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for everyone

Mobile coverage open data: signal strength measurements

How it works and example applications of the data

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Annex

1. Overview

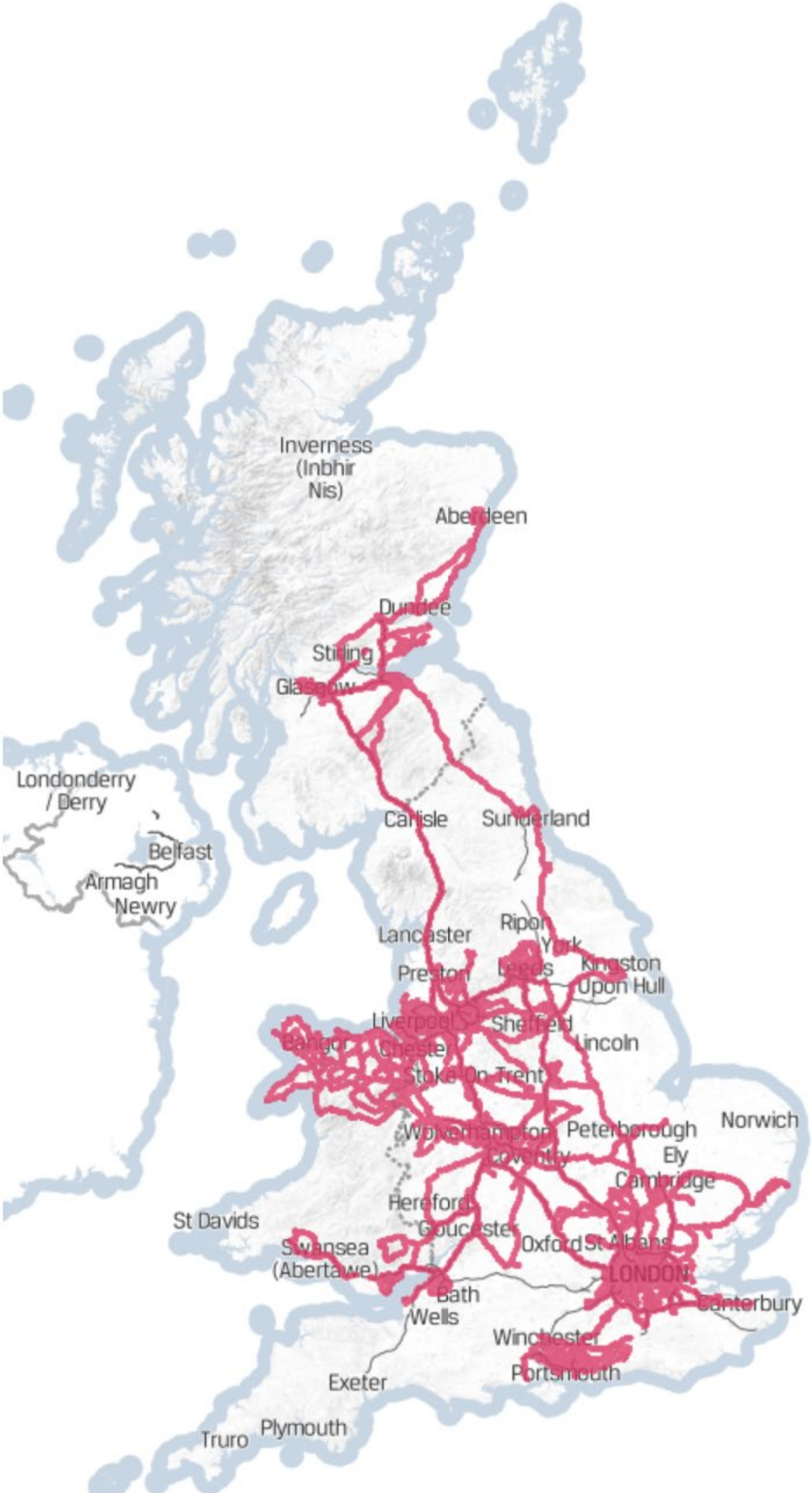
In the summer of 2020, Ofcom began a new, rolling data collection exercise to monitor the extent of mobile coverage in the UK. This data helps us to assess mobile network operators' (MNOs) coverage predictions and their reasonableness across different regions and terrains.

