RootMetrics®

H1 2023 - Claims Substantiation

Updated August 2023

Introduction to RootMetrics®

RootMetrics® is an independent mobile analytics firm that collects mobile network performance data to provide a unique and comprehensive view of the consumer mobile experience. As part of the RootScore® Report series, hundreds of millions of network performance data points are sampled each year, with all tests designed to reflect the different ways people use their smartphones.

UK and Nation RootScore® Reports are based on a combination of results from testing in 16 large metro areas as well as testing across the entirety of the UK and within each of the four UK nations. Providing mobile network performance information from nation to neighborhood, RootMetrics reporting can empower the mobile industry and consumers to make more informed mobile decisions.

The United Kingdom RootScore Report shows how the networks performed at a UK-wide level, while our England, Northern Ireland, Scotland, and Wales RootScore Reports provide a detailed look at network performance at the nation level.

The goal of UK and Nation RootScore Reports is to provide an accurate and consumer-focused assessment of mobile performance on the networks of EE, O2, Three, and Vodafone for the entirety of the UK, as well as for nations within the UK.

Based on RootMetrics testing, RootScore Awards are granted to operators in the following performance categories: Overall, Reliability, Accessibility, Speed, Data, Call, and Text. The Overall RootScore factors in results across all test categories; a good Overall RootScore means good overall performance and a good consumer experience. It's that simple.

The most important factors of a good mobile experience for consumers are reliability, accessibility, and speed. To address these consumer concerns, our Network Reliability and Accessibility RootScore Awards are based on a combination of results from data, call, and text testing, and the Network Speed RootScore Award is based on downlink and uplink speeds. These awards illuminate network performance from a holistic viewpoint.

The RootMetrics testing methodology represents the consumer experience of downloading and uploading files, downloading small files that represent web and app usage (secure and non-secure connections), making mobile-to mobile phone calls, and sending and receiving text messages.

The details of this methodology are listed later on within this document.

Understanding RootScore®

RootScores offer a simple way to translate thousands or millions of complex data points into clear and easy-to-understand marks of performance. RootScores are designed to reflect a consumer's experience of network performance; the higher the score, the better the performance. For instance, the Overall RootScore reflects a consumer's everyday experience across data, call, and text usage. A good Overall RootScore means a good overall consumer experience and good overall network performance.

Using an educational analogy, think of RootScores like you would a final grade in a semester-long course: scores approaching the upper limit (100) indicate extraordinary performance, like receiving an "A" grade at the end of the semester. Scores approaching the lower limit (0) represent network performance that would be clearly unacceptable to everyday consumer usage, similar to receiving a poor grade at the end of the semester.

Just as a final grade in a semester-long course is a function of performance across multiple exams, no single test determines RootScore results for any performance category; RootScores are calculated from multiple tests that are weighted according to the impact to a consumer's experience.

RootScore® Rankings & Verifiability

After compiling thousands of test results in a market, we estimate each network's RootScore. Based on statistical principles, RootScores have uncertainty associated with them. Confidence intervals represent this uncertainty and reflect the distribution of possible RootScore values based on our sampling of network performance. More specifically, confidence intervals reflect the underlying statistical uncertainty associated with any estimate based on random sampling.

The number of samples available impacts confidence intervals; the greater the number of samples within a test location, the more precise the estimate and the smaller the confidence interval.

Network rankings are determined through statistical comparison of RootScores; RootMetrics utilizes a bootstrap t-test at an achieved significance level of 0.1. Specifically, the t-test provides probabilistic evidence that two networks' scores are not equivalent to each other.

Through this process, networks with divergent scores are at times determined to be statistically indistinguishable and therefore receive the same rank, and networks with very close scores can receive different final rankings depending on the level of precision of the scoring.

For example, a Data RootScore might distinguish a clear ranking separation between 94.5 and 95.0, while a Call RootScore could result in a tie between scores of 93.0 and 95.0, based on observed differences in the uncertainty of the final RootScore.

RootScore® Reports

The United Kingdom RootScore® Report shows how the networks performed at a UK-wide level, while our England, Northern Ireland, Scotland, and Wales RootScore Reports provide a detailed look at network performance at the nation level.

