Mobile Matters

Using crowdsourced data to assess people's experience of using mobile networks

Published 20 July 2023

Welsh version available

Contents

Section

Overview

Smartphones and mobile connectivity are an essential part of daily life for most people in the UK. To better understand the experience they receive, Ofcom has analysed crowdsourced data collected between October 2022 and March 2023 from mobile devices across the UK. In this report, we focus on the share of data connections across wireless network technologies (2G, 3G, 4G, 5G,[1] Wi-Fi), the success rate for mobile data connections, the response times for different mobile technologies, the time to download and upload different sized files, and download and upload speeds. We also look at how these vary by mobile network operator (MNO) and location.

Our report is based on test results provided by a new data supplier (Opensignal) and the findings are not directly comparable to those published in previous Mobile Matters reports. Mobile network performance is only one factor that people may wish to consider when making decisions about their mobile service. Price, handset type, quality of customer service, coverage and contract terms are other relevant aspects that should be considered.

This research is part of a wider programme of work by Ofcom to research and provide information regarding mobile quality of experience. The data in this report relate to performance when network coverage is available from an operator. For information on the coverage provided by the UK's four mobile networks, please see Ofcom's Broadband and mobile coverage checker.

What we have found – in brief

Network share

- **Most cellular network use was over 4G.** Mobile users were connected to a 4G network for an average of 88% of the time and were without any cellular connection for around 1% of the time.
- **Mobile users spent an average of 6% of the time connected to 3G.** As mobile network providers prepare for 3G switch off, they will need to ensure broadly the same 4G coverage as 3G and support mobile users who need an updated handset in order to minimise disruption.
- **Time spent on 5G was comparatively low.** With the technology used in most current UK 5G deployments (5G non-standalone), devices only connect to 5G when a data connection is needed. As a result, mobile users were connected to 5G for an average of just 4% of the time (10% among 5G users).
- **Wi-Fi continues to be a fundamental part of the consumer experience.** Mobile users spent an average of 62% of their time connected to Wi-Fi.

Comparison of cellular technologies

- **Cellular network data connection success rates were highest on 5G.** Looking at connection success rates when someone was actively using their phone in a coverage area, 5G data connections succeeded 98.4% of the time, compared to 97.8% for 4G and 91.3% for 3G.
- **Download times for 2MB files were much shorter over 5G and 4G than 3G.** On average, it took around twice as long to download a 2MB file on a 4G network than on a 5G network (0.8s vs 0.4s) and 2MB file download times on 3G (3.6s) were more than four-times longer than those over 4G.

[1] In this report, we include connections to both 5G non-standalone (NSA) and standalone (SA).

- **The benefit of 5G over 4G was more apparent with larger file downloads.** A 5MB download over 5G was, on average, 56% shorter than over 4G. This compared to average 5G 2MB download times being 46% shorter than those over 4G.
- **Upload times for 1MB files were shortest on 5G networks.** Looking at the experience of uploading files, the average time to upload a 1MB file was shortest over 5G (0.7s) and longest on 3G (3.6s).
- **Download speeds were more than four times higher on 5G than on 4G.** We also analysed download speeds measured using tests that consume as much data as the connection can download over the duration of the test. These showed that download speeds were fastest over 5G, averaging 129.9 Mbit/s compared to 29.5 Mbit/s over 4G and 5.9 Mbit/s on 3G.
- **Average upload speeds over 5G were almost twice those recorded on 4G networks.** 5G upload speeds averaged 14.7 Mbit/s, compared to 7.6 Mbit/s over 4G and 2.0 Mbit/s on 3G.

MNO comparisons

- **EE customers spent the highest proportion of their time connected to 4G.** The proportion of time that mobile users spent connected to 4G ranged from 84% for O2 customers to 91% for EE customers. O2 customers spent the highest proportion of their time connected to Wi-Fi (67%).
- **There were no differences in average 5G and 4G data connection success rates by MNO.** However, EE and Three customers had the highest average 3G connection success rates and O2 3G data connections were less likely to succeed than those of the other MNOs.
- **O2 customers had the longest average file download times.** The time taken to download a 2MB or 5MB file on O2 was longer than the other MNOs' download times for 5G, 4G and 3G.
- **The average response time was significantly better on EE than the other MNOs' networks.** EE's average response times (latency) were the fastest among the MNOs for all cellular technologies (18ms on 5G and 4G, and 29ms on 3G). O2 had the slowest 5G and 3G response times (22ms and 47ms respectively) and Vodafone the slowest 4G response time (24ms).
- **O2 customers experienced the slowest average download speeds over 5G and 4G networks (74Mbit/s and 19Mbit/s respectively).** O2 was also joint-slowest with Vodafone for 3G download speeds (5Mbit/s). Three had the fastest average 5G download speed (235Mbit/s) and EE was quickest over 4G (44Mbit/s), and EE and Three had the joint-fastest average 3G download speeds (7Mbit/s).
- **EE customers had the fastest average 4G and 3G upload speeds (9Mbit/s and 3Mbit/s respectively) and were joint-fastest with Three for 5G (17Mbit/s).** O2 customers experienced the slowest 5G and 4G upload speeds (10Mbit/s and 5Mbit/s respectively) and Three was slowest over 3G (2Mbit/s).

Comparisons by nation/rurality

- **People in Northern Ireland spent the highest proportion of time connected to Wi-Fi.** The proportion of time that people spent connected to a Wi-Fi network was 66% in Northern Ireland, compared to 62% in each of the other nations.
- **There were no differences in 5G and 4G data connection success rates by nation and rurality.** However, the average 3G connection success rate was higher in urban areas than in rural ones and lower in Wales than in the other UK nations.

- **Variations in 5G and 4G 2MB file download times by nation and rurality were only small.** The differences were more marked for 3G, with Scotland having the shortest time to download a 2MB file and Northern Ireland and Wales the longest times.
- **Wales had the fastest average 5G download speed and England the quickest 4G download speed.** There were no significant differences between 3G download speeds across the UK nations.
- **Northern Ireland had the slowest average 5G upload speed and was joint-slowest with Wales for 4G.** England had the fastest average upload speed over 4G and there were no differences in 3G upload speeds across the UK nations.

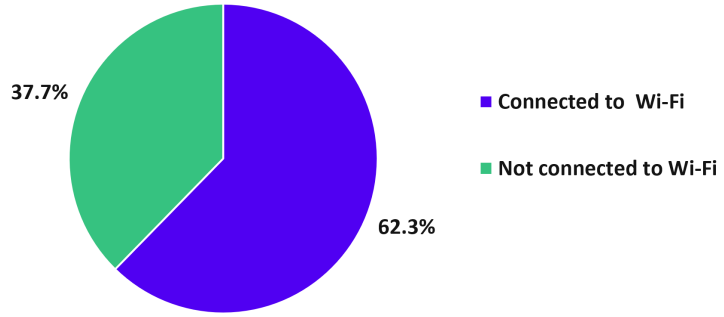
The analysis in this report is conducted at the MNO retail customer level, i.e. customers using mobile virtual network operators (MVNOs) are excluded from the analysis. The sample distribution broadly matches both the population distribution of the UK and the relative operator shares and we have ensured that the sample sizes are sufficient to ensure the robustness of the findings.

For a more detailed description of the data collection and analysis, please see A1. Technical methodology and A2. Statistical methodology. An **interactive dataset** can be accessed here.

Network share

Analysis of the time spent connected to different wireless networks gives an indication of how people use their mobile phones. Our findings show that Wi-Fi continues to be a fundamental part of consumers' experience, with mobile users spending an average of 62.3% of their time using Wi-Fi.

Figure 1: Average (mean) proportion of time spent connected to Wi-Fi (%)



Source, Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.

Network share and 5G

Unlike the analysis published in previous Mobile Matters reports, the Opensignal cellular network share data used in this report includes time when the user's handset may simultaneously be connected to a Wi-Fi network.

The proportion of time connected to 5G figures in our analysis are not a proxy for 5G availability. Currently, almost all 5G in the UK is offered using 5G non-standalone access (5G NSA), which provides 5G connectivity over both 4G and 5G network infrastructure. Unlike previous generations of mobile technology, with 5G NSA a 5G network is only accessed when a data connection is needed, and the phone stays connected to 4G at other times (even if 5G is available).