More specifically, we have been collecting 4G and 5G signal strength measurement data using our spectrum assurance vehicles along roads in England, Scotland and Wales.[1] At any one time we have up to three vehicles collecting data as our engineers go about their day-to-day work. We rotate the vehicles to different home locations approximately every three months. We do not generally target specific roads or locations for our measurements as part of this work, although we do sometimes direct our engineers to areas that might be of particular interest (for example, the switch on of a new 5G service in a specific location).

Since 2020, our engineers have driven over 12,000 miles, collecting signal strength data along the routes shown in Figure 1. The current data release (April 2022) is the second round of published data.

[1] We plan to include data for Northern Ireland in a future update.

Figure 1: Example of routes travelled as part of the drive testing, and for which data is available



We make the data we collect available to download from our website wherever possible, under our open data initiative, so that interested parties can use the information for their own applications.

Our mobile coverage measurement open data for 4G and 5G can be used for a wide range of purposes with suitable data analysis. To help organisations wanting to use our data, we have set out here what the data represents, how to interpret it and provided some example use cases. This document is aimed at a mainly technical audience with some prior knowledge of mobile communications and the use of database applications to process large data files.

To best understand how to apply and process the data for your requirements, this note is best read alongside our drive testing methodology document.

While Ofcom can only measure a fraction of roads across the UK, this growing dataset provides a useful evidence base. Availability of real-life data to complement and challenge theoretical models is an essential element of a sound scientific approach. We are sharing this data in anticipation that it can be of value to a range of stakeholders in addition to our own validation work.

Please let us know if you find this data useful by contacting us at drivetestingdata@ofcom.org.uk. We will use any feedback to inform our decision on whether to publish more data in the future.

The data collected – in brief

- **Our measurement data is different from mobile coverage predictions provided by mobile network operators**. The signal measurements are taken in a snapshot of time and location and cannot be directly compared to mobile coverage predictions provided by the MNOs. The practical measurements are influenced by local factors, whereas the predictions are based on computer modelling of an expected signal level on a statistical basis, typically over a broader area of many metres.
- **The data represents the strongest mobile signals (per mobile operator) for 4G and 5G received by rooftop antennas**. It does not include signal loss into the vehicle and therefore does not represent what a mobile handset inside the vehicle would receive.
- **We do not have data for the whole of the UK**. Our data is limited to the locations visited by our field engineers as they go about their day-to-day work. An interactive map is available on our website showing the locations for which data is available in an open format and in line with our open data policy. We intend to include data for Northern Ireland in a future dataset update.

Disclaimer

As indicated above, we measure signal levels received at a point in space and time using antennas fitted on the rooftop of a vehicle. In addition to measurement uncertainties, there are several factors which could make these measurements non-representative for any other systems. For instance, the received signal on a handset at a different height to the vehicle rooftop antenna or inside a vehicle may be different. As such, this data is not suitable for assessment of safety critical services or their operation as it is indicative only and covers only the circumstances in which it was collected.

2. What the data represents and how we measure

2.1 This section explains what the data shows, how we gather it and how we process it.

What the data represents

2.2 The data represents the mobile signal strength measured for 4G and 5G technologies, for each of the four main mobile operators, on different roads across the UK. The data also comprises several other technical parameters as listed in Annex 1.

> By 'main mobile operators' we mean the four mobile network operators (MNOs): EE, Vodafone, Three and O2. We do not collect data for mobile virtual network operators.[2]

You can find the data on our website

2.3 The open data is available to download on our website. The data is split across several files representing 4G and 5G measurements gathered over different periods of time.

We publish the data in .csv format

2.4 Currently, the 4G dataset file size is 14GB and the 5G dataset file size is 50GB. This will increase as more measurement data is added in future data releases. The data is in comma delimited value (.csv) format and would be best processed using a database tool or other software designed for handling large data sets.

Our engineers take the measurements as they carry out their day-to-day work

2.5 Typically, the measurements are taken as our engineers carry out their day-to-day business, for example when they are out on call investigating spectrum interference cases. We have covered over 12,000 miles collecting the measurement data. The locations for which we are making data available can be seen on a map showing the routes our vehicles have taken. We do not have data for locations that are not currently shown on the map, although we expect to make more locations available in future data releases.