The goal of UK and Nation RootScore® Reports is to provide an accurate and consumer-focused assessment of mobile performance on the networks of EE, O2, Three, and Vodafone for the entirety of the UK, as well as for nations within the UK. The RootMetrics testing methodology strives to provide an accurate, unbiased, and balanced assessment of operator performance.

UK and Nation RootScore® Reports are based on a combination of results from testing in 16 large metro areas as well as testing across the entirety of the UK and within each of the four UK nations. To provide an objective means of testing in areas where people live, the RootMetrics UK and Nation RootScore Report methodology uses results from tests previously conducted in the 16 most populous Larger Urban Zones (LUZs) across the UK, as well as data collected in officially designated Built-Up Areas (BUAs) in England and Wales and officially designated Settlements in Scotland and Northern Ireland.

To ensure that sample collection provides a balanced and representative view of operator performance across different-sized communities, the UK and Nation RootScore Report individual nation sampling methodology targets small, medium, and large "places" that were not sampled for Metro RootScore Reports and are based on population size.

UK and Nation RootScore Reports consist of Overall, Reliability, Accessibility, Speed, Data, Call, and Text RootScore Award winners at UK-wide and Nation levels.

RootMetrics pairs engineering expertise with statistical approaches to design operator performance tests, collect data on operator performance that reflects a consumer's experience, and employ statistical techniques to determine results. This approach ensures that all operators are measured on a level playing field, without bias, allowing RootMetrics to provide real-world data that confirms or challenges mobile performance metrics that are otherwise only theoretical or based on ideal conditions.

Methodology

Measuring UK and Nation performance

Employees of RootMetrics called Scouters collect test samples. Mobile performance testing is conducted with our proprietary application that measures network performance across mobile network operators simultaneously. Our application is installed and runs on advanced off-the-shelf smartphones available to the public at the time of testing. A different mobile network operator services each device, and each device runs the application to test data, call, and text performance. Testing is conducted while driving.

To evaluate operator performance at a UK-wide level, all data contributing to each nation's calculation is factored into the UK-wide characterisation.

Data Collection

RootMetrics utilises a data collection strategy intended to reflect a consumer's mobile experience by testing where and when consumers are likely to use their phones, and all tests are designed to reflect real-world consumer mobile behaviours.

At the beginning of a shift, each Scouter is provided with a list of randomly selected test locations, which have been selected in advance using an algorithm. Mobile network performance is measured while driving.

Before collecting samples, Scouters complete a pre-test checklist to ensure that all testing equipment is configured and operating correctly. All data is sent to secure servers at RootMetrics to be processed, aggregated, and analysed.

Drive tests are conducted along motorways, major routes, and residential roads where the population within a market generally lives and travels. Drive testing takes into consideration common traffic patterns. RootMetrics makes efforts, based on estimating common travel patterns for each market, to perform tests on routes that consumers would likely utilise on a daily basis.

Sample Design

RootMetrics uses a sampling scheme that:

- Is randomised to reduce spatial and temporal bias.
- Includes route optimisations that approximate estimated travel patterns common within markets that RootMetrics tests.
- Weights sample collection times to ensure that peak consumer usage and travel periods are well represented within each market.

Timing of the data collection period is scheduled to measure performance during representative usage periods. Therefore, testing is not conducted during major holidays, extreme weather, or during periods of significant population migration effects (e.g.Christmas Holiday).

Test equipment and data collection parity

To ensure that testing aligns with the latest consumer experience, RootMetrics makes an effort to select phones that support the most advanced network technology available at the time of selection (device models are evaluated twice per calendar year). Each smartphone is purchased with all recent operator updates, and the current operator-provided version of Android is installed.

Benchmarking smartphone models before testing helps remove limitations that can be caused by specific model/network interactions. All phones used for testing are configured identically and execute the same tests within each testing kit simultaneously. All phone times and schedules are synchronised for data collection. Testing has been structured to negate any testing effects that may impact network capabilities.

