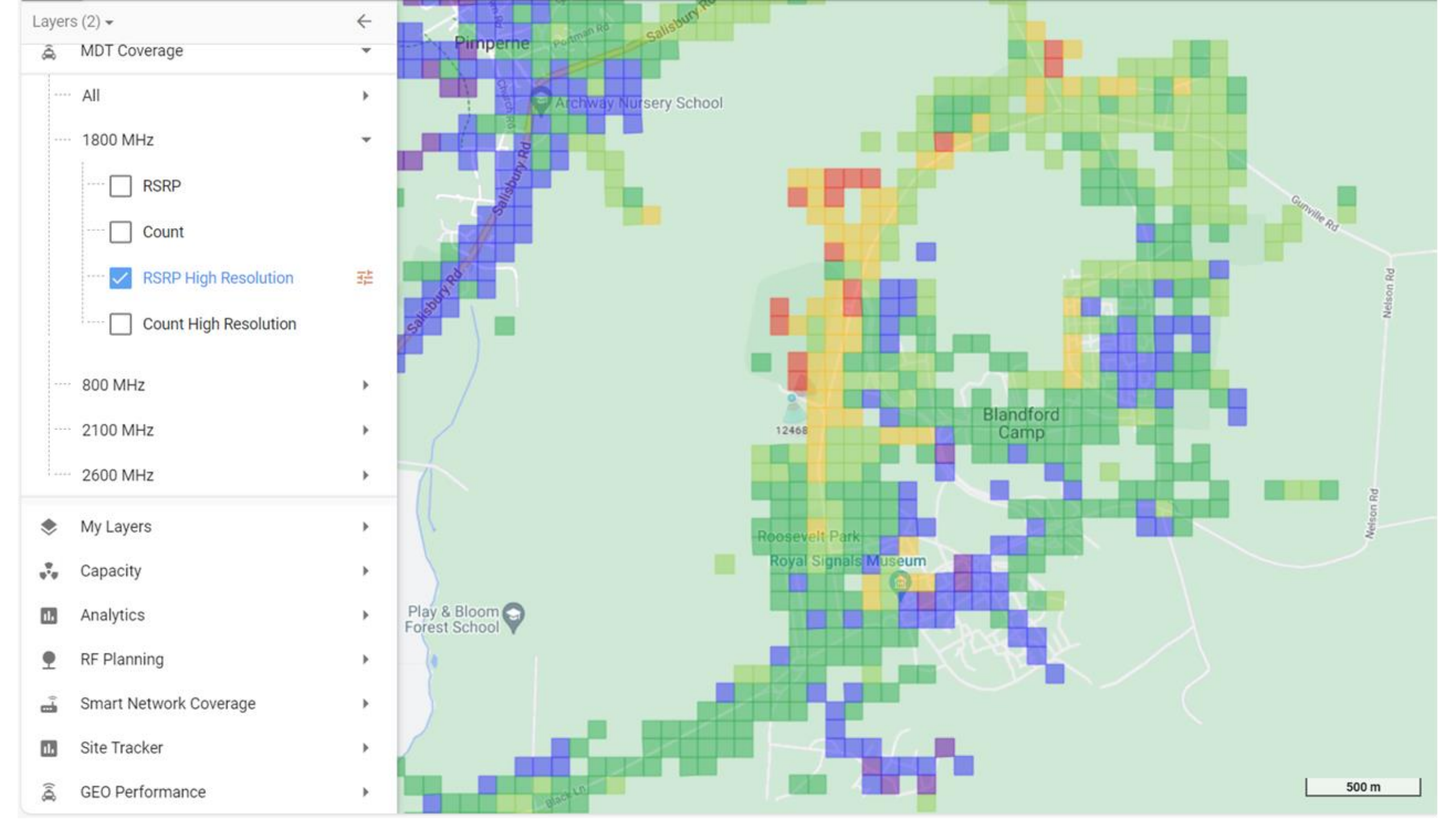


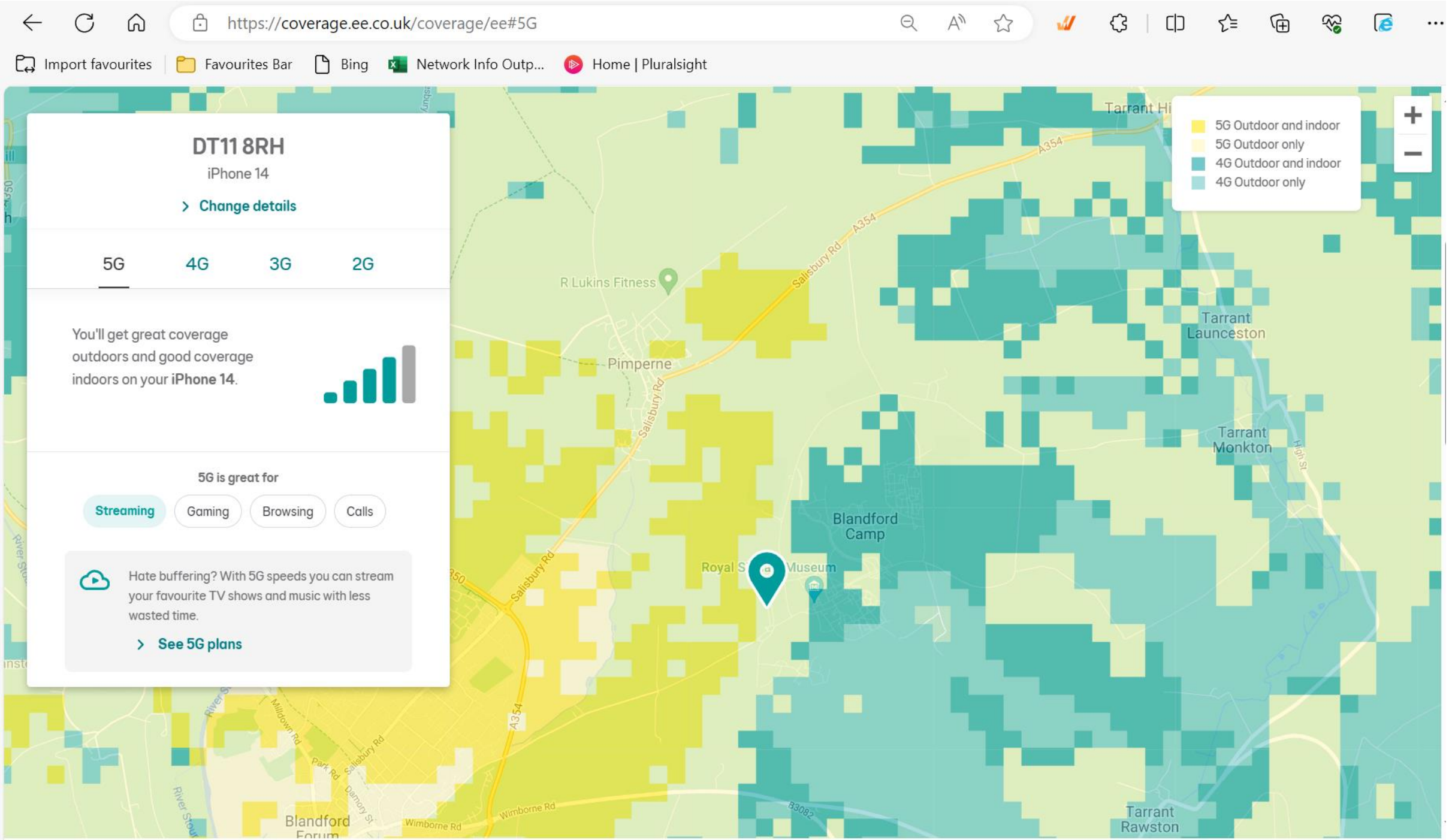
Blandford Camp topographic map



Source: https://en-gb.topographic-map.com/


Blandford Camp
Downlands Community School
Blandford Camp


Layers (2)
MDT Coverage
All
1800 MHz
RSRP
Count
RSRP High Resolution
Count High Resolution
800 MHz
2100 MHz
2600 MHz
My Layers
Capacity
Analytics
RF Planning
Smart Network Coverage
Site Tracker
GEO Performance
Pimperne
Archway Nursery School
Salisbury Rd
Portman Rd
Gunville Rd