We have only released the data collected since Summer 2020

2.6 We have released data we have collected since the summer of 2020 for 4G and 5G technologies, for the four MNOs. The data we have may not be complete for certain months and only limited data was collected during the Covid-19 lockdowns. Furthermore,

[2] Mobile virtual network operators are third-party companies that provide services to their customers based on agreements they have to use the network resources of the main mobile network operators.

the time and date fields has been partly anonymised to protect information on detailed vehicle usage which is not relevant to the data collection exercise. The data collection month can be determined, and the sequence the results are collected in for each hour, but not when in the month the hour occurred.

We will release the data periodically until the end of 2022

2.7 We started collecting data in 2020 and started publishing it on our website in November 2021. We will continue releasing the data periodically for an initial period of 12 months, until the end of 2022. We will take a decision in November 2022 on whether we will continue to collect the data and make it available in future years.

The data shows signal strength at particular points in time and space

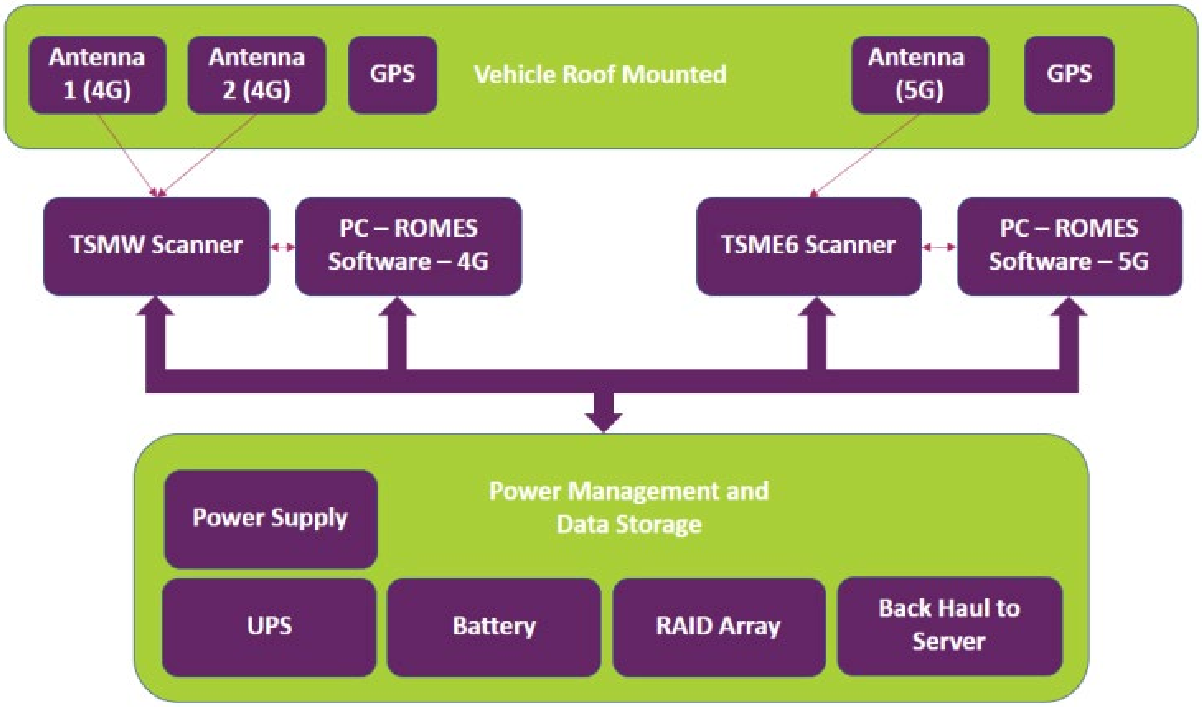
2.8 The data reflects measurements made at a height of 1.5m using an antenna mounted on the roof of a vehicle. It shows 4G and 5G signal strength at a particular point in time and space, e.g. the precise path crossed by the vehicle. It is not directly comparable with the mobile network operators' coverage predictions, as these provide an average signal strength across a 100m x 100m pixel.

How we make the measurements and process the data

2.9 We currently have three measuring systems fitted in Renault Kangoo vans, which are part of the Ofcom fleet of vehicles. The measuring system consists of two Rohde & Schwarz network scanners that are independently calibrated on an annual basis; a TSMW[3] used for collecting 4G system data and a TSME-6 used for collecting 5G data. The scanners connect to three roof-mounted PCTEL OP278H antennas.

[3] We are in the process of upgrading the TSMW scanners for additional TSME-6 scanners for future measurement campaigns.