Mobile network performance is impacted by congestion. RootMetrics does not have information regarding the number of people within each test location or traffic on each of the networks at the time of testing. Device information for tests carried out are listed below:

Device information

Operator	Make	Model
EE	Samsung	Galaxy S22 5G
EE	Samsung	Galaxy S22 5G
EE	Samsung	Galaxy S22 5G
EE	Samsung	Galaxy S22 5G
O2	Samsung	Galaxy S22 5G
O2	Samsung	Galaxy S22 5G
O2	Samsung	Galaxy S22 5G
O2	Samsung	Galaxy S22 5G
Three	Samsung	Galaxy S22 5G
Three	Samsung	Galaxy S22 5G
Three	Samsung	Galaxy S22 5G
Three	Samsung	Galaxy S22 5G
Vodafone	Samsung	Galaxy S22 5G
Vodafone	Samsung	Galaxy S22 5G
Vodafone	Samsung	Galaxy S22 5G
Vodafone	Samsung	Galaxy S22 5G

Data integrity controls

RootMetrics Field Operations Management has developed a procedural set of requirements for each Scouter to ensure that data collection is performed according to a specific data collection protocol. For instance, Scouters perform regular equipment checks, maintain progress notes, and record any procedural anomalies.

RootMetrics employs a sophisticated monitoring system that includes automatic alarms to identify any data integrity concerns during data collection. The alarm system allows RootMetrics to identify and solve problems while they occur.

Once data is collected and sent to the RootMetrics servers, the data is filtered through a series of algorithms designed to flag anomalies. If, during the RootMetrics quality control processes, any anomalies are found to have contributed bias to the results, the anomalous data is removed. Multiple software and human safeguards help to ensure data quality.

A flexible, evolutionary framework

RootMetrics regularly assesses and reviews all tests and methodologies with a high level of scrutiny. As consumer behaviour, technology, and the mobile industry changes, the RootMetrics methodology will evolve to provide a current and representative measurement of the consumer mobile experience.

RootScore® Awards

RootScore® Awards are available in the following performance categories: **Overall (1), Network Reliability (2), Network Accessibility (3), Network Speed (4), Data (5), Call (6), and Text (7)**. The top-performing network within each performance category earns the corresponding RootScore Award.

If two or more networks share the highest rank in the same category by recording statistically indistinguishable results, each network earns a RootScore Award in that category.

1. **Overall RootScore (weighted results):**
   - *Data RootScore 55%*
   - *Call RootScore 40%*
   - *Text RootScore 5%*

2. **Network Reliability RootScore:**
   - *Lite data secure reliability*
   - *Downlink/uplink throughput reliability*
   - *Mobile-to-mobile blocked and dropped call reliability*
   - *Intra - and inter-operator text send and receipt reliability*

3. **Network Accessibility RootScore:**
   - *Lite data secure speed*
   - *Downlink/uplink access speed*
   - *Mobile-to-mobile call setup time*
   - *Intra - and inter-operator text send speed*

4. **Network Speed RootScore:**
   - *Downlink/uplink throughput speed*

5. **Data RootScore:**
   - *Lite data secure reliability and speed*
   - *Downlink/uplink throughput reliability and speed*

6. **Call RootScore:**
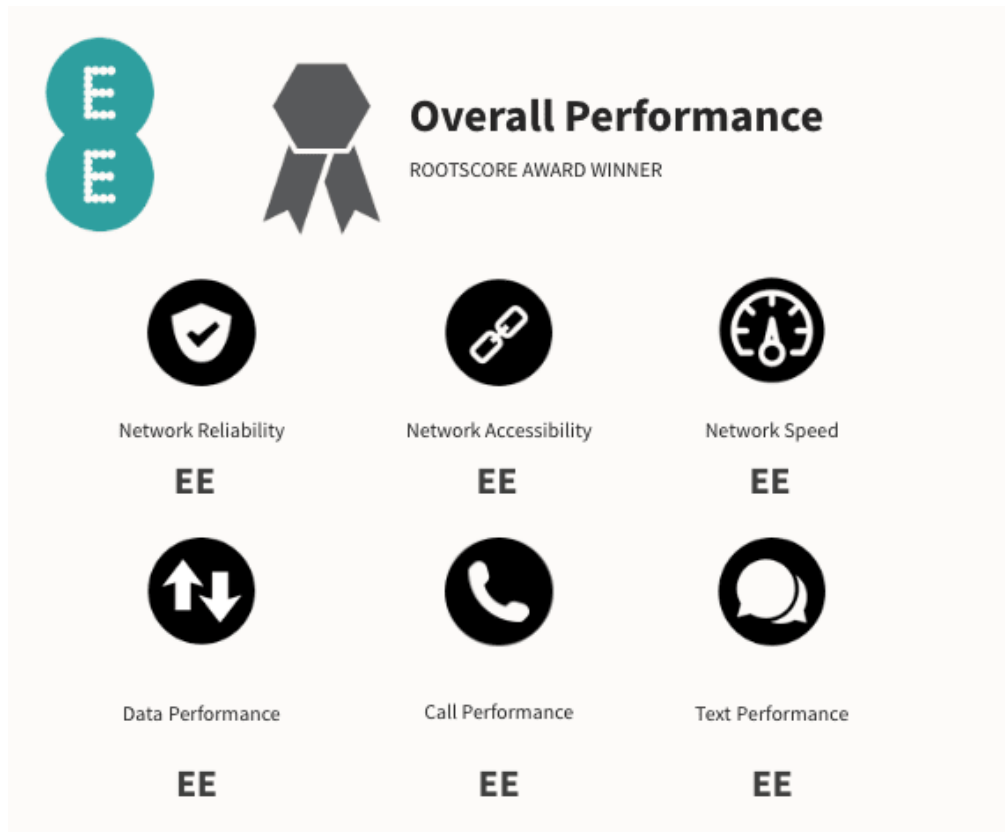   - *Mobile-to-mobile blocked and dropped calls*