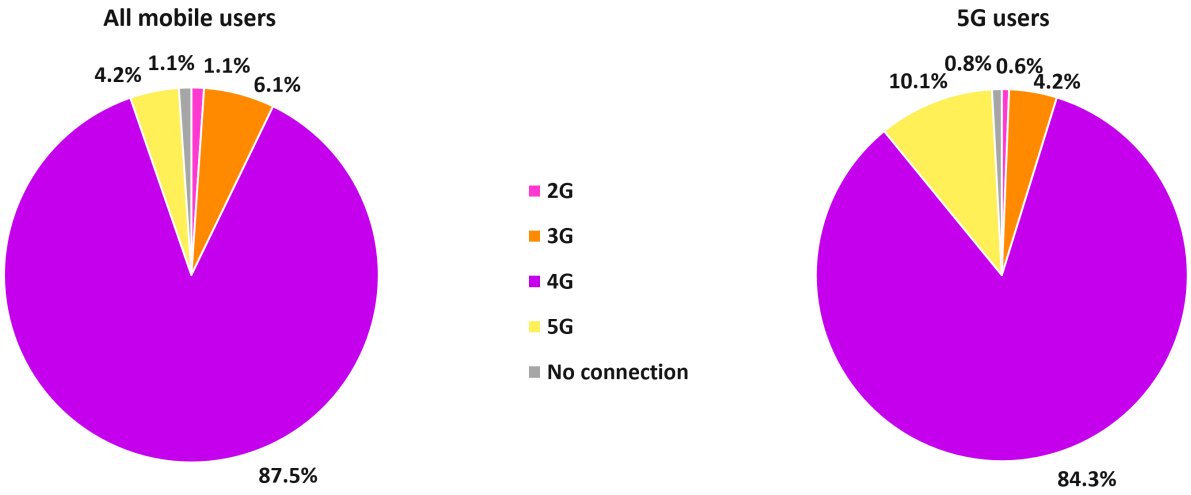
As such, our analysis shows time being spent on a 4G connection for an inactive phone which, if a 5G network is available, may connect to a 5G NSA network when a data connection is required. Therefore, our figures do not represent the proportion of time that 5G networks were available to 5G users (which will be higher). As operators launch 5G standalone access (5G SA) services, users will be connected to 5G more often because, unlike 5G NSA, the technology no longer relies on a 4G signal being available.

Across all mobile users, people were connected to a 4G network for an average of 87.5% of the time. Mobile users spent an average of 6.1% of the time connected to a 3G network and 4.2% of the time on 5G (although this is calculated including mobile users who do not have access to 5G services and, for the reasons outlined in the box above, does not include time when the phone was inactive but 5G was available when needed). A further 1.1% of the time was spent connected to a 2G network and, on average, people had no cellular connection for just 1.1% of the time.

3G networks are due to be closed over the next few years, with Vodafone having started switching off its 3G network, and it is anticipated that EE and Three will do the same in 2024.[2] Mobile operators are expected to contact customers if they are affected and told the steps they need to take to continue to use their mobile service. Vulnerable customers, particularly those struggling financially, will need to be given additional support. MNOs are also expected to ensure that they offer a broadly equivalent level of 4G coverage ahead of 3G (and subsequently 2G) switch-off.[3]

On average, 5G users spent 10.1% of the time connected to a 5G network. We found that 5G users were connected to a 4G network for most of the time (84.3%), with a further 4.2% of their time being spent on 3G, 0.6% on 2G; for 0.8% of the time 5G users were without a cellular connection.

Figure 2: Average (mean) network share by cellular technology, all mobile users and 5G users

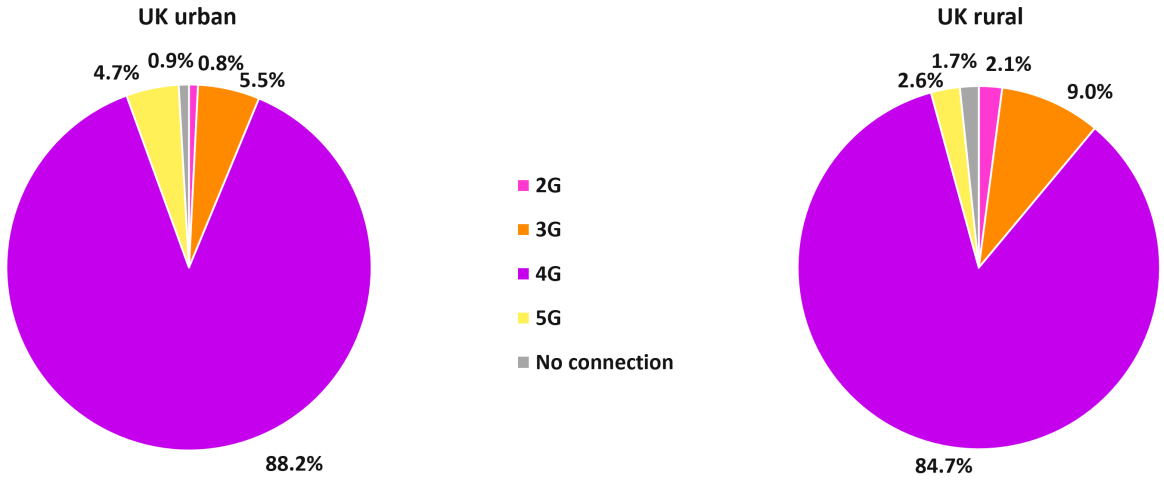


Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.

A comparison of network shares in urban and rural parts of the UK shows that the share of time spent on 5G and 4G was higher in urban areas than in rural ones, whereas rural mobile users spent higher proportions of their time connected to 2G and 3G or with no cellular connection. This suggests that urban mobile users are likely to receive a better user-experience than those in rural areas.

[2] Ofcom, 2022: Switching off the UK's 3G mobile networks: what you need to know.
[3] Ofcom, 2023: 3G and 2G switch-off: Our expectations of mobile providers.

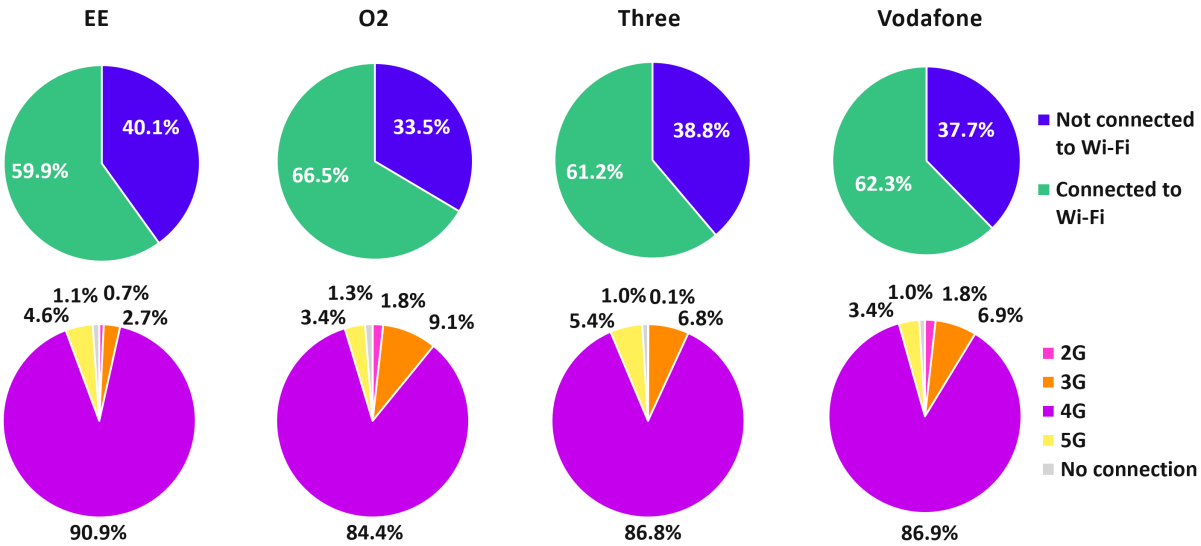
Figure 3: Average (mean) network share by cellular technology, by rurality (%)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.

Across all users, EE customers spent a lower proportion of the time connected to Wi-Fi and O2 customers a higher proportion compared to the other MNOs. EE customers also spent the highest proportion of their time on 4G and O2 customers the lowest proportion. These results were transposed for 3G, with O2 customers spending the highest proportion of time on 3G and EE customers the lowest proportion. Three customers spent the highest proportion of time connected to 5G.

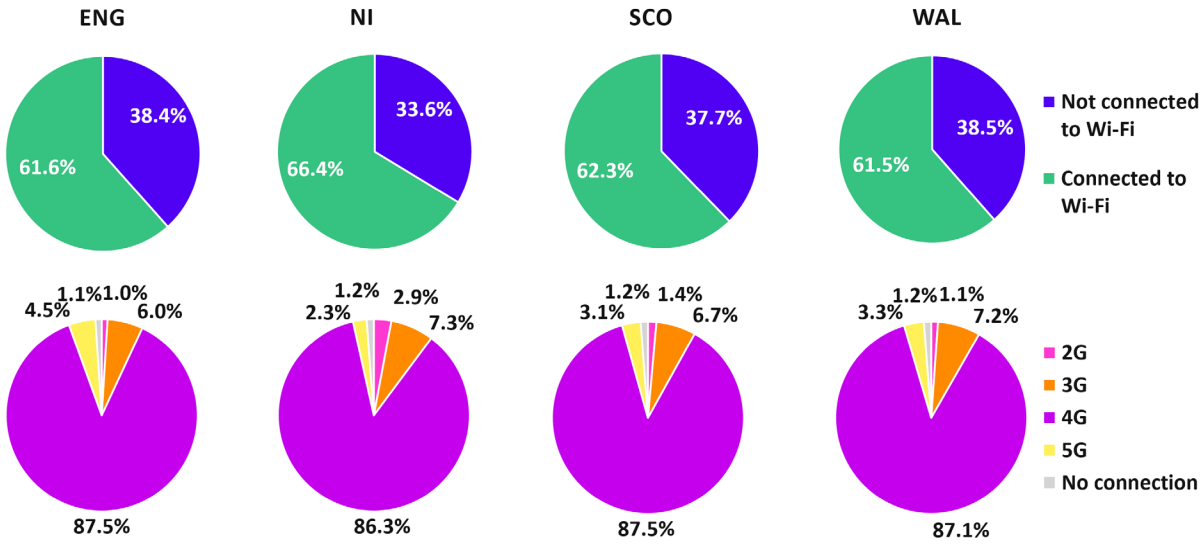
Figure 4: Average (mean) network share, by wireless technology and MNO (%)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.