Figure 2: Schematic figure of the measurement system



What we measure

2.10 The remote measurement systems collect information whenever the vehicles are in operation. For every measurement location the system records:

- Date and time to millisecond precision
- Latitude and longitude coordinates using GPS information
- Signal level parameters for every 4G and 5G mobile base station that can be detected at a given location

The measurements are a snapshot in time, but are broadly representative

2.11 Although the measurements are a snapshot in time and network performance can change depending on traffic, reference system parameters such as Reference Signal Received Power (RSRP) are likely to be quite stable over time, absent significant network changes (e.g. new site deployments, or amendment to operating power of the best serving site). However, there could be some variations due to seasonal propagation impacts (changes to atmospheric conditions, foliage etc.), local obstructions, and mobile network upgrades. Some of these impacts are minimised by the vehicle movement smoothing out the peaks and troughs in the measurements, and multiple passes over the same roads over a long period of time.

We rank the results for each MNO and technology

2.12 The measurements occur at an extremely fast rate (approx. every 100 milliseconds) and the system averages and ranks the results for each MNO and technology (4G or 5G). This happens over a rolling two second window, with the strongest cell being ranked number one, second strongest ranked number two, etc. The ranking is independent of mobile bands and individual RF channels. The ranking of results for 5G differs slightly from 4G as measurements are based on a combination of the strongest cell and the antenna beam (based on measurement of the Synchronisation Signal Block (SSB)). The top one to four ranking of each MNO are provided in the 4G results, but only the strongest one for each MNO in the 5G results.

2.13 There is a result from the ranking process approximately every 200ms. This means when a measurement vehicle is traveling at 60MPH, a ranked result can be generated every 6m of travel. In this example, one hour of driving in an area with consistent mobile network coverage could result in approximately 18,000 rows of 4G measurement data. For 5G, there could be up to ten times that amount, as a single result is displayed on multiple rows.

5G results are presented slightly differently

2.14 As indicated above, for 4G each row of results in the .csv data file provides the complete measurement parameters for all MNOs and top four ranked cells. For 5G, the different measurement results for each MNO are represented as several rows at a time. This means that if all the measurement parameters need to be referenced to each individual cell ID (PCI), the time sequence of the results needs to be considered and grouped together. For example, the first result row is the individual cell ID (PCI), beam index, average signal level (RSSI) and RF channel number (EARFCN). The sequential result rows then represent the associated beam reference signal power (RSRP), quality (RSRQ), and signal to interference/noise ratio (SINR). Note the associated sequential result rows might be repeated or entirely absent. As the main result rows are output at a very fast rate (approximately every 200ms), duplicate rows can be disregarded or averaged.

Application of spatial averaging to the data

2.15 Each measurement result we record is tagged to a particular location using GPS information. As the results are produced at a fast rate, this leads to many results needing to be analysed across small geographical areas. The number of results we record can vary due to many factors including speed of the vehicle, location (e.g. whether in urban or rural locations), the number of base stations serving a particular area, the number of MNO networks available and the type of technology (4G or 5G). As the vehicle moves the received signal level can also be affected by localised conditions such as tall structures blocking the signal or causing reflections that give rise to enhancement or reduction (fading) of the measured level. To smooth out these localised effects and to reduce the number of data points, results are generally grouped together by geographical area and statistical calculations performed on the grouped measurement data. A common method is to group the results together in tiles, such as 100m x 100m. This means in every 100m x 100m bounding box, statistical calculations such as median signal strength can be done.

3. Example applications of the data

3.1 Ofcom collects signal strength data predominantly for the purpose of monitoring mobile coverage in relation to MNO coverage predictions, which we use to report coverage levels in our Connected Nations reports, and to make coverage maps available through our broadband and mobile coverage checker. However, we consider this measurement data may be useful to a range of other parties who could use it for different applications. Most immediately, we consider that various organisations may be interested in undertaking analyses of the data to provide them with insights into the nature of mobile coverage in particular locations, along the road network.

3.2 We also consider that providing detailed signal strength information may usefully inform analyses as to the potential availability of services with different requirements than are typical for mobile coverage - e.g. Internet of Things (IoT) type applications on mobile networks and text-based services. This data may also be of interest for more theoretical analysis of real-world propagation measurements on mobile technologies.