7. **Text RootScore:**
   - *Intra - and inter-operator send and receipt reliability*
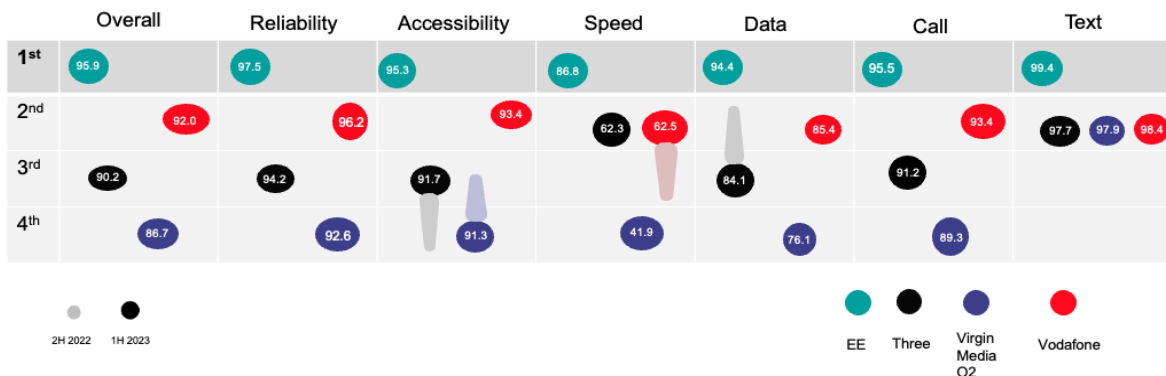   - *Intra - and inter-operator send and receipt speed*

EE - H1 2023 Claims

- **The UK's #1/Best Network (A)**
- **The UK's #1/Best Network Ten years in a row (A)**
- **The UK's #1/Best Network Twenty times in a row (A)**

As can be seen in the summary below, EE won outright or shared awards in all categories of **RootMetrics H1 2023 testing**. With this strong performance across subcategories, EE was also announced as the winner of the Overall (Best) Network performance award. Please see the appendix for a breakdown of competitor performance against EE in each category.

UK-wide RootScores 1H 2023

	Overall	Reliability	Accessibility	Speed	Data	Call	Text
1st	95.9	97.5	95.3	86.8	94.4	95.5	99.4
2nd	92.0	96.2	93.4	62.3 / 62.5	85.4	93.4	97.7 / 97.9 / 98.4
3rd	90.2	94.2	91.7		84.1	91.2	
4th	86.7	92.6	91.3	41.9	76.1	89.3	

