A2. Statistical methodology

This report analyses findings collected from panellists from the umlaut crowdsourced data between 1 January and 30 April 2020. Data were separated by date because of the restrictions imposed on the 23 March 2020 due to the Coronavirus pandemic. Therefore, analyses were divided into 'pre-lockdown (data before 23 March 2020) and 'post-lockdown' (data from 23 March to 30 April 2020).

Overall panellists' records were included in the analysis if they met the following criteria (other records were filtered out):

- the wholesale mobile network was either EE, O2, Three or Vodafone
- the location was in the UK and the UK nation was either England, Northern Ireland, Wales or Scotland
- the location was also classified as a rural or urban area[1]
- the data technology was known – either 2G, 3G, 4G, 5G[2] or Wi-Fi, depending on the metric

To estimate the number of panellists, and to check that there was a sufficient number of people behind each sub-group analysis, the distinct number of unique ids were counted for each dataset, each metric and sub-group analysed. We wanted to make sure there were at least 100 unique ids for the smallest sub-group. The actual number of unique ids for the smallest sub-group was much higher than this for every metric.

For an overall count of the number of people in the data that had records that met the criteria above, the count of unique ids in the connection test dataset were looked at. The distribution of those counts are as follows:

Pre-lockdown (before 23 March 2020)

- Panellists with mobile records – 167,618
- Panellists with either mobile and/or Wi-Fi records – 236,616
- By nation (those with mobile records)
  - 143,193 panellists with records in England
  - 5,630 panellists with records in Northern Ireland
  - 16,432 panellists with records in Scotland
  - 11,272 panellists with records in Wales
- By rurality (those with mobile records)
  - 88,055 panellists with records in rural areas
  - 163,091 panellists with records in urban areas
- By nation and rurality (those with mobile records)
  - 73,233 panellists with records in rural England

[1]These locale classifications are derived from Bluewave Geographics, which harmonises the rural and urban classifications between ONS (for England and Wales), Northern Ireland Statistics and Research Agency (NISRA, for Northern Ireland) and the National Records of Scotland (for Scotland).

[2] For a small number of panellists who had a 5G enabled android smartphone

- 139,456 panellists with records in urban England
- 3,588 panellists with records in rural Northern Ireland
- 5,311 panellists with records in urban Northern Ireland
- 9,608 panellists with records in rural Scotland
- 15,579 panellists with records in urban Scotland
- 7,399 panellists with records in rural Wales
- 10,253 panellists with records in urban Wales

- By mobile network (those with mobile records)
  - 55,605 panellists on the EE network
  - 63,665 panellists on the O2 network
  - 29,916 panellists on the Three network
  - 27,984 panellists on the Vodafone network

Post-lockdown (from 23 March 2020 to 30 April 2020)

- Panellists with mobile records – 167,618
- Panellists with either mobile and/or Wi-Fi records – 113,263
- By nation (those with mobile records)
  - 94,512 panellists with records in England
  - 3,693 panellists with records in Northern Ireland
  - 10,217 panellists with records in Scotland
  - 6,139 panellists with records in Wales
- By rurality (those with mobile records)
  - 40,863 panellists with records in rural areas
  - 107,221 panellists with records in urban areas
- By nation and rurality (those with mobile records)
  - 32,174 panellists with records in rural England
  - 90,036 panellists with records in urban England
  - 1,958 panellists with records in rural Northern Ireland
  - 3,275 panellists with records in urban Northern Ireland
  - 4,507 panellists with records in rural Scotland
  - 9,396 panellists with records in urban Scotland
  - 3,072 panellists with records in rural Wales
  - 5,449 panellists with records in urban Wales
- By mobile network (those with mobile records)
  - 34,504 panellists on the EE network
  - 41,968 panellists on the O2 network
  - 19,990 panellists on the Three network
  - 18,901 panellists on the Vodafone network

Metrics and analysis methodology

For the 2020 Mobile Matters report the following metrics were analysed:

- Network share
- Reliability of data connections
- Performance in high-traffic areas
- Response times for data requests
- Data use
- Mobile phone calls
- 5G services: pilot analysis
- Mapping network usage changes during the lockdown