3.3 Below we set out some examples of how the data can be interpreted and used for different applications.

Example 1: Evaluating mobile coverage for EV chargers or parking ticket machines

3.4 Electric Vehicle (EV) charging systems often require a smartphone application to be used to initiate a charging cycle. Similarly, many car parks now allow parking sessions to be initiated through a smartphone app. The EV charger or ticket machine may also require connectivity for telemetry purposes (e.g. to communicate with a central billing database).

3.5 It is worth noting that other forms of connectivity might be equally or more appropriate for such uses as, in particular, new fixed broadband networks are being deployed. It is also worth stressing that any infrastructure deployment plans that require reliable mobile connectivity from all four main networks at specific point locations should be based on real world measurement data, rather than the much less granular predictive coverage maps that the operators themselves publish. The data set we describe here could help installers to identify the best areas along the roadside to install an EV charger or ticket machine that was reliant on such connectivity, choosing a location to help maximise coverage from the four mobile network operators. This activity, in conjunction with our methodology, might also provide a template for others to carry out informative measurement campaigns in relevant areas. System installers may also need to complement the Ofcom data with measurements from other sources, including using *ad hoc* site surveys where necessary.

3.6 The first step is to check the interactive map on the Ofcom website to find out if we have measurement data for the chosen location. The map shows the routes our measurement vehicles have taken and can be used to determine if the road of interest, or a nearby location, has been covered by the measurement vehicles.

3.7 The best data set to use in this particular example is the 4G measurement data. Around 92% of the UK landmass is predicted to have good 4G coverage from at least one operator.[4] If the location has been covered by our measurement vehicles, the next step is to process the 4G dataset to extract the measurement data just around the areas of interest.

3.8 This can be done by importing the raw .CSV file into a database table or some other searchable format. Options can include using Python, SQLite, and PostgreSQL. A geographical ‘bounding box’ query can then be used to select the measurement data for each area of interest.

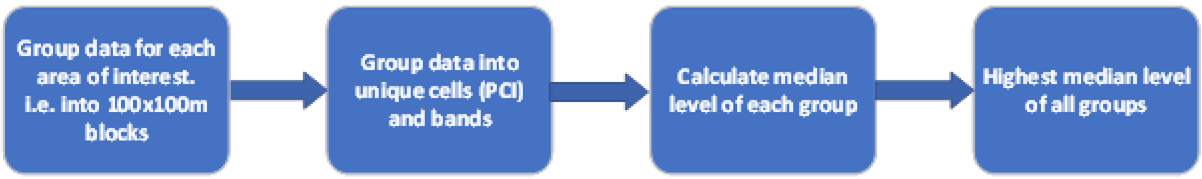
Figure 3: Use of a bounding box to select the data for the area of interest

```
WHERE ST_SetSRID(ST_MakePoint(longitude, latitude),
4326) && ST_MakeEnvelope(-0.1
                                , 51.5
                                , -0.1299
                                , 52.0100
                                , 4326);
```

3.9 The average signal level in the area of interest could then be determined by:

- Grouping the measurement data for each area of interest together.
- For each Physical Cell Identifier (PCI)[5] in the group, determine the median signal level.
- Consider the highest of the PCI median levels to be the result.

Figure 4: Process for determining the signal level for the area of interest



[4] Ofcom, Connected Nations update: Spring 2022, 20 May 2022.

[5] The Physical Cell ID is used by network operators during planning to identify the area covered by a particular base station. These areas often overlap so at any given location our measurements may detect more than one PCI (i.e., we may measure the signals from more than one base station at a particular location).

Figure 5: Selecting the highest median cell in the group

PCI	100	122	155	180
Ranking	1	2	3	4
Median	-90	-95.6	-108.5	-117.75
Meas. 1	-87	-101.8	-102	-123
Meas. 2	-92	-94	-105	-119
Meas. 3	-94.9	-97.2	-121.2	-116.5
Meas. 4	-88	-89.9	-112	-109
Meas. N	…	…	…	…

3.10 If the area of interest is not too large it could be displayed visually by importing it into a Geographic Information System (GIS) software tool. Examples include MapInfo, ArcGIS, and QGIS.

3.11 When selecting the best locations for installing the EV charger (or ticket machine), visualising the data would have the advantage of easily determining the locations that have the best mobile coverage just by looking at the map.