Nelson Rd
12468
Blandford Camp
Roosevelt Park
Royal Signals Museum
Play & Bloom Forest School
Black Ln
500 m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5G Outdoor only
4G Outdoor and indoor
4G Outdoor only
Tarrant Hi
A354
Salisbury Rd
R Lukins Fitness
Pimperne
Tarrant Launceston
Tarrant Monkton
High St
Blandford Camp
Royal S
Museum
Wimborne Rd
B3082
Tarrant Rawston
Blandford Forum
Milldown Rd
Park Rd
Damory St
River Stour

Shared access licences - enabling innovation in 5G private networking

Spectrum bands	Channel bandwidths	Deployment environment
1781.7 - 1785 MHz 1876.7 - 1880 MHz	2 x 3.3 MHz	Indoor and Outdoor (Outdoor ≤ 10m height)
2390 - 2400 MHz	10 MHz	Indoor and Outdoor (Outdoor ≤ 10m height)
3800 - 4200 MHz	10, 20, 30, 40, 60, 80 & 100 MHz	Indoor and Outdoor (Outdoor ≤ 10m height)
24.25 - 26.5 GHz	50, 100 & 200 MHz	Indoor Only

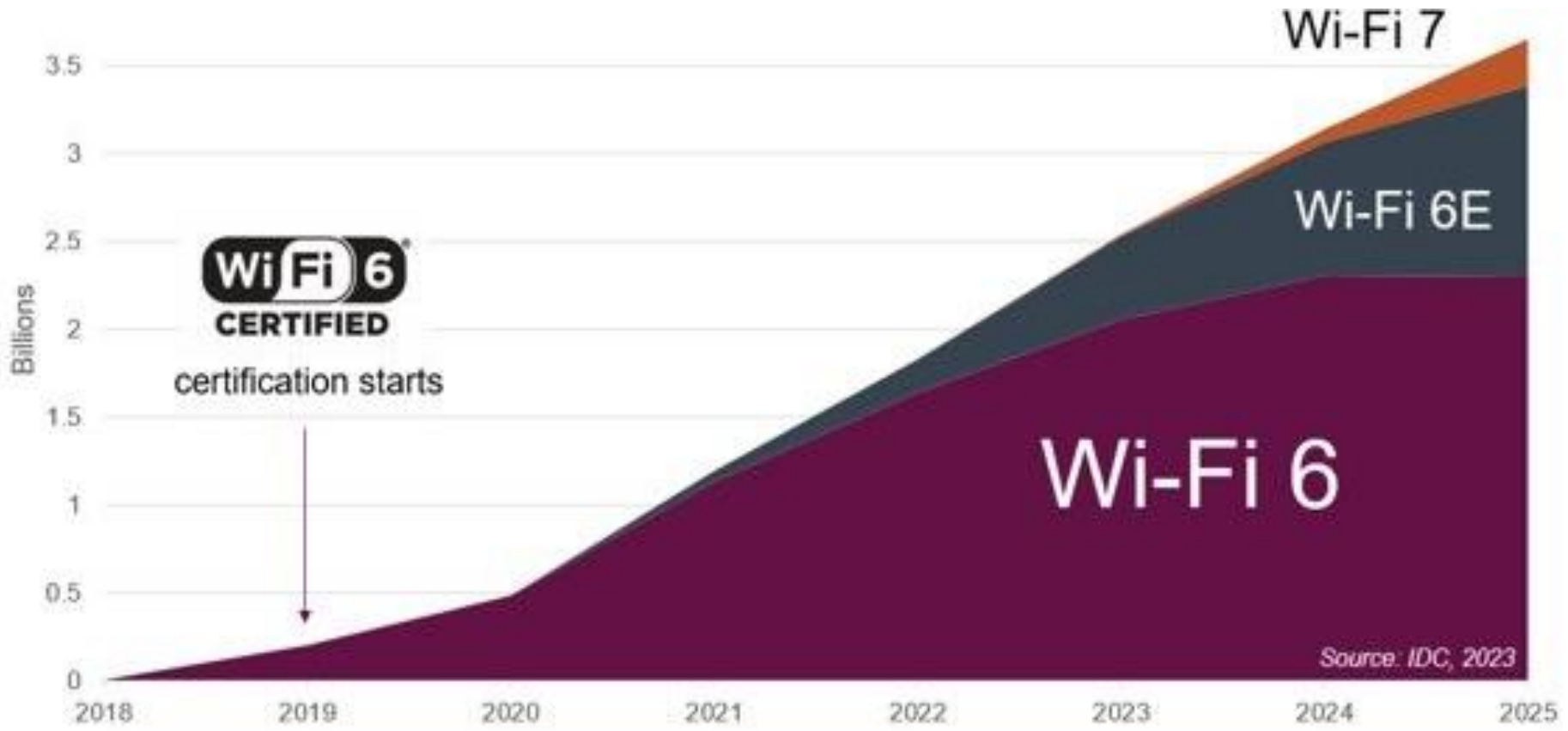
Further information: https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/shared-access