Outage period – 17th to 19th March 2020

There were three days in March – the 17th, 18th and 19th – that we have excluded from some of our analysis. This is because there was a significant increase in mobile voice traffic around the time of the Government's Covid-19 announcements, with growth in both call volume and duration. This created a temporary congestion condition on the Interconnect services between mobile network operators. This was resolved by increasing the capacity of the Interconnect services progressively over a few days. In our data, we found that this had a substantial impact on mobile phone calls and the reliability of data connections. Because of the unusual circumstances, we did not include data for these days in our pre-lockdown analysis for mobile phone calls, reliability of data connections and the response time for data requests.

Network share

The data in the connection test dataset enabled us to look at what percentage of the time panellists were connected to each technology – 2G, 3G, 4G and Wi-Fi. Of particular interest is the comparison between the amount of time panellists are connected to cellular technologies versus Wi-Fi.

This was simply calculated by totalling the count of records for each technology and looking at this by rurality and by mobile network. Comparisons were carried out by using a two-tailed test to look for statistically significant differences which are shown in the report. The percentage of 5G connections are shown for the small number of panellists with 5G enabled android smartphones in the 5G services pilot analysis section.

Reliability of data connections

Every 15 minutes, a test is run which attempts to download a small file and logs whether this can be completed successfully. By using records where the mobile screen was active during this test, we can assess the percentage of cases when the user was able to connect to data services when the device was in use.

To analyse this data, the filters stated above were applied to the data, plus an additional filter which selects records where the device screen is on. This is an indication of when panellists' phones are in

use[3] and therefore when connection to a data service would be more important to them. Analysis was carried out directly on the number of readings. Due to the millions of readings, it was essential to look at the size of any differences and not just at whether findings were significantly different, as determined by running statistical tests.

When there is such a large number of readings, even very small differences between averages or proportions can be statistically significant. However, this may not equate to a noticeable or practical difference for the consumer in their experience of using their phone. Differences were only reported in the report if they were statistically significant and the difference between sub-groups was at least 2 per cent.

The percentage of successful tests was calculated, and comparisons were made, using two-tailed statistical tests. Analysis was carried out comparing 3G and 4G data access technologies and rurality to look for any statistically significant differences were the data service was better or could be improved.

Comparisons between mobile networks were also checked against a subset of data filtered for the top 75 most popular handsets. The same analysis for data service availability was then carried out on this subset of data and compared to the full analysis. No statistically significant differences were found for 3G and 4G technologies.

Performance in high-traffic areas

We looked at the success rates of connection tests around busy train stations across the UK. To obscure the exact location of each test reading, the coordinates of the reading are aggregated to a roughly 700m^2 area. This is done using Google maps zoom levels and is equivalent to zoom level 15. To analyse the data for each train station we filtered the data using the coordinates for these tiles which cover each train station. This means that although users who were in the station are captured, it also captures some users who would have passed through that tile but may not have passed through the station. Though this is a trade-off between accuracy of the reading and privacy, we feel this is a necessary trade-off, and are comfortable that this level of aggregation shows a reasonable picture of the experience at these busy train stations.

[3] This can include consumers actively using their phones, receiving notifications or updates running on the phone with the screen on.

Table 1: Exact locations used for high-traffic area analysis

Grid on map	Latitude and longitude coordinates of grid
Belfast Lanyon Place Station 	(-5.921631, 54.591163) to (-5.910645, 54.597528)
Cardiff Central Station 	(-3.186037, 51.474543) to (-3.175050, 51.481385)
Edinburgh Waverly Station 	(-3.197023, 55.949198) to (-3.186037, 55.955349)

Manchester Piccadilly Station 	(-2.241207, 53.474968) to (-2.230220, 53.481506)
London Waterloo Station 	(-0.120850, 51.501906) to (-0.109864, 51.508745)

The time period for this analysis was Monday 6 January to Sunday 15 March. As we were interested in the differences in success rate by day of the week and time of the day, we ensured the sample were representative weeks. The first week of the year (1-5 January) had significantly lower footfall in train stations, so the analysis period began on 6 January to not skew the results. Between 17-19 March there was a network outage, so the last week included in the analysis before the lockdown period began was the week ending 15 March, so as not to skew the results for Tuesday, Wednesday and Thursday by including the outage period.