Example 2: Identifying mobile coverage 'not-spots' for 4G and 5G

3.12 A mobile coverage not-spot is a geographic area that receives no 4G (or 5G) coverage from any MNO. A partial mobile not-spot is a geographic area served by at least one, but not all four MNOs.

3.13 Our mobile coverage data could help rural councils to identify 'not-spots' (areas with lack of mobile network coverage) along a particular number of roads in the local area. It could help councils investigate if these areas are substantial in nature, and how often they occur. This could provide important information when considering, for example, where to locate a heart defibrillator.[6] These are sometimes placed in cabinets with an access code that is provided when a caller contacts the emergency services.[7]

3.14 As with the previous example, the first step is to check the interactive map on the Ofcom website to determine if the roads of interest or nearby locations have been covered by one of our measurement vehicles.

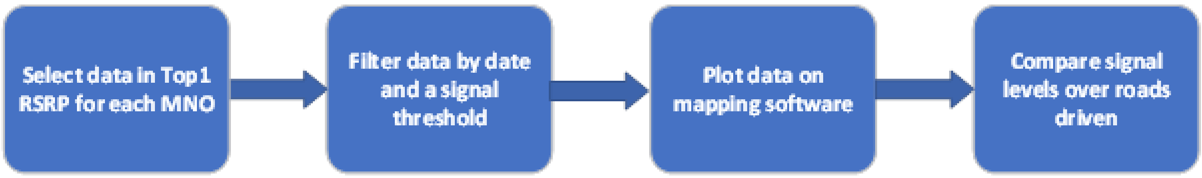
3.15 The best way to understand the locations of any 'not-spots' on the roads of interest is to process the measurement data for visualisation on a map. As there could be many datapoints to be displayed, sometimes the data will need to be averaged or filtered.

3.16 The next step is to process the 4G or 5G dataset to extract the measurement data just around the roads of interest. As in the previous example, this can be done by importing the raw .CSV file into a database tool and running a geographical 'bounding box' query to select the measurement data of interest.

[6] Although we use heart defibrillators as an example where such data could inform thinking, our data should not be used for ultimate decision making with regard to safety critical applications, where separate validation will be required.
[7] Source: Resuscitation Council UK.

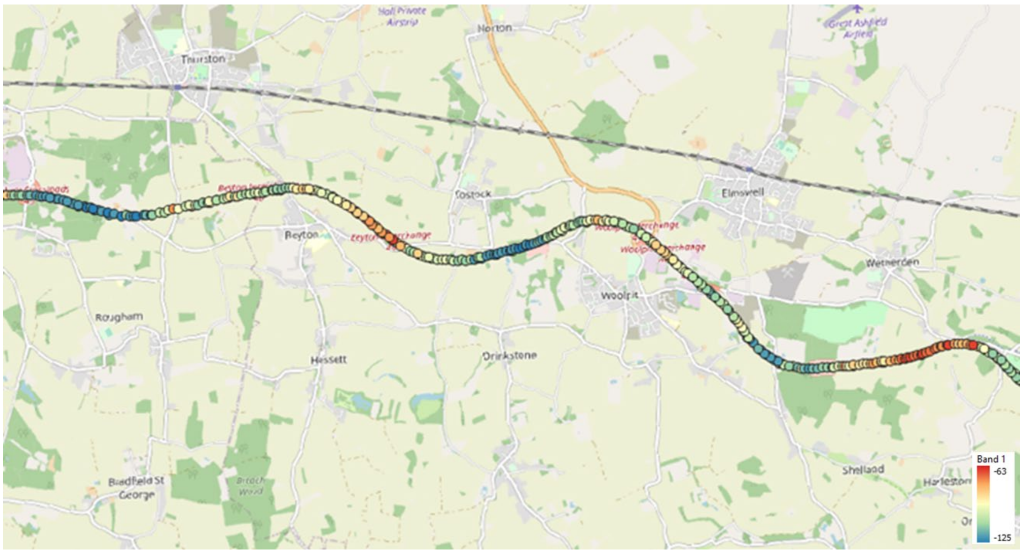
3.17 The data can then be filtered by date, and then an appropriate signal level threshold is applied depending on the technology and required confidence level. This is to set a cut-off for the edge of mobile network coverage and will allow the 'not-spots' to be visible. The resulting data can then be plotted visually in mapping software, such as QGIS or MapInfo.