Our analysis shows that, across all users, the average proportion of time spent on Wi-Fi in Northern Ireland (66.4%) was over four percentage points higher than in the other nations. The higher proportion of time spent on Wi-Fi in Northern Ireland corresponds with O2 take-up being higher than average (40% in Northern Ireland, more than double that in any other nation according to our latest Tech Tracker research).

Figure 5: Average (mean) network share, by wireless technology and UK nation (%)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.

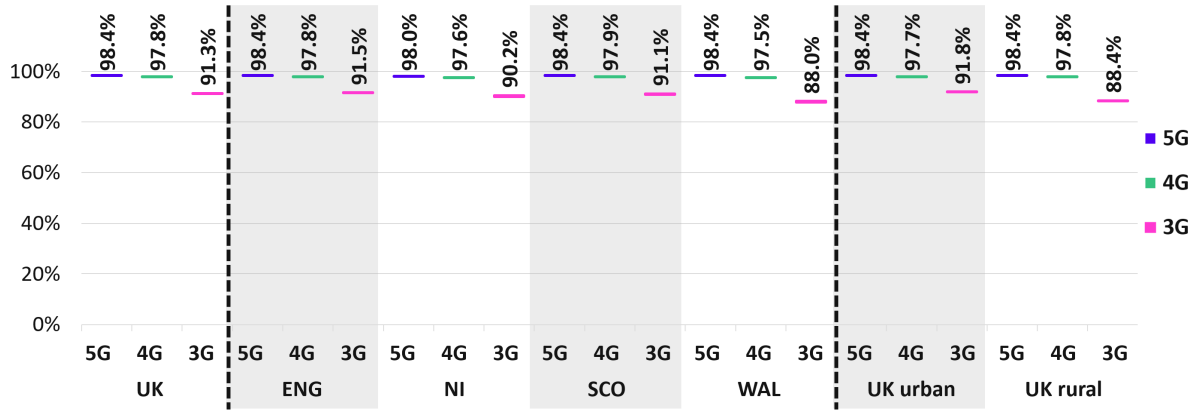
Data connection success rate

With mobile phones being increasingly important for everyday tasks like reading the news, making payments, or booking appointments, people rely on being able to connect to data services wherever they are. Our analysis shows how often people could access data services when they were actively using their phone in a coverage area. This is not a measure of mobile coverage, but of how frequently people could connect to data services, when they needed to and were in areas where the specified network was available.

On average, people could use data services on 5G networks on 98.4% of occasions when the screen was active and they were in an area with 5G network coverage, while the comparable average 4G connection success rate was 97.8%, with no significant differences by UK nation and rurality over both 5G and 4G.[4]

The average connection success rate for 3G connections was lower than those of 4G and 5G connections, and higher in urban areas than in rural ones. This may be because 3G connections are more likely to be at the 'edge' of a network, where a 4G network is not available. Across the UK nations, the average 3G success rate was lowest in Wales.

Figure 6: Average proportion of successful 3G, 4G and 5G connections while the screen was active, by cellular technology, UK nation, and rurality

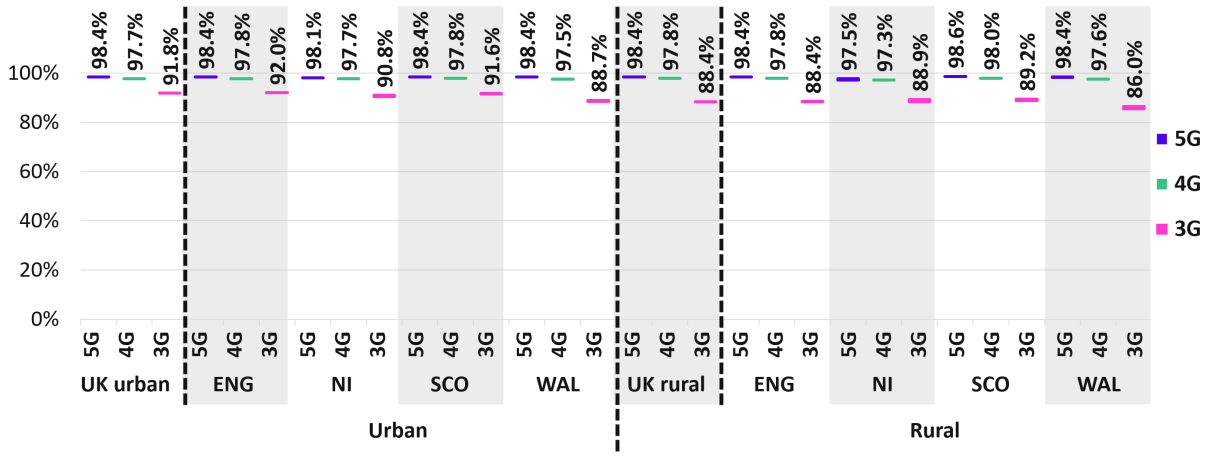


Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Our analysis shows that on 5G and 4G networks, both in urban and rural areas, the average data connection success rates were not significantly different by UK nation. Looking at 3G networks across the UK nations, the average success rate was lowest in Wales in both urban and rural areas, and success rates were higher in urban areas than in rural ones in all four UK nations.

[4] This success rate reflects the availability of the network in the places that people in the panel visited or travelled through, not the overall landmass coverage of the network.

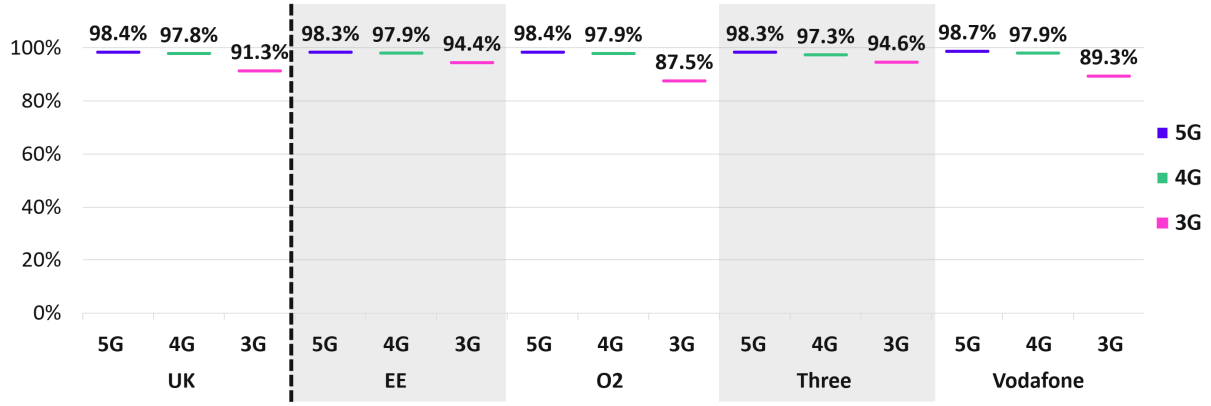
Figure 7: Average proportion of successful 3G, 4G and 5G connections while the screen was active, by cellular technology, rurality, and UK nation



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

On 5G and 4G networks, the average data connection success rates were not significantly different by MNO. Looking at 3G networks, O2 data connections were less likely to succeed than those of the other MNOs, with EE and Three customers experiencing the highest connection success rates.

Figure 8: Average proportion of successful 3G, 4G and 5G connections while the screen was active, by cellular technology and MNO



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Time to download files

People use their smartphones for a variety of purposes, some of which are more demanding in terms of connectivity than others. To understand file download times, we looked at the average time taken to download different sized files over 3G, 4G and 5G mobile connections.

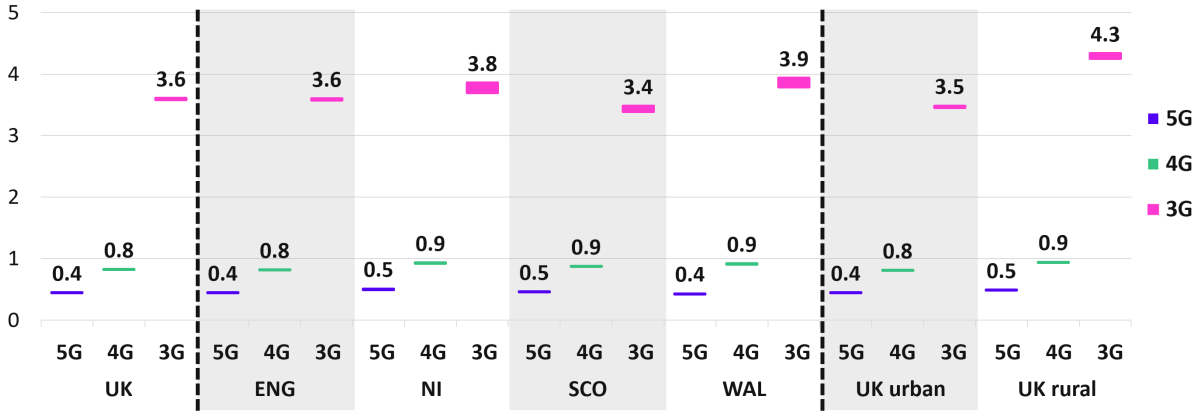
Time to download a 2MB file

Downloading a smaller (2MB) file can be representative of many typical activities undertaken on mobile devices, for example downloading photos or short low-resolution video clips in messaging apps or social media usage.[5]

Our analysis shows that, on average, it took around twice as long to download a 2MB file on a 4G network than on a 5G network (0.8s and 0.4s respectively), and more than four-times longer on a 3G network (3.6s) than over 4G. While the observed differences in 4G and 5G download times are only small, they may be the difference between content feeling as though it is being accessed almost "instantaneously" or with a short delay, which will impact the user experience.