Unlike the analysis of the connection tests for the rest of the report, we analysed the success rate of connection tests with both screen on and off for the major train stations. This was firstly to ensure we had enough test readings to form a robust sample. Secondly, we believe consumers would be more interested to know how likely it is they can successfully connect to their network whilst at a busy train station, regardless of whether they are looking at their phone or not.

Response time for data requests

Response time, which is the delay in milliseconds between a consumer making a request to their mobile network for information and the network providing this information to the device, were compared by data access technology, rurality and nation. A two-tailed test of median response times was carried out on all sub-group comparisons.

Comparisons by mobile network were carried out using the same methodology to filter the data as for the reliability of data connections. Analysis was also run on the most popular top 75 handsets as

a check against the whole panel. A two-tailed test of the median response times was carried out on this subset of data.

Data use

We looked at data use during the day by looking at the amount of data uploaded and downloaded per hour. This data was present in the network throughput record dataset. The percentage of data use by time of day was looked at and plotted in graphs to see if there were any peak hours of usage. A comparison was made for Mobile vs Wi-Fi technologies for weekdays and weekends separately as data use by hour of the day follows a different pattern at the weekend compared to during the week.

Comparisons between Mobile and Wi-Fi were analysed by carrying out two-tailed tests to see if any differences were statistically significant.

Mobile phone calls

We analysed data on the percentage of panellists who made a mobile phone call (for both pre and post-lockdown) and the average voice call duration. This data is captured in the voice call dataset. Data for each mobile call made, by panellists in the crowdsourced data during the fieldwork period, was analysed.

We calculated the percentage of all panellists making a mobile phone call by comparing the panellists from the connection test dataset who also had data showing that they had made a call in the voice call dataset. The average call length for the fieldwork period was calculated and these averages were also then grouped to show the distribution of values by the percentage of calls. Differences in average call length were compared between pre and post lockdown periods. These comparisons were analysed by running two-tailed tests to see if any differences were statistically significant.

5G services: pilot analysis

A pilot analysis was carried out on 5G services for a relatively small number of panellists where data showed that they had used 5G during the fieldwork period. Out of all panellists, 272 were found to have a 5G enabled device. Of the approximately 9,500 5G records generated, 99% were in Urban areas, with just over two thirds of all records being in London. As there were a small number of panellists in a limited number of locations in the UK, this analysis cannot be generalised to how the 5G network is performing across the UK beyond the panel.

Average cellular network share was calculated for 5G users with the methodology being the same as described in the network share section above. Comparisons were made between the total number of 3G, 4G and 5G records. The reliability of data connections and the response times for data requests were also looked at specifically for 5G. The methodology used was also the same as stated in previous sections in this annex.

Mapping Network Usage Changes During the Lockdown

Data Used

To assess the impact of lockdown on people's movement and on network usage, we looked at the percentage change in the number of both mobile and Wi-Fi connection tests from a baseline week in January. We performed this analysis by aggregating the data into 1x1km squares and analysing all nations' capital cities. We note that the original data was already aggregated into quadtiles at zoom 15, i.e. squares having a variable side of 700-800 metres depending on the location. We decided to use a larger square size for representation purposes and to have a uniform square size across all capital cities.

We considered the week of 13-19 January as the baseline week, which is set to represent a regular network usage by panellists, and compared that to three other weeks under analysis:

- 20-26 January, also thought to reflect a normal network usage by panellists;
- 23-29 March, which was the first week of national lockdown;
- 20-26 April 2020, which is the last full week contained in our dataset and sits in the middle of the lockdown.

We considered all the tests performed by the panellists, including those made while having either screen on or off, but only including those whose location provider was known.

Types of Maps and Graphics

We created both interactive web-based maps, which allow users to hover the mouse over the various squares and get relevant information on each of them, as well as static maps, which we used for the written report. The aggregated data which was used to create the maps is also provided as separate csv files.