Major ISM bands

Freq band (MHz)	Comments
900	The band nominally referred to as 900 MHz is not internationally agreed and world region allocates different sub-bands, and the channels number depends on the starting frequency of the sub-band it belongs to. As a result, there is no global channel plan
2400 - 2500	Often referred to as the 2.4 GHz band, this spectrum is the most widely used of the bands available for Wi-Fi. Used by 802.11b, g, & n. It can carry a maximum of three non-overlapping channels. This band is widely used by many other non-licensed items including microwave ovens, Bluetooth, etc.
5725 - 5875	This 5 GHz Wi-Fi band or to be more precise the 5.8 GHz band provides additional bandwidth, and being at a higher frequency, equipment costs are slightly higher, although usage, and hence interference is less. It can be used by 802.11a & n. It can carry up to 23 non-overlapping channels but gives a shorter range than 2.4 GHz. 5GHz Wi-Fi is preferred by many because of the number of channels and the bandwidth available. There are also fewer other users of this band…
3550 - 3700	This band has been allocated in the USA under what is termed the Citizens Broadband Radio Service, a 5 MHz band gap is allowed at either end of the allocation to prevent interference spilling out of the band. It is allocated under the premis that users do not cause interference to the primary users. It may be divided into eight 5 MHz channels, four 10 MHz channels, or two 20 MHz channels.
5945 - 7125	This band is being utilises by the Wi-Fi 6E, E for extended as it accesses the nominally named 6 GHz band which enables channel bandwidths of 20, 40, 80 & 160 MHz to be used.

Source: https://www.electronics-notes.com/articles/connectivity/wifi-ieee-802-11/channels-frequencies-bands-bandwidth.php