Figure 6: How to determine the location of mobile 'not-spots'



3.18 Finally, it is helpful to colour-code the datapoints on the map by signal strength, as this will make high signal level areas stand out. It will also make it easier to determine where low signal strength areas transition into locations with no mobile coverage.

Figure 7: Colour-coded map showing areas with different 4G signal strength



Example 3: Establishing 4G and 5G location variability

3.19 In this example, we provide a technical case study of how the data can be used to better understand the on-the-ground variability of 4G and 5G signals. This variability is usually referred as "Location Variability (LV) [8]" and provides a mechanism in propagation prediction methods[9] to address the spatial variability of signals. This variability influences the fade (safety) margins needed to achieve the desired predicted reliability of wireless systems.

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[8] More specifically, the spatial variability of the received signal is attributed to slow fading (shadow fading); widely accepted to follow a log-normal distribution and its standard deviation (in dB) is termed as Location Variability.

[9] Propagation models are used to predict the behaviour of radio waves as they travel (propagate) further away from the transmitter, for example the methods used to generate coverage maps available on operators' websites or Ofcom's mobile coverage checker.

3.20 An appropriate data processing methodology capable of differentiating between 4G and 5G reporting procedures is essential to extract reliable LV statistics from this measurement data. As noted above in section 2, there are some differences in the way the measurement data is reported; 4G measurement reporting is cell based, i.e., signal level is captured for each detected mobile cell, while 5G technology makes use of beamforming so signal level is captured at the beam level.

3.21 For simplicity, we have limited this example to LV statistics based on 4G measurement data for the 800 MHz and 1800 MHz bands, and the 5G data for the 3.4 GHz band only. First, relevant network level parameters were extracted from the data, including the PCI for both 4G and 5G to identify the serving cell, as well the Synchronisation Signal Block Index (SSB_IDX) to identify the captured beam indices of the 5G detected cells.

3.22 To account for the 5G beam specific (SSB_IDX) measurement reporting, two methods were subsequently developed, i.e. ‘PCI method’ and ‘SSB method’. The PCI method averages the received signal level over all detected beams of a PCI, whereas the SSB method distinguishes the beam with the strongest signal level and only considers its spatial variability.

3.23 Next, the filtered raw measurements were binned into 50 x 50 m or 100 x 100 m bins referenced to OSGB36 Grid[10] as we are interested in understanding the spatial variability of signals in such small grided bins (i.e., commonly used prediction resolutions of propagation models to generate wide area coverage maps).

3.24 Depending on the specific 5G method, the number of unique PCIs detected in each bin or the number of unique SSB indices associated with those PCIs were determined for each bin. For those unique identifiers (PCIs in the case of ‘PCI method’ or SSB indices for ‘SSB method’), the median signal strength (RSRP for 4G or SS-RSRP for 5G) and its standard deviation (LV) were calculated for each bin[11].

3.25 Finally, the PCI or the SSB (*for the best SSB method*) with the strongest median signal strength was selected for each bin and its standard deviation (LV) was recorded.

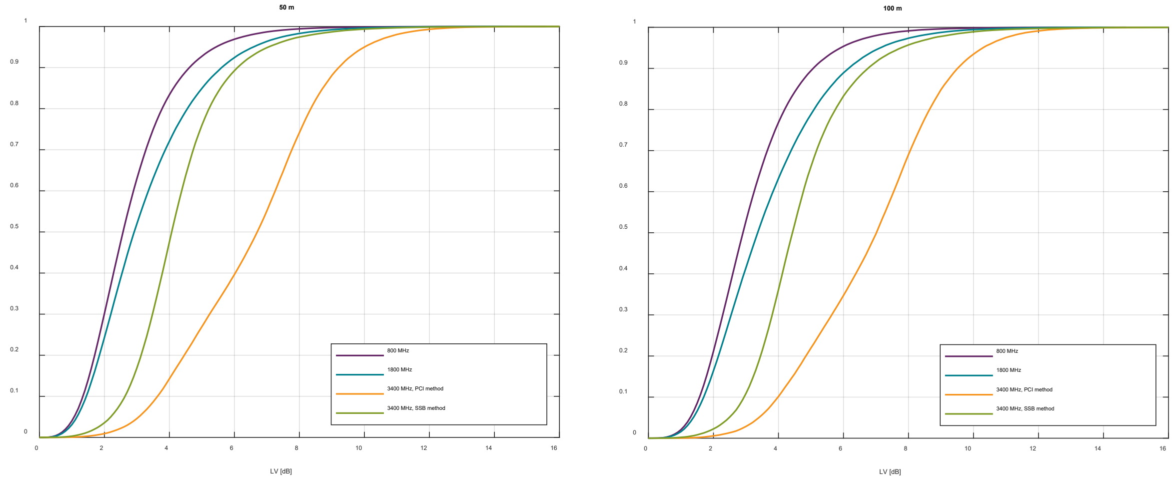
3.26 In Figure 7, the individual standard deviations (LV) of all the bins are compiled into a cumulative distribution function (CDF) representing the full range of variation observed over the 4G and 5G data. We can observe frequency and bin size dependency in the LV statistics with variability increasing with frequency as well as with bin size. The other notable observation is the significantly higher variability in the 5G PCI method statistics which can be explained as this approach takes into account of all detected beams in a bin.