We chose to use colour-blind safe diverging colour schemes generated by the website https://colorbrewer2.org/ for colouring the squares according to the corresponding values, and we adopted a grey background to make it easier to distinguish the various colour shades. We filled squares that saw no connection tests during both baseline week and the week under analysis, or that saw connection tests only during the week under analysis with stripe and circle patterns, respectively, to distinguish them visually from the others.

Reference Grid in the .csv Data Files

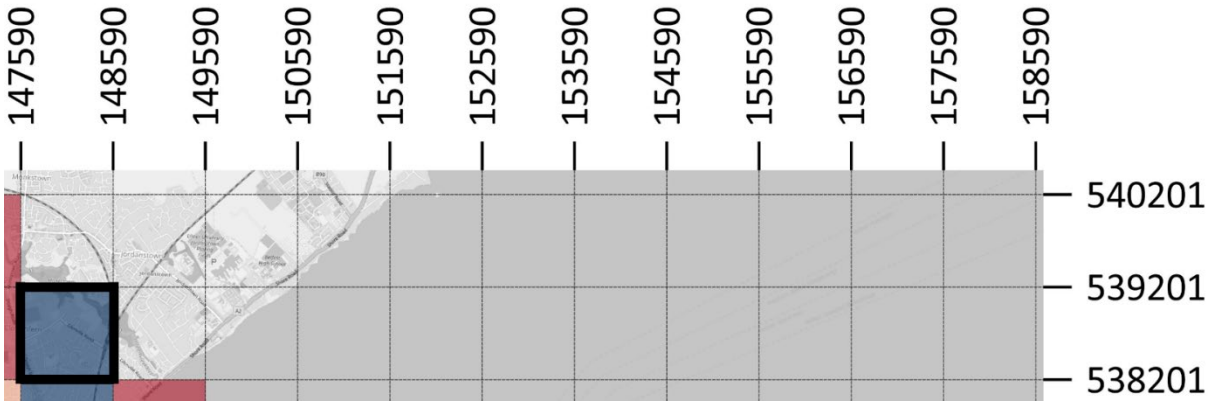
The .csv data files also contain a reference grid which the readers can use to index the data in the maps. The grid horizontal and vertical axes represent the British National Grid coordinates eastings and northings of a location (based on the OSGB36 datum), respectively.

Each record in the csv file has eastings and northings attributes, which are the bottom left corner coordinates of the corresponding square in the static map. For example, the record below refers to the square whose bottom left eastings/northings coordinates are 147590 and 538201, respectively:

eastings	northings	constituencies	percent_difference	tests_during_20_26_april	tests_during_13_19_january
147590	538201	Belfast North	252	763	217

In the corresponding map, this record refers to the 1km x1km square highlighted by a black solid outline below:

Figure 1: Example of eastings and northings coordinates



Mapping 4G Connection Tests

We mapped the success percentage in connecting to the 4G network into 10x10km squares over the entire UK, producing both an interactive and a static map. These maps cover the pre-lockdown period and exclude the outage period during 17-19 March. Moreover, we only used records where the mobile screen was active during the connection test, to assess the percentage of cases when the user was able to connect to data services when the device was in use. The .csv data for this map is indexed through a reference grid that has been created using the same method described in the section on mapping lockdown changes.

We noticed that the data distribution is very skewed towards higher success percentage values, and for this reason we used a colouring scheme with non-uniform intervals. We decided not to colour areas where the number of tests was lower than 50 to avoid those areas to be characterised by a small number of tests and hence to skew our representation.

Mapping Response Time

We mapped response time on tests made on 3G, 4G, and Wi-Fi networks into 10x10km squares over the entire UK, producing both an interactive and some static maps. These maps cover the pre-lockdown period and exclude the outage period during 17-19 March. The .csv data for this map is indexed through a reference grid that has been created using the same method described in the section on mapping lockdown changes.

For each square, we first considered the median of the response times of each test performed in that square, and then we considered the overall median. We chose to use the median rather than the average value to avoid our representation from being skewed by very low or very large values. Similar to the 4G connection tests success percentage maps, we decided not to colour areas where the number of tests was lower than 50.