WiFi Alliance - WiFi shipment forecasts

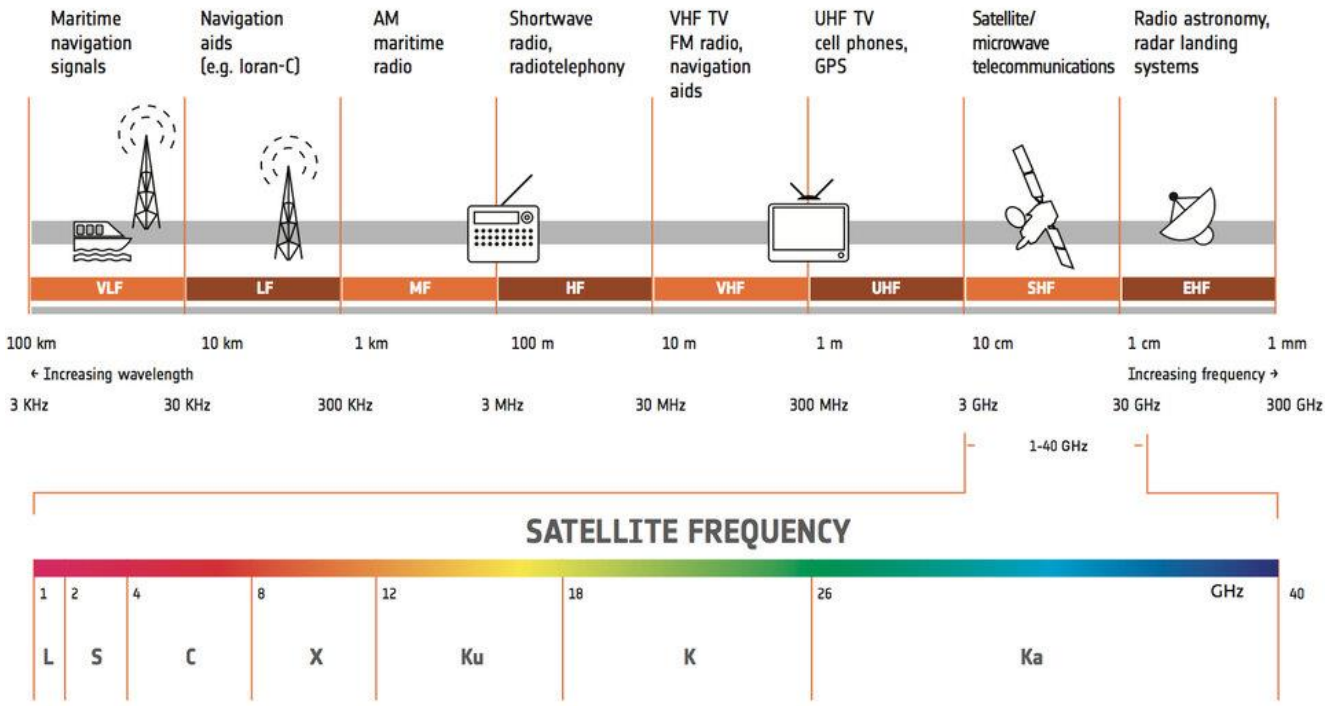


Wi-Fi devices in use, including access points, smartphones, laptops, security cameras, and smart plugs

Source: https://www.wi-fi.org/beacon/the-beacon/wi-fi-by-the-numbers-technology-momentum-in-2023

New Space and the growth of satellite and airborne communications…

Treat these types of diagrams as being illustrative and indicative – we know cellular is operating above 3 GHz, in fact it is now operating in ka band and could operate in unlicenced spectrum in V-band…



Source: https://www.esa.int/Applications/Connectivity_and_Secure_Communications/Satellite_frequency_bands

GEO satellite communications example…

- Both ViaSat-1 and ViaSat-2 operate in the 28.1-29.1 GHz and 29.5-30.0 GHz bands (Earth-to-space) and the 18.3-19.3 GHz and 19.7-20.2 GHz bands (space to-Earth), and ViaSat-2 also includes the 17.7-18.3 GHz (space-to-Earth) and the 27.5-28.1 GHz (Earth-to-space) bands.
- The satellite network provides service to small user antennas. In addition, a number of larger gateway-type antennas have been deployed for ViaSat-1 and additional earth stations will be employed for ViaSat-2.
- The gateway-type antennas have the capability of transmitting in any channel within the 28.1-29.1 GHz and 29.5-30.0 GHz bands (as well as 27.5-28.1 GHz for ViaSat-2).
- Uplink transmissions from the smaller user terminals currently occur in the 28.35-29.1 GHz and 29.5-30.0 GHz bands, but ViaSat will be seeking authority in the U.S. to operate user terminals in the lower portion of the 28.1-28.35 GHz band for ViaSat-1 and eventually the 27.5-28.1 GHz portion for ViaSat-2.
- We plan to ask for similar authority in other areas of the world as our satellite fleet expands…