2H 2022   1H 2023

EE   Three   Virgin Media O2   Vodafone

	Overall Performance	Network Reliability	Network Accessibility	Network Speed	Data Performance	Call Performance	Text Performance
2nd Half 2022	EE	EE	EE	EE	EE	EE	EE
1st Half 2022	EE	EE	EE	EE	EE	EE	EE, O2
2nd Half 2021	EE	EE	EE	EE	EE	EE, Vodafone	EE
1st Half 2021	EE	EE, Vodafone	O2	EE	EE	EE, Vodafone	EE, Vodafone
2nd Half 2020	EE	EE	EE, Vodafone	EE	EE	EE	EE
1st Half 2020	EE	EE	EE	EE	EE	EE	EE, Vodafone
2nd Half 2019	EE	EE	N/A	EE	EE	EE	EE, Vodafone
1st Half 2019	EE	EE	N/A	EE	EE	EE	EE, Vodafone
2nd Half 2018	EE	EE	N/A	EE	EE	EE, Three	EE
1st Half 2018	EE	EE	N/A	EE	EE	EE	EE
2nd Half 2017	EE	EE	N/A	EE	EE	EE, Three	EE
1st Half 2017	EE	Three	N/A	EE	EE	Three, Vodafone	EE, Vodafone
2nd Half 2016	EE	EE	N/A	EE	EE	EE	EE
1st Half 2016	EE	EE	N/A	EE	EE	EE	EE
2nd Half 2015	EE	Three	N/A	EE	EE	EE	EE
1st Half 2015	EE	EE	N/A	EE	EE	EE	EE
2nd Half 2014	EE	EE, Three	N/A	EE	EE	EE	EE
1st Half 2014	EE	EE, Three	N/A	EE	EE	EE	EE
2nd Half 2013	EE	EE	N/A	EE	EE	EE	EE

● EE ● O2 ● Three ● Vodafone

- **The UK's Best Combined 4G and 5G Network (B)**

As can be seen in the summary above, EE won outright or shared the award in all categories of RootMetrics H1 2023 UK testing. With this strong performance across subcategories, EE was also the winner of the Overall (Best) Network performance award. Please see the appendix for a breakdown of competitor performance against EE in each category.

These awards represent experiences on available network technologies. In the case of EE, 99.57% of tests from the UK RootScore Report were conducted on 4G and 5G networks. Additionally, in some urban areas 100% of tests were conducted on these network types. With the level of 4G and 5G availability demonstrated by all operators, RootMetrics considers these awards to be a comparison of each operator's combined 4G and 5G network. Therefore, the best overall performance award is bestowed upon EE based on their combination of 4G and 5G network performance.

Network Operator	EE	Virgin Media O2	Three	Vodafone
Percentage of tests conducted on 4G or 5G networks	99.57%	96.59%	97.95%	97.55%

- **The UK's Fastest Network (C)**

The below table summarizes the overall UK results and individual metros in which median download speeds have been tested in order to make a metro or nationwide claim as the Fastest Network in the UK. Based on the results below EE's median download speed is higher than all other operators in all 16 metro's tested and therefore is eligible to make claims as the fastest network in X metro or the fastest network in the UK, England, Scotland, Wales and Northern Ireland.

UK-wide median download speeds 1H 2023

65.1 Mbps	34.7 Mbps	15.5 Mbps	29.4 Mbps
EE	Three	Virgin Media O2	Vodafone
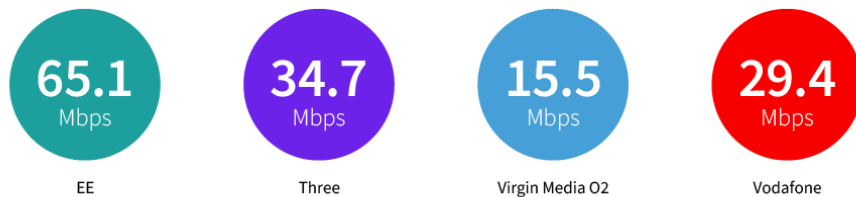
The speeds above show each operator's aggregate median download speed across the entirety of the UK.

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UK Nation aggregate median download speeds (Mbps) 1H 2023

Operator	England	Northern Ireland	Scotland	Wales
EE	66.2	53.7	57.1	64.8
Three	35.7	21.7	34.8	23.1
Virgin Media O2	16.0	16.5	12.2	10.8
Vodafone	30.2	28.3	22.7	27.4