The average time to download a 2MB file was longer in rural areas than in urban ones over all three mobile technologies, although the difference was only small over 5G and 4G. Across the UK nations, there was little variation in the average time to download a 2MB file over 5G and 4G; however, the differences were more marked for 3G, with Scotland having the shortest time to download a 2MB file, and Northern Ireland and Wales the longest times.

Figure 9: Average (median) time to download a 2MB file, by cellular technology, UK nation, and rurality (seconds)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

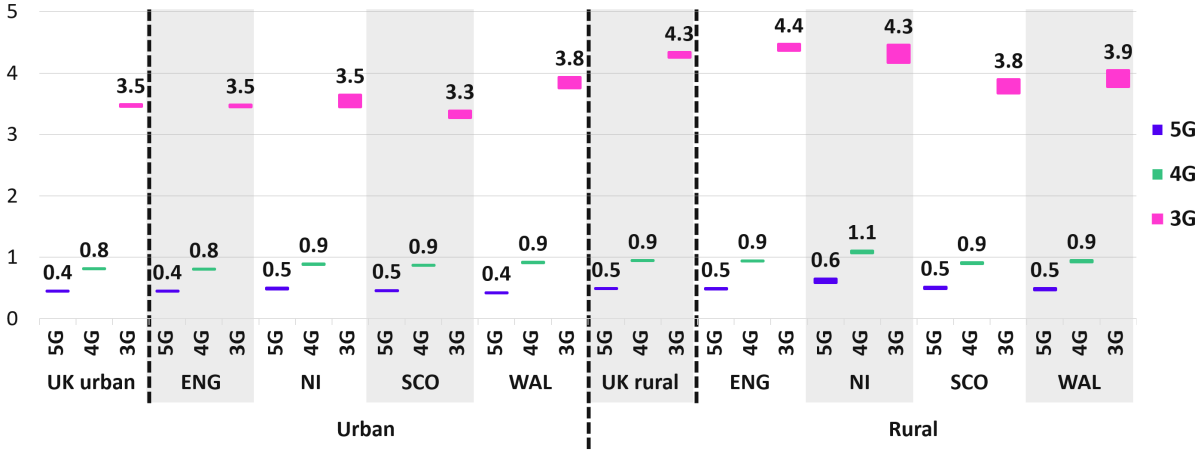
There were only minor differences in average urban and rural times to download a 2MB file over 5G and 4G between the UK nations. Over 3G, the average 2MB download time was longer in rural than

[5] As the test is a single file download, it is only indicative of the performance of these types of services, rather than an exact representation.

in urban areas, with the exception of Wales, where there was no significant difference between urban and rural 3G 2MB file download times.

In urban areas, the differences between 2MB download files across UK nations were only small for 5G and 4G; they were more marked over 3G, with average 2MB download times ranging from 3.3s in Scotland to 3.8s in Wales. In rural areas, the average time to download a 2MB file was longest in Northern Ireland on both 5G and 4G networks. On 3G networks, the average 2MB download times in Scotland and Wales were shorter than in England and Northern Ireland.

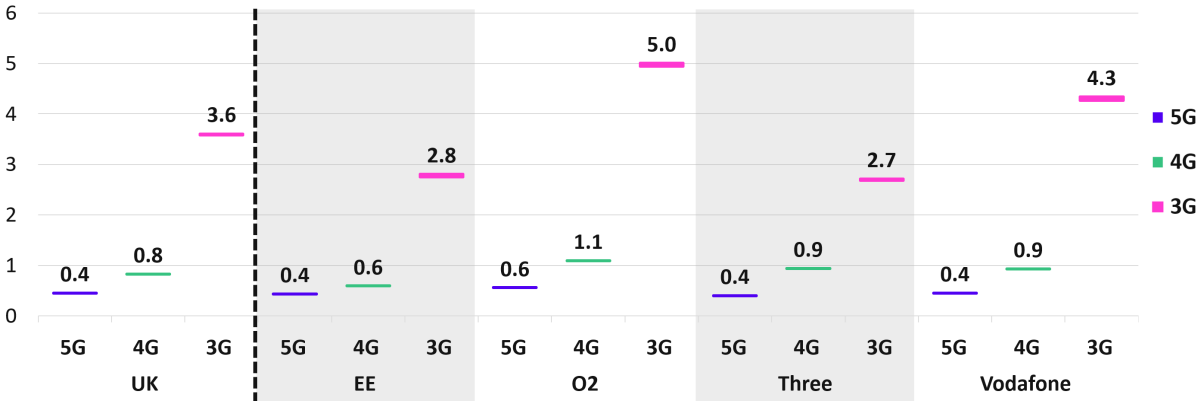
Figure 10: Average (median) time to download a 2MB file, by cellular technology, rurality, and UK nation (seconds)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

O2 customers had the longest average time to download a 2MB file over all three cellular technologies. EE customers had the shortest average 2MB download time over 4G, while Three customers enjoyed the shortest download times over 3G.

Figure 11: Average (median) time to download a 2MB file, by cellular technology and MNO (seconds)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Time to download a 5MB file

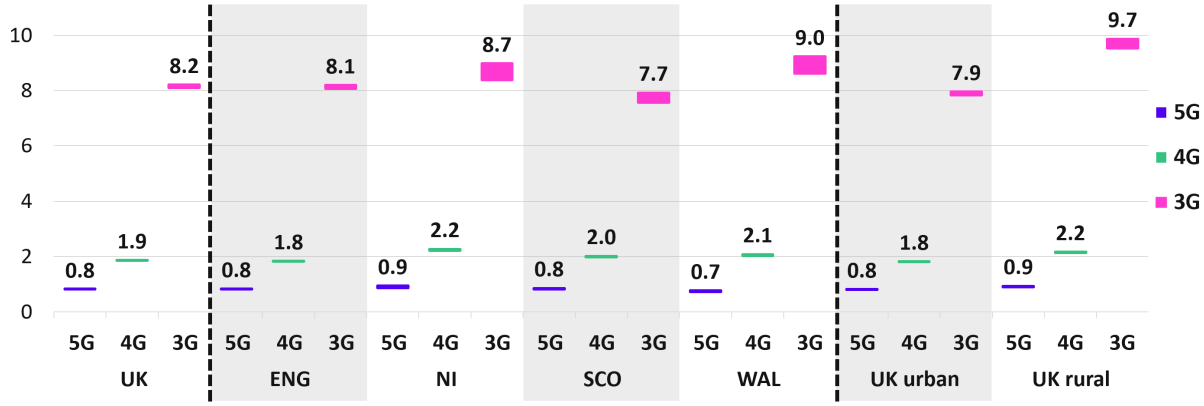
A 5MB file download can be representative of opening a photo in an email, a longer low-resolution video via instant messaging, or downloading a short audio file.[6]

Our analysis shows that the average time to download a 5MB file on a 5G network was around twice as long as downloading a 2MB file (0.8s vs 0.4s for a 2MB file). The benefit of 5G over 4G was more apparent with a larger file download, with a 5MB download over 5G being 56% shorter than it was over 4G, compared to 5G being 46% shorter with a 2MB file.

Across the UK nations, the average time to download a 5MB file was longest in Northern Ireland over 5G and 4G, while it was shortest in Wales over 5G and in England over 4G. 3G download times were shortest in Scotland and longest in Northern Ireland and Wales.

The average time to download a 5MB file was shorter in urban areas of the UK than in rural areas for all three cellular technologies.