Text Source: https://www.ofcom.org.uk/__data/assets/pdf_file/0037/49879/viasat.pdf

Background image source: https://www.bbc.co.uk/news/science-environment-40123180

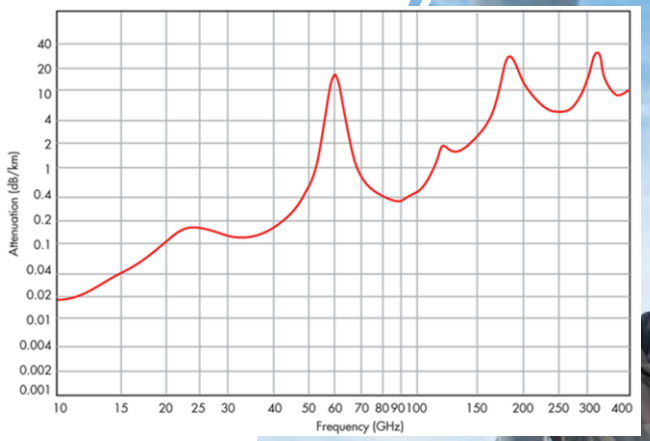
OneWeb spectrum utilisation example (USA)

Type of link and transmission direction	Frequency ranges
Gateway to satellite	27.5 to 29.1 GHz 29.5 to 30.0 GHz
Satellite to gateway	17.8 to 18.6 GHz 18.8 to 19.3 GHz 19.7 to 20.2 GHz*
User terminal to satellite	12.75 to 13.25 GHz* 14.0 to 14.5 GHz
Satellite to user terminal	10.7 to 12.7 GHz

* Although the OneWeb satellites have the capability to operate in the Earth-to-space direction in the 12.75-13.25 GHz band, and the space-to-Earth direction in the 19.7-20.2 GHz band, FCC authorization is not being requested for these bands at this time and they will not be used from any US territories.

Ku-band refers to frequencies from 12 GHz to 18 GHz, while Ka-band refers to frequencies from 26.5 GHz to 40 GHz

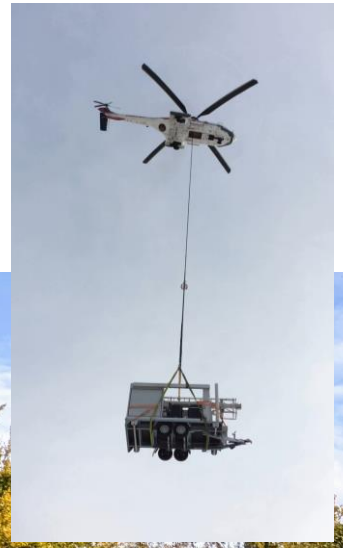
V-band (57 to 71 GHz)



- The WiGig market size was valued at USD 16.29 billion in 2022 and is projected to grow from USD 19.71 billion in 2023 to USD 81.45 billion by 2030, exhibiting a CAGR of 22.5% during 2023-2030
- The 60 GHz band is also used for point to point, point to multi-point and mesh-based radio systems
- 60 GHz radar sensors for automotive applications are already shipping in volume
- Developments are on-going for LEO satellite access in V-band