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Market	EE median download speed (Mbps)	O2 median download speed (Mbps)	Three median download speed (Mbps)	Vodafone median download speed (Mbps)
Belfast	86.56	32.17	30.22	56.26
Birmingham	127.19	13.71	92.22	51.77
Bristol	82.06	11.21	32.51	59.05
Cardiff	105.97	22.24	43.00	56.18
Coventry	63.41	31.08	36.29	23.28
Edinburgh	80.10	29.13	48.90	34.93
Glasgow	74.56	10.38	63.53	35.09
Leeds	78.31	27.64	70.06	28.86
Leicester	93.45	29.18	80.50	34.48
Liverpool	105.46	27.25	87.83	75.78
London	78.46	24.42	40.66	44.87
Manchester	90.36	14.11	60.68	43.12
Newcastle	59.22	27.95	33.46	34.86
Nottingham	92.47	21.96	65.10	25.95
Sheffield	79.05	24.79	42.64	33.76

- **The UK's Most Reliable Network (D)**

The RootMetrics Network Reliability category provides a holistic look at reliability performance across data, call, and text testing. The reliability category addresses the two questions most fundamental to a reliable mobile experience for consumers: can I access the network and can I then stay connected to complete my intended task?

To answer these critical questions, RootMetrics assesses performance across the following key areas:

	Reliability
Call	• Mobile-to-mobile blocked outgoing call • Mobile-to-mobile dropped outgoing call
Data	• Lite data (web/app) access success • Lite data (web/app) task success • Lite data (web/app) secure access success • Lite data (web/app) secure task success • Download/upload access success • Download/upload task success
Text	• Intra/inter-network text send failure rate • Intra/inter-network text receive failure rate

To evaluate downlink throughput performance, the RootMetrics testing application attempts to open and maintain 4 simultaneous HTTP connections to measure the total bytes transferred during the test period. Downlink throughput speed is measured during this testing. Below are the listed Reliability RootScores for each metro, each metro is linked to the relevant RootMetrics report for reference. EE wins/tied for the Reliability RootScore in more markets than any other operator allowing it to make claims in the metros it wins alongside making the national claim of the UK's Most Reliable Network for its overall win.

Market	EE Reliability RootScore	O2 Reliability RootScore	Three Reliability RootScore	Vodafone Reliability RootScore
Belfast	97.3	96.0	94.6	98.1
Birmingham	99.2	94.0	98.3	97.7
Bristol	98.0	94.6	94.9	98.3
Cardiff	99.2	96.8	98.4	98.3
Coventry	98.9	99.0	98.8	99.1

Edinburgh	98.3	95.5	96.1	96.6
Glasgow	98.8	88.6	95.7	96.6
Hull	95.1	92.5	91.9	94.8
Leeds	99.2	97.1	98.2	99.3
Leicester	99.2	97.9	99.3	99.2
Liverpool	99.6	97.3	98.8	99.4
London	98.4	94.8	97.1	97.3
Manchester	99.2	95.8	98.6	98.3
Newcastle	98.7	97.0	94.9	98.9
Nottingham	99.1	97.4	98.5	99.7
Sheffield	99.4	96.8	98.8	99.0

- **UK's Unbeatable Network for Mobile Gaming (E)**
- **UK's Most Reliable Network for Mobile Gaming (E)**

Mobile Gaming Methodology

To determine which operator can provide the best real-world mobile gaming experience, RootMetrics developed a star rating system that offers a holistic and objective measurement of each network's ability to deliver a smooth real-world gaming experience based on the metrics that matter most to gamers. To determine an operator's star rating, RootMetrics focuses on multiple key performance indicators (KPIs) that are critical to mobile gaming performance. All KPIs are recorded across all network technologies, including 4G LTE, any sub-4G LTE technologies, and 5G, when available.

When calculating ratings, each KPI is assigned a maximum number of stars an operator can earn, with a total possible rating of 5 stars across all included KPIs. For each KPI, an operator earns stars by exceeding a defined performance threshold. The KPIs used in our mobile gaming rating are:

1. **Median Download Throughput Speed:** Minimum levels of download throughput that must be maintained for gameplay

2. **LDRS Access Speed (Latency):** Low latencies required for smooth, reactive gaming experience

3. **UDP Packet loss:** Packet loss can lead to missing information disrupting gameplay
4. **UDP Jitter:** High jitter indicates inconsistent latency and can result in choppy or laggy gameplay

The above KPIs are used to analyse two major facets of the mobile gaming experience: (1) bandwidth and (2) latency and reliability. Bandwidth is represented in our ratings by using median download throughput speed, which we use as a proxy for bandwidth. Latency refers to the reliability of a user's experience and is represented in our ratings by LDRS access speed, UDP packet loss, and UDPjitter.