3.27 This example highlights how this data can be used to extract LV statistics from live mobile networks’ measurements and further used in refining propagation prediction methods.

[10] Ordnance Survey factsheet: Using the National Grid.

[11] Additional data cleansing steps were undertaken to remove erroneous data and to ensure data is representative of the analysis bins of 50 and 100 m. For example, if the road driven only clips a corner of the 50 or 100 m bin, it was excluded from the dataset

Figure 8: Location variability CDFs for varying frequency and bin sizes



4. Summary

4.1 In this paper we have provided an overview of the 4G and 5G signal strength measurement data we have been collecting using our spectrum assurance vehicles along roads in England, Scotland and Wales. We have been collecting this data on a rolling basis since the middle of 2020 and we publish it periodically on our website as part of our wider open data initiative.

4.2 Our mobile coverage measurement open data for 4G and 5G can be used for a wide range of purposes with suitable data analysis. Most immediately, we consider that various organisations may be interested in undertaking analyses of the data to provide them with insights into the nature of mobile coverage in particular locations, along the road network.

4.3 We have presented three different case studies in this paper, but we consider the measurement data may be useful to a range of other parties who could use it for different applications. Our cases studies are intended to stimulate some ideas about how the data could be used, rather than to provide definitive solutions to the examples presented.

4.4 We will continue to publish our measurement data periodically throughout 2022. Please let us know if you find this data useful by contacting us at drivetestingdata@ofcom.org.uk. We will use any feedback to inform our decision on whether we continue to make the data available in future years.

A1. Guide to technical parameters

A1.1 This section provides a guide to some of the 4G and 5G technical parameters found in the data sets. A full list of parameters is available in the measurement methodology document.

Parameter	Definition
E-UTRA Absolute Radio Frequency Channel Number (EARFCN)	This identifies the RF channel number of a 4G cell. The EARFCN can be converted from the channel number to the band and/or frequency in MHz using the formula found in the 3GPP Specification TS 36.101.
Physical Cell Identifier (PCI)	This identifies the cell that the measurement results refer to. Each signal level measurement result is referenced to a particular cell ID (PCI) for 4G.
Reference Signal Received Power (RSRP)	The linear average power of the 4G resource elements that carry cell-specific reference signals. RSRP does a better job of measuring signal power from a specific cell while potentially excluding noise and interference from other cells. The number in the dataset is referenced to the input of the mobile network scanner hardware, and no calibrations or offsets have been applied.
Reference Signal Received Quality (RSRQ)	The ratio of the RSRP to the RSSI across the full channel bandwidth. RSRQ provides a measure of how well the wanted cell reference signal can be discriminated from other cell signals, noise, interference, etc.
Reference Signal Received Power of SSB Beam (SS_RSRP)	The reference signal level of the identified SSB beam of the cell. The number in the dataset is referenced to the input of the mobile network scanner hardware, and no calibrations or offsets have been applied.
Received Signal Strength Indicator (RSSI)	A measure of the power level received from all base stations plus noise and interference by a client device.
Signal to Interference and Noise Ratio (SINR)	The ratio of measured usable signals in a channel to the interference and noise. SINR is a measure of signal quality as well, however it is sensitive to the loading of the cell.
Synchronisation Signal Block (SSB)	The part of the received signal that provides cell and broadcast beam index (for 5G) information.
SSB Beam index (SSB_idx)	Identifies which Synchronisation Signal Block (SSB) beam of the cell is measured. Each signal level measurement result is referenced to a particular cell ID (PCI) and SSB beam index combination for 5G.