University of Salford MANCHESTER

Rapid Response Vehicles and other Tactical Deployable Capabilities

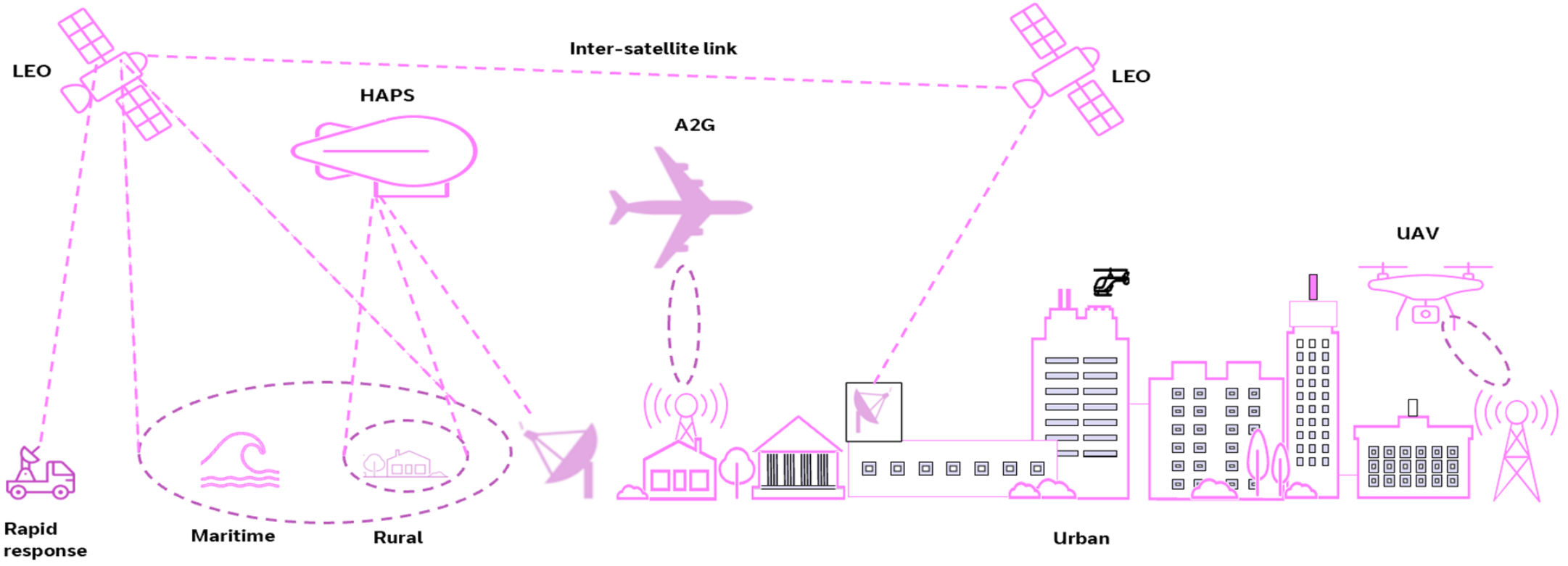


Satcom on the move + unlicensed 5G private network or WiFi - hiding in the noise…

It is possible to build a deployable mobile communications system at low cost to provide local wireless access and global reach-back through the integration of COTS equipment - enabling operation with a low-profile, but not necessarily invisible, if we know where to look...

LEO mega-constellations & 3GPP NTN

GEO & MEO



The increasing commercialisation of space is presenting ever more connectivity solutions, including new LEO mega-constellations, High Altitude Platform Systems (HAPS) and drones - Air to Ground networks are becoming increasingly popular too.

Summary

- RF engineering is a complex subject, with many variables
- The range of frequency bands in commercial use has, and is continuing to increasing rapidly
- Our use of, and reliance on, radio frequency spectrum has never been greater
- We have more degrees of freedom now than ever before with multi-band and multi-technology terrestrial solutions plus airborne and space-based assets at low cost
- It is essential that we, as Royal Signals, have a detailed understanding of the RF environment - to maximise opportunities while minimising threats…