The thresholds in our mobile gaming ratings for **Median Download Throughput Speed**, a proxy for bandwidth, were determined using requirements published by popular cloud gaming platforms (i.e., Google Stadia and Microsoft Xbox Game Pass), game developers, and industry publications. For lower resolution (ex., 720p) gaming, a 10 Mbps median download throughput speed threshold is referenced by Google Stadia[1], Microsoft Xbox Cloud Gaming[2], and Polygon[3]. For higher quality (ex., HD, 4k) gaming, speed thresholds ≥30 Mbps are defined by these organizations. Regarding bandwidth, more bandwidth (represented by faster median download throughput speeds) is an indicator of a connection's ability to potentially mitigate unforeseen network congestion that might affect a user's gameplay. A user may not need their full bandwidth all at one time, but it may offer the capacity required to recover from moments of latency spikes, packet loss, or inconsistent and/or high jitter. For Stadia, Google states "a slower network speed can cause issues while playing games on Stadia" in reference to the 10 Mbps threshold noted above. Further, Google's troubleshooting page notes that more bandwidth is better for the service in general and overall gaming experience. The ability for bandwidth to alleviate potential latency or reliability issues is the reason for the higher potential star accumulation for median download throughput speeds in our ratings, when compared to our latency and reliability KPIs (LDRS access speed, UDP packet loss, and UDP jitter).

Latency and reliability are also critical for gamers, which is why we have divided our latency measures into three categories worth a total of 3.5 stars.

LDRS access speed: most consumers would understand this KPI simply as "latency." We have allocated 1.5 of the 3.5 stars available for latency and reliability to this KPI because it has a more noticeable impact on a user's gaming experience. High latency can disrupt (or even stop) a game in mid-stream, while low latency can provide smooth, buffer-free gaming. The latency results in this KPI are based on our secure web and app testing, which characterises use cases that require continuous data usage on a secure connection, which is the most common mobile cloud gaming experience. Microsoft Xbox Game Pass recommends latency below 60ms for optimal cloud gaming, and we've used that benchmark as a proxy for good cloud gaming on any cloud-gaming platform, both casual games in SD and online games in HD. Understanding that lower latency provides a better experience, we have determined that <30ms is the next threshold for a smoother mobile gaming experience. Looking ahead at future 5G capabilities and the reality of wired in-home internet access as a benchmark, we've also included <10ms as a final threshold for mobile gaming latency as this offers a true comparison to available gaming alternatives.

UDP Packet Loss: we measure packet loss during our UDP tests. Packet loss, which is a measure of reliability relating to latency, can lead to a frustrating gaming experience since, in effect, packet loss means that pieces, or packets, of game data are lost in transit to and from the user and cloud server. Packets can also arrive out of order, which could theoretically lead to a game that's unintelligible. Based on our initial research and information published by industry advocates and press outlets, we recommend packet loss of below 3% for smooth casual gaming in SD; this metric was derived from the ICTP's recommendation[4] of between 2.5-5.0% for acceptable quality.

RootMetrics has selected a rounded metric on the lower end of this range to simplify the thresholds for easier comprehension while also keeping a reasonably high standard. Both ICTP and Cisco[5] recommend packet loss of 1% or lower for activities such as video streaming and audio/voice communication which are critical for multiplayer online games in HD quality. In recent research, we have found several site developers who indicate anything above 1% packet loss is detrimental to the gaming experience.

UDP Jitter: we measure this KPI during our UDP tests. Jitter indicates that latency is inconsistent rather than stable. The effects of jitter are similar to those of latency: high jitter can lead to choppy or laggy gameplay and/or distorted audio and chat functionality, while low jitter can keep games running smoothly (as long as latency is also low). In short, the lower the jitter, the better. According to Cisco[6], jitter below 30ms is ideal for streaming video and audio/voice communications. We have used this metric as a baseline for casual games in SD and, knowing that lower latency offers a better experience, jitter below 10ms for multiplayer online games in HD is required for a smooth mobile gaming experience.