Figure 12: Average (median) time to download a 5MB file, by cellular technology, UK nation, and rurality (seconds)

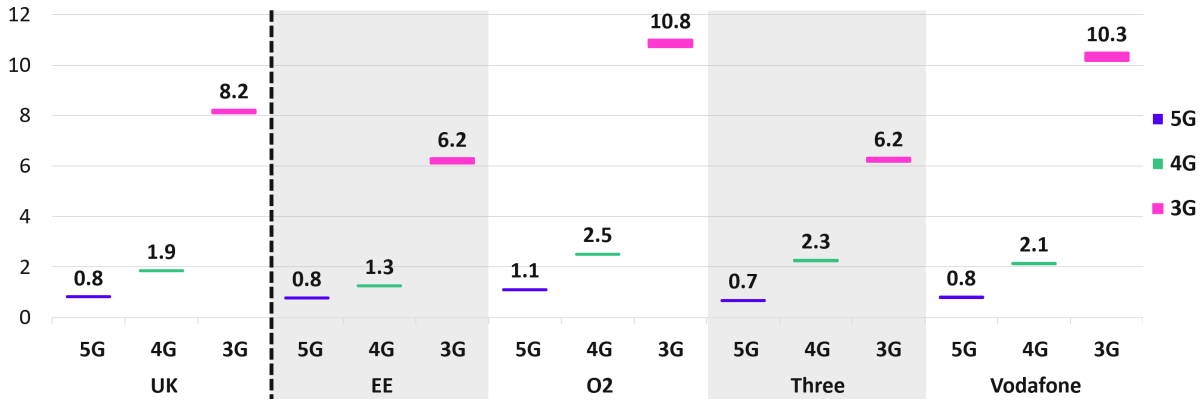


Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

The average time to download a 5MB file was longest on O2 for all three cellular technologies. Three had the shortest average download time on 5G, EE had the shortest over 4G, and EE and Three had joint-shortest on 3G.

[6] As the test is a single file download, it is only indicative of the performance of these types of services, rather than an exact representation.

Figure 13: Average (median) time to download a 5MB file, by cellular technology and MNO (seconds)



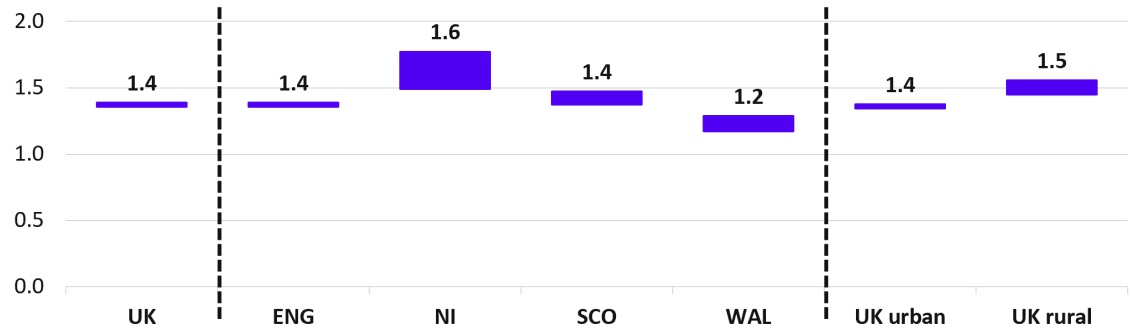
Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Time to download a 10MB file

Downloading a 10MB file can be representative of activities such as downloading higher quality short-form video in messaging applications.[7]

The 10MB file download test was only run on 5G networks. Across the nations, the average time to download a 10MB file on 5G networks was shortest in Wales and longest in Northern Ireland. Downloading a 10MB file was shorter in urban areas of the UK than in rural ones.

Figure 14: Average (median) time to download a 10MB file on 5G networks, by UK nation, and rurality (seconds)

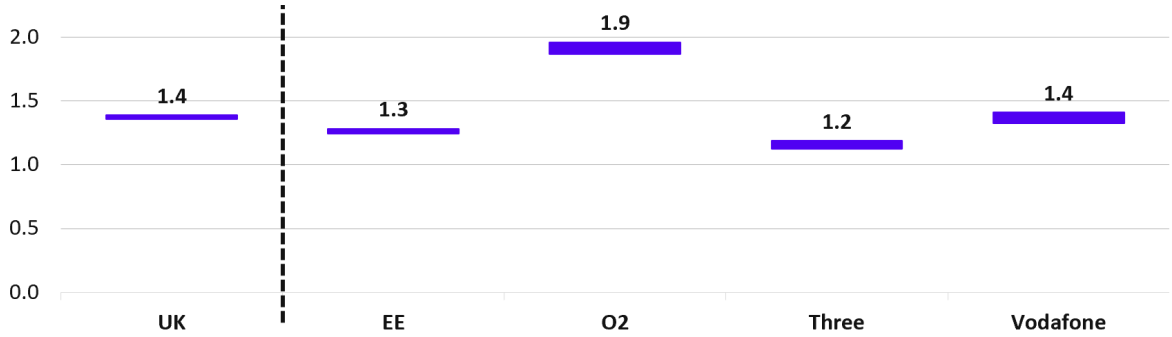


Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Notes: Lower values indicate better performance; due to the methodology, we were only able to analyse this metric on 5G; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

The average time to download a 10MB file was longest for O2 customers on 5G networks and shortest for Three customers.

[7] As the test is a single file download, it is only indicative of the performance of these types of services, rather than an exact representation.

Figure 15: Average (median) time to download a 10MB file on 5G networks, by MNO (seconds)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; due to the methodology, we were only able to analyse this metric on 5G; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

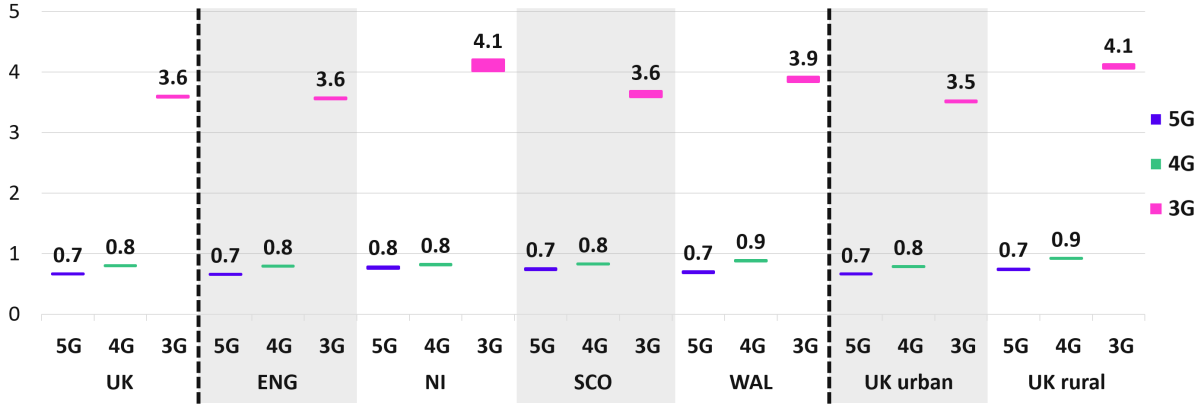
Time to upload files

Time to upload a 1MB file

Uploading a 1MB file can be representative of sharing photos or a short low-resolution video via messaging apps or social media.[8]

Our analysis shows that the average time to upload a 1MB file was shortest over 5G and longest over 3G, with 1MB upload time being longer in rural areas on all three cellular technologies (although the difference over 5G was only small). Across the nations, there were only minor differences in average 1MB upload times between UK nations over 5G and 4G, while the average 1MB upload time over 3G connections was longest in Northern Ireland.

Figure 16: Average (median) time to upload a 1MB file: by cellular technology, UK nation, and rurality (seconds)



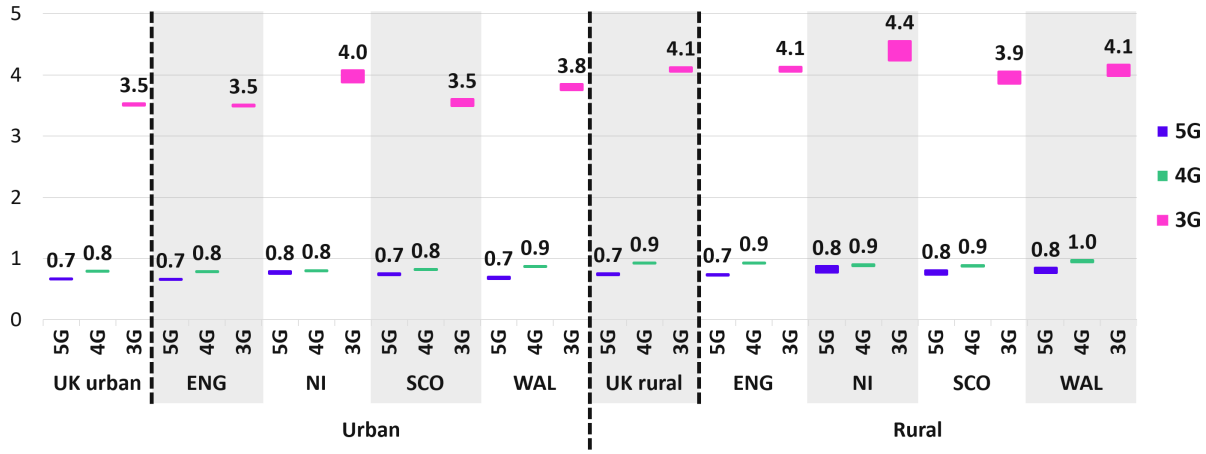
Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

In both urban and rural areas, the differences in average 1MB file upload times were comparatively small over 5G and 4G. On 3G networks, Northern Ireland had the longest average 1MB upload time in both urban and rural areas, while in urban areas, England and Scotland had the shortest ones.

Within all of the UK nations, rural upload times were longer than those in urban areas for all three cellular technologies, although the differences were smaller over 5G and 4G and there were no statistically significant differences between urban and rural 5G upload times in Northern Ireland and Scotland.

[8] As the test is a single file upload, it is only indicative of the performance of these services, rather than an exact representation.

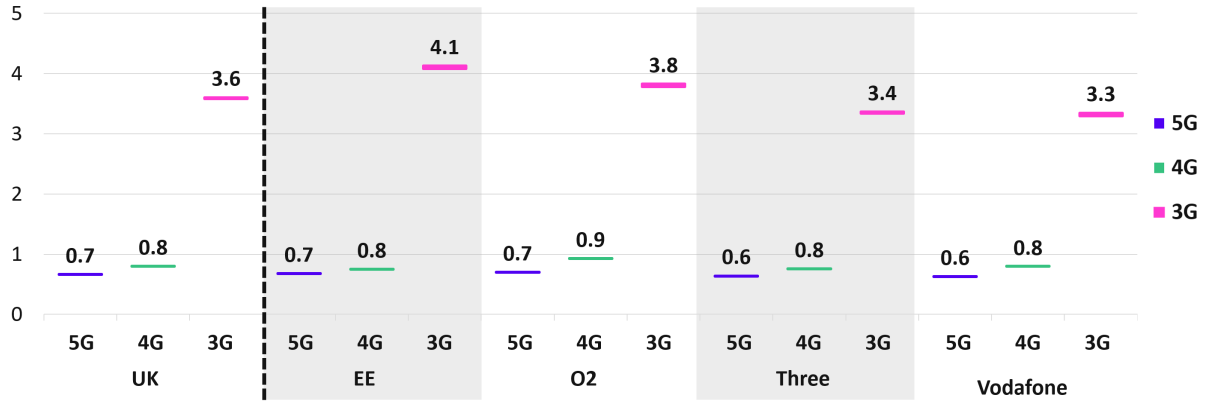
Figure 17: Average (median) time to upload a 1MB file: by cellular technology, rurality, and UK nation (seconds)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

There were only minor differences in the average time to upload a 1MB file over 5G and 4G networks by MNO, however, the differences were more marked for 3G. Three and Vodafone customers had the joint-shortest average 1MB upload time over 3G and EE customers the longest averages.

Figure 18: Average (median) time to upload a 1MB file: by cellular technology and MNO (seconds)



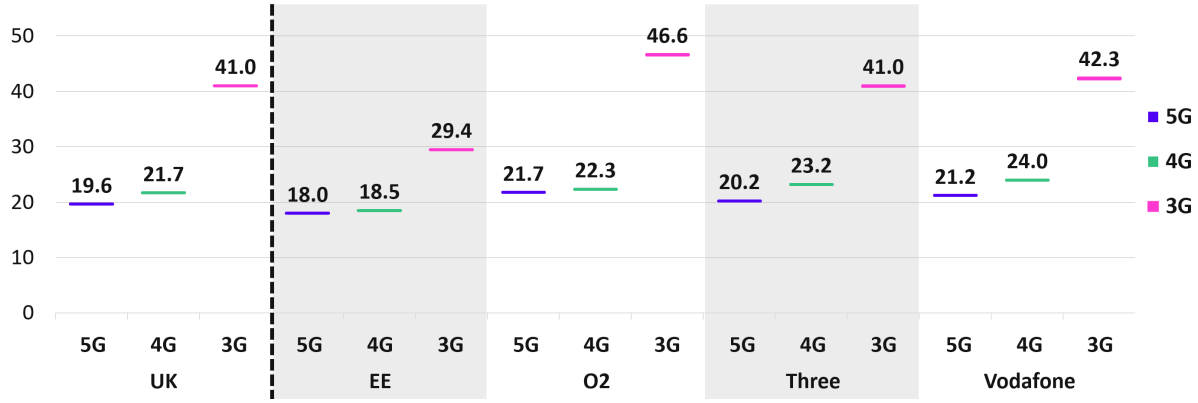
Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Response time (latency)

The time it takes the network to respond to a data request can have a noticeable impact on user experience. Real-time activities such as video calling, voice chat (VoIP) and multiplayer gaming perform much better with a lower response time, while other activities including web browsing give a satisfactory user experience with a slower response time.

Our analysis shows that on average, response time was significantly faster on the EE network for connections on all cellular technologies. O2 had the slowest average response times over 5G and 3G, while Vodafone had the slowest over 4G. Response times on 3G were much slower than those on 5G or 4G networks, with the differences between 5G and 4G being much smaller.

Figure 19: Average (median) response time by cellular technology and MNO (ms)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: Lower values indicate better performance; the chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Connection speeds

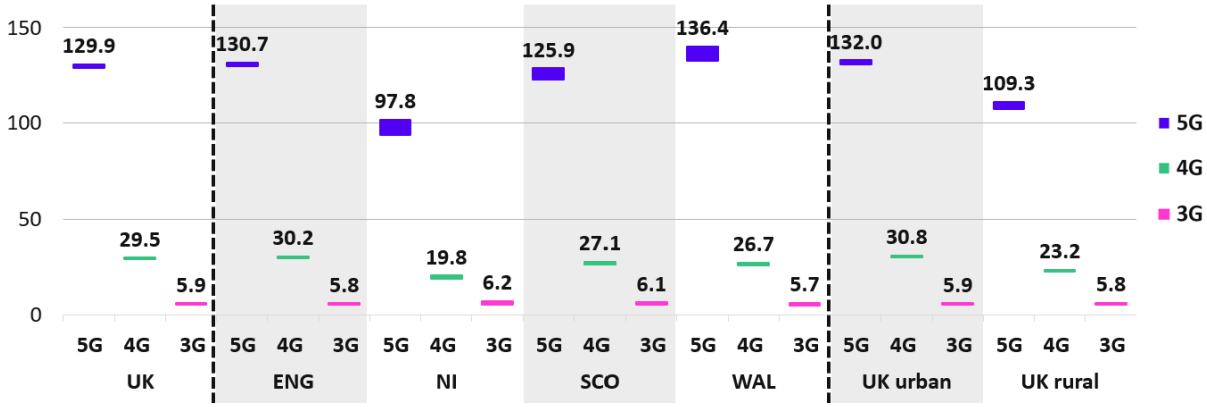
Download speeds

To understand download speeds, we have analysed the results of Opensignal time-based tests. These differ from the fixed file size "time to download/upload" tests as they use as much, or as little, data as the connection can consume over the duration of the test.

On faster connections, these time-based tests consume more data than the fixed file size tests and provide a better measure of the typical download speeds available to the user as the connection has sufficient time to ramp up to its usable speed. The fixed file size and timed tests are therefore reflective of different types of mobile use: the timed tests simulate activities that require larger amounts of data, such as downloading a mobile app, TV programme or music album, whereas the smaller fixed file tests replicate the experience delivered to users undertaking online activities that are more 'bursty' in nature and/or involve accessing smaller amounts of data.

Our analysis shows that download speeds were fastest over 5G, averaging 129.9 Mbit/s in the six-month period we looked at. This compared to averages of 29.5 Mbit/s over 4G and 5.9 Mbit/s on 3G. Northern Ireland had the slowest average 5G and 4G download speeds among the UK nations. Wales benefitted from having the fastest average 5G download speed, followed by England and Scotland. England had the fastest 4G download speed and there were no significant differences between 4G speeds in Scotland and Wales, or in 3G download speeds across any of the UK nations. Average urban 5G and 4G upload speeds were faster than those in rural areas, while there was no significant difference between average urban and rural download speeds over 3G.

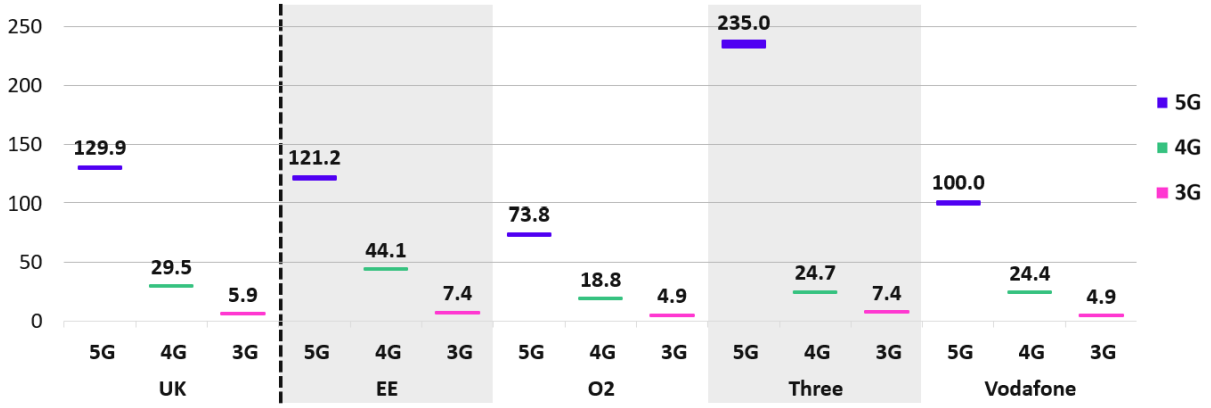
Figure 20: Average (mean) download speed, by cellular technology and nation (Mbit/s)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Among the MNOs, Three had the fastest average 5G download speed, O2 the slowest and EE's average 5G download speed was faster that Vodafone's. O2 also had the slowest average 4G download speed, at 18.8 Mbit/s, less than half the 44.1 Mbit/s average recorded by EE (which had the fastest 4G download speed among the MNOs). EE and Three had the joint-fastest average 3G download speeds and O2 and Vodafone the joint-slowest.

Figure 21: Average (mean) download speed, by cellular technology and MNO (Mbit/s)



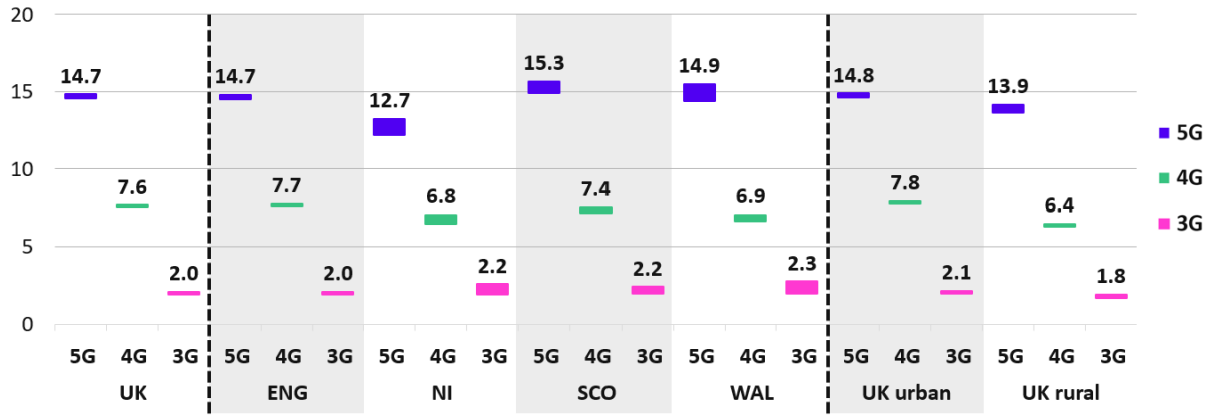
Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Upload speeds

Opensignal also uses time-based tests to measure connection upload speeds. These show that average upload speeds over 5G (14.7 Mbit/s) were almost twice those over 4G (7.6 Mbit/s) with 3G upload speeds averaging just 2.0 Mbit/s.

Across the UK nations, Northern Ireland had the slowest average 5G upload speed and was joint-slowest with Wales for 4G. There were no significant differences between average 5G upload speeds in England, Scotland and Wales, and England had the fastest average upload speed over 4G. There were no significant differences in 3G upload speeds among the UK nations, and average urban upload speeds were all quicker than those in rural areas over all three cellular technologies.

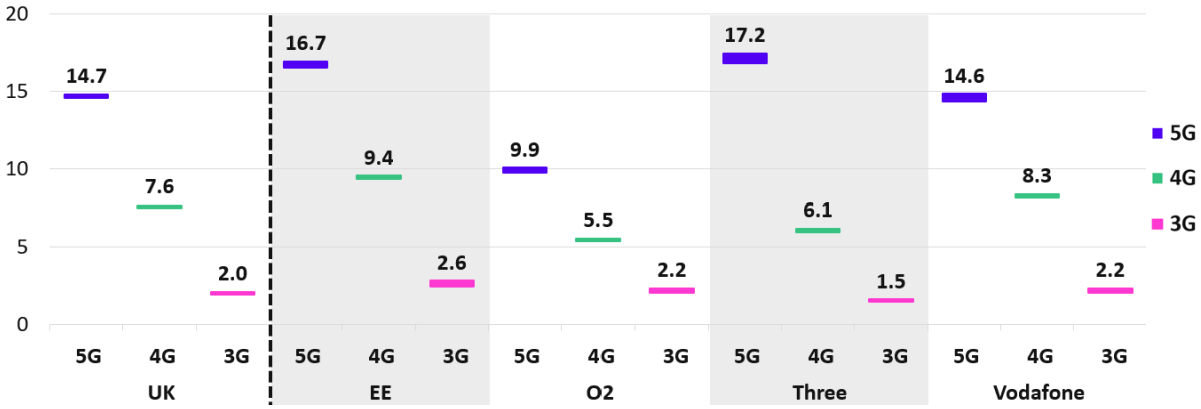
Figure 22: Average (mean) upload speed, by cellular technology and nation (Mbit/s)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

Among the MNOs, EE customers had the fastest average 4G and 3G upload speeds and was joint-fastest with Three over 5G. O2 customers experienced the slowest 5G and 4G upload speeds and Three was slowest over 3G.

Figure 23: Average (mean) upload speed, by cellular technology and MNO (Mbit/s)



Source: Ofcom, using crowdsourced data provided by Opensignal; October 2022 to March 2023 data.
Note: The chart bars/lines show that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown.

A1. Technical methodology

Ofcom uses measurements collected from real mobile users to measure the mobile network performance and the consumer experience of using different mobile services. The methodology uses a panel of UK smartphone[9] users who have installed apps that include the Opensignal software development kit (SDK) on their device. The data collection framework and panel are developed and managed by Opensignal Limited ('Opensignal') and data was licensed to Ofcom. Opensignal also managed the collection and aggregation of the collected data and advised on data analysis.

Data collection

Individual measurements from smartphones are collected every day, under conditions of normal use. These include measurements in both indoor and outdoor locations: as users spend most of their time indoors, most measurements are collected from indoor locations.

Opensignal does not use dedicated test servers. It measures the end-to-end consumer network experience and the full path from the user device all the way to the Content Delivery Network (CDN) that host popular apps, services, and websites.

Measurements of network speed are collected based on both user-initiated tests and automated tests. The majority of measurements are generated through automated tests (i.e. no user interaction), executed independently and at random intervals to capture what users are experiencing at a typical moment in time.

A rigorous post-processing system is used that takes the raw measurements and calculates robust and representative metrics. This includes a number of steps to quality-assure the measurements.

For example, if a user failed to download any content, this measurement is eliminated and treated as a "failed test" rather than being included in the average speed calculation.

Table A1: Data collection processes and actions

Process	Action taken
Initial filtering	Certain entries are automatically filtered out (e.g. when a phone is in a call), which are known to produce non-typical results.
Operator name mapping	To ensure that the results only reflect the experience of customers who bought the operator's own branded service, Opensignal removes results from mobile virtual network operator (MVNO) subscribers and subscribers who are roaming from results for mobile network operators (MNOs). These subscribers may be subject to different Quality of Service (QoS) restrictions than an operator's own customers and so their experience may be different.
Selection of network type	Opensignal consolidates data into technology types — e.g. when considering 3G connections, Opensignal includes the various 3GPP releases that include HSDPA, HSUPA and UMTS R99 into one group.

[9] Predominantly Android.

The metrics analysed by Ofcom are:

- Network share (Opensignal calls this metric “Availability”)
- Data connection success rate
- Response time (latency)
- Time to download a 2MB/5MB/10MB file
- Time to upload a 1MB file
- Download speed
- Upload speed

Metrics

Network share

Data network share measures the proportion of time people have a network connection, in the places they most commonly frequent.

The network share metric (called “Availability” by Opensignal) shows the proportion of time people on an operator’s network had either a 2G, 3G, 4G, 5G or Wi-Fi connection, or no connection at all.

5G network share shows the proportion of time people with a 5G device and a 5G subscription had an active 5G connection.

4G network share shows the proportion of time people with a 4G device and a 4G subscription — but who have never connected to 5G — had a 4G connection.

3G network share shows the proportion of time that all users are connected to a 3G network.

2G network share shows the proportion of time that all users are connected to a 2G network.

Wi-Fi network share shows the proportion of time that all users are connected to Wi-Fi (Network Connection Type is Wi-Fi) AND cellular network does not have a valid cellular type.

The proportion of time typical users on each network spend connected to each wireless network technology is assessed, or whether they have any network connection at all. These are calculated by continually measuring whether users have any network connection at all, and if so, what kind of connection that is (2G, 3G, 4G, 5G or wi-fi).

As such, they are a user-centric measure of how people experience the network, rather than, for example, a measure of network geographical coverage.

To calculate these metrics, Opensignal begins from a dataset that regularly captures a user’s location, time and a series of parameters associated with their network connection state, then follows a 3-step process:

a) Filtering the data, to remove any data that might be invalid or lacking required information, such as location.
b) Classifying the data, which defines whether each piece of data applies to each metric/calculation.
c) Averaging the data, which seeks to (a) ensure that a fair representation of each user’s network experience is achieved and (b) that each user applies equally to the overall average

over the population of users to ensure that the metric is a measure of typical experience rather than being over-weighted by users who report more data.

The network share metrics are calculated across all network generations.

Table A2: Identification of network generations

Category	Description
2G	Records when the user was connected to 2G (Network Type is one of “GPRS”, “EDGE”, “GSM”)
3G	Records when the user was connected to 3G (Network Type is one of “UMTS”, “WCDMA”, “HSDPA”, “HSUPA “, “HSPA”.
4G	Records when the user was connected to LTE (Network Type is “LTE”) i.e. 4G
5G	Records when an NR connection has been allocated to the device (NR State=3 in non-standalone access) or when there is a standalone access 5G connection.
No connection	1. Cellular network is registered (Network Connection Type is a cellular one) but there is no valid data connection (Data State is disconnected). 2. Connected to Wi-Fi (Network Connection Type is Wi-Fi) AND cellular network does not have a valid cellular type (Network Type is not one of those listed in the above definitions for 2G, 3G, 4G or 5G). 3. No valid network connection reported (Network Connection Type is not valid). For all three situations, if the user has manually switched off data connections (i.e. airplane mode) it will not count as a ‘No Signal’ measurement.

Data connection success rate

The data connection success rate metric provides a view on the success of an Opensignal server response test to connect to the internet using a 3G, 4G and 5G mobile data network connectivity when a mobile phone screen is on to mirror consumer behaviour. The Opensignal server response test is used to measure the latency, jitter, & packet loss and its methodology is recorded below.

Response time (latency)

Response time, often referred to as latency, is the delay between a consumer making a request to their mobile network for information and the network providing this information to the device.

Server response tests are performed against a number of leading content delivery networks (CDNs) that are typically used to host popular apps, websites, and mobile services.

A server response (SR) test is defined as a test which determines the latency, jitter and packet loss of the current connection using UDP. To accurately measure these KPIs, a predetermined number of packets are sent to the test servers, usually 100 packets. Each of these packets contains a 32-byte payload which holds a number indicating the ordering of that packet in the sequence of packets sent out.

The SDK chooses the closest test server based on the geographical distance between the device and the server locations. Each packet is then sent to the test server via UDP which is connectionless. This

means that, unlike TCP connections, there is minimal handshaking involved which could produce measurement results that indicate slower-than-actual speeds.

The UDP protocol is also used to simulate latency-sensitive applications, such as video and VoIP calling. The precise time that each packet is sent out is recorded to nanosecond precision and stored for later calculations. The packet spacing is 20ms between packets

The test server receives the packets sent from the SDK and then immediately echoes them back to the listening device. The precise time that each packet is received back on the device is also recorded along with the specific payload of each packet. As this payload indicates the ordering of the packets returned to the device. The Metro Ethernet Forum (MEF) 10 specification is used to calculate the latency.

Latency is determined as half of the round-trip travel time of each packet from the time the packet is sent from the SDK to when the same packet is received.

Time to download a 2MB/5MB/10MB file and upload a 1MB file

The Opensignal SDK performs a collection of active tests, where phones are prompted to download a 2MB, 5MB or 10MB file and upload a 1MB file, and the throughput experienced when downloading / uploading these files is recorded.

The download throughput is measuring the duration it takes to download a 2MB file from a randomly selected CDN test server over a TCP connection. 2MB is selected to simulate downloading photos or short low-resolution video clips in messaging apps or social media usage. The measured download throughput is recorded against the current wireless connection (2G,3G,4G and 5G).

Download throughput tests are performed against CDNs commonly used to host popular website and other web applications over HTTPS. This allows test files to be downloaded with a low latency through one of the CDN edge servers located around the world. The payload is requested via URL. The actual end server that delivers the payload is determined by the CDN.

The fixed sized throughput tests do not measure the maximum throughput of the network. There is a technical limitation with the download throughput tests that limit the minimum throughput to 350Kbps. This is the result of the timeout implementation within the Opensignal SDK.

Each CDN service determines the closest edge test server to serve the download test file based on the IP address of the device. The SDK opens a TCP connection (HTTPS GET) to the test server to start downloading the test file.

The current time is then recorded in nanoseconds, as well as a received (Rx) byte count. The received byte count is a numerical count of how many bytes have been delivered over the wireless radio at a given time. This is the last step performed before the actual bytes are streamed from the server, to ensure that the measurements have the highest level of accuracy. Data bytes are streamed-in as 1024-byte blocks until either the file has completed downloading or a timeout or a cancel test event is triggered. The connection is then closed, the current time and the device's current received byte count are recorded.

Download and upload speed

Opensignal's download and upload speed metrics assess the mean speeds experienced on data connections to mobile networks.

Opensignal's speed tests involve downloading or uploading a file for a set period (30 seconds) in order to test the data performance of a user's mobile network, directly from their handset.

The test is performed over HTTPS connections and multiple threads are used to simulate a typical mobile app data connection. The download and upload servers are the same as those used by popular mobile apps, websites, and mobile services that internet users connect to every day, provided by major content delivery networks (CDNs).

Opensignal collects data primarily via automated tests that run in the background. These tests are run at various points in time to ensure that the metrics are truly reflective of the speed users experience during normal usage of their mobile network.

To calculate the metrics for download and upload throughput speed, Opensignal begins from a dataset of individual test records which contains a series of fields including: the test location, time, type (user-initiated or automated), the network connection type (e.g. Wi-Fi, UMTS, LTE, 5G etc.), the servers that were used, the IP address, various RF parameters and a series of metrics associated with the speed and latency of the data connection that was measured during the test.

Opensignal then follows the process below:

a) Filtering to remove any data that might not be valid or is lacking any required information, such as location.
b) Averaging the data, which seeks to (a) ensure that for each user Opensignal is achieving a fair representation of users' network experience and (b) that each user is weighted equally when calculating the overall average over the population of all users to ensure that the metric is a measure of typical experience rather than being overrepresented by users who report more tests or other data.

A2. Statistical methodology

The 2023 Mobile Matters report analyses findings collected from Opensignal's crowdsourced data panel between 1 October 2022 and 31 March 2023.

Crowdsourced panellists' records were included in the analysis if they met the following criteria:

a) the mobile network was either EE, O2, Three or Vodafone.
b) the location was in the UK and the UK nation was either England, Northern Ireland, Scotland, or Wales.
c) the data technology was known – either 2G, 3G, 4G or 5G, or Wi-Fi for network share analysis.

Records that did not meet the above criteria were excluded from the analysis.

Both Ofcom and Opensignal have ensured that the sample sizes are sufficient to ensure the robustness of the findings shown in the report and that the sample distribution broadly matches both the population distribution of the United Kingdom and the relative operator shares.

Metrics and analysis methodology

For the 2023 Mobile Matters report the following metrics were analysed:

- Average (mean) network share - % of time ("Availability" by Opensignal).
- Average proportion of successful data connections (%).
- Average (median) response time (ms).
- Average (median) time to download a 2MB/5MB/10MB file (seconds).
- Average (median) time to upload a 1MB file (seconds).
- Average (mean) download speed (Mbps).
- Average (mean) upload speed (Mbps).

Network share

This measure assesses the proportion of time all Opensignal users on a network were connected to Wi-Fi or, when they were not connected to Wi-Fi, the proportion of time they had either a 2G, 3G, 4G or 5G connection, or had no connection. Opensignal calls this metric "Availability". Our analysis then looked at differences by nation, rurality, and mobile network operator (MNO). Confidence intervals around each proportion were created using bootstrapping. These were used to perform two-tailed comparisons to look for statistically significant differences which are shown in the report.

Data connection success rate

To assess the data connection success rate, we looked at the total number of server response tests performed and calculated the percentage of these tests that were successful. The proportion of successful tests was then compared by nation, rurality, MNO, and cellular technology (2G, 3G, 4G or 5G). We used records where the mobile screen was on during this test, so we can assess the percentage of cases when the user was able to connect to data services when the device was in active use.

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.

The proportion of successful tests was calculated for each subgroup, and comparisons were made using two-tailed statistical tests. Analysis was carried out comparing 2G, 3G, 4G and 5G cellular technologies, nation, rurality, and MNO, and to look for any statistically significant differences in the performance of data services.

Response time (latency)

Response time, or latency, which is the delay in milliseconds between a consumer making a request to their mobile network for information, was compared by cellular technology and MNO. A two-tailed test of median response times was carried out on all sub-group comparisons.

Time to download files

The Opensignal dataset performs a collection of active tests, where phones are prompted to download a file of size 2MB, 5MB or 10MB, and the throughput experienced when downloading this file is recorded. We applied a conversion to this measure by multiplying the file size by 8 (to convert from MB to Mbit) and divided this figure by the recorded throughput to produce a measure showing the time taken for the user to download a 2MB, 5MB or 10MB file, respectively. The median time taken to download files of each size was calculated for each subgroup. Two-tailed tests of median download times were carried out on all sub-group comparisons.

Time to upload files

The Opensignal dataset also contains active upload tests, where the throughput experienced when prompted to upload a 1MB file is recorded. We applied the same conversion as above to produce a measure assessing the time taken to upload a 1MB file. The median time taken to upload a 1MB file was calculated for each subgroup. Two-tailed tests of median download times were carried out on all sub-group comparisons.

Download and upload speeds

To assess download and upload speeds, the Opensignal speed test downloads or uploads data for a set period of time. Over a 30 second measurement period, the download/upload speed received is recorded every 30ms, and this collection of measurements is trimmed[10] and averaged to give a single value. These values are then aggregated and averaged over network generation categories, individual users, rurality, and nations.

Confidence intervals around each average download/upload speed were created using bootstrapping. These were used to perform two-tailed comparisons to look for statistically significant differences, which are shown in the report.

[10] Top and bottom 10% of the tests were discarded.