References:
[1] https://support.google.com/stadia/answer/9607891?hl=en
[2] https://support.xbox.com/en-US/help/games-apps/cloud-gaming/about-cloud-gaming#about-cellular-gameplay
[3] https://www.polygon.com/2020/10/14/21499262/cloud-gaming-setup-internet-router-how-to
[4] https://web.archive.org/web/20131010010244/http://sdu.ictp.it/pinger/pinger.html
[5] https://www.ciscopress.com/articles/article.asp?p=471096&seqNum=6

The table below shows the KPIs with corresponding thresholds for the mobile gaming rating:

RootMetrics KPI	Performance Element	Maximum Achievable Stars	Units	Meas-ure	0.5 Star Threshold	1.0 Star Threshold	1.5 Star Threshold
Median Download Throughput Speed	**Speed**	1.5★	Mbps	≥	10	20	30
LDRS Access Speed (Latency)	**Accessibility**	1.5★	ms	≤	60	30	10
UDP Packet Loss	**Reliability**	1.0★	%	≤	3	1	
UDP Jitter	**Accessibility**	1.0★	ms	≤	30	10	
		5.0★					

To evaluate an operator's ability to support gaming performance across the UK, data from testing in 16 urban areas is combined with data from drive routes throughout each of the 4 nations. This data is weighted by the testing areas' population consistent with other National awards given by RootMetrics. These UK-wide aggregate values are then compared to the KPI thresholds to determine each operator's star rating. The operator(s) with the highest rating is able to make claims on gaming performance.

H1 2023 UK rating results

The table below shows the values of the relevant key performance indicators, stars earned for key performance indicator result, and final gaming rating for each of the four major UK operators in the first half of 2022 population-based aggregation. EE & Three finished with a tie and achieved a 3.0 star rating. In this situation where the two carriers are tied no one carrier is entitled to claim they have the best network for gaming - rather both carriers are in a position of being unbeatable therefore EE can utilize 'Unbeatable' for claims.

Alongside the claim mentioned above, EE is also eligible for the claim of the "UK's Most Reliable Network for Mobile Gaming". UDP Packet Loss is a measure of reliability relating to the latency or responsiveness of a user's gaming experience and EE have the lowest UDP Packet Loss among all operators in the UK market enabling EE users to experience the least amount of disruption to their gaming experience as their UDP Packet Loss sits at 3.1% whilst the next operator in market achieved 6.0% UDP Packet Loss.

When this is coupled with the Overall Reliability Award for EE's mobile performance in the UK it enables EE to make the claim of the "UK's Most Reliable Network for Mobile Gaming".

Operator	Median downlink throughput (Mbps)		Latency - median LDRS access speed (ms)		Packet Loss		Jitter (absolute ms)		Star Rating
EE	65.1	1.5★	55.2	0.5★	3.1%	0.0★	-0.45	1.0★	3.0★
O2	15.5	0.5★	47.7	0.5★	8.6%	0.0★	-0.22	1.0★	2.0★
Three	34.7	1.5★	49.5	0.5★	7.6%	0.0★	0.00	1.0★	3.0★
Vodafone	29.4	1.0★	54.7	0.5★	6.0%	0.0★	-0.29	1.0★	2.5★

- **5G Claims (F)**

Context and current ecosystem overview

In parallel with the changes consumers are experiencing due to the Covid-19 pandemic, innovative technology teams around the world are releasing emerging technologies which will change the shape of communication interaction. For instance, Ofcom released a report on the 14th January 2021[1] shining a light on some of these emerging technologies, along with expectations of the type of network performance evolution that is required to support them in the real-life environment in the near term and longer-term futures.

To further understand what consumers and business users expect from connectivity and these evolving mobile networks, RootMetrics undertook a User Perception Survey in October 2020. The framework was designed to help us understand consumer and enterprise decision-maker perceptions on future purchasing decisions. With 3,000 responses, the data indicated that both consumer and enterprise identified availability of 5G service and data throughput speeds as important factors influencing their next purchase.

5G offers a bright future, but 5G today is first and foremost beginning to address enhanced mobile broadband (eMBB) use cases. These eMBB usage scenarios will come with new

application areas and requirements in addition to existing mobile broadband applications for improved performance and an increasingly seamless user experience.

In particular, a smartphone customer needs high levels of 5G availability to provide seamless coverage, with a much-improved user data rate compared with existing data rates. Hotspot use cases also exist, typically in an area with high user density; for these scenarios, very high traffic capacity is needed, the requirement for mobility is low, and the user data rate is higher than that of wide area coverage.

During these initial phases of 5G rollout, the end user will benefit from faster access to media content whilst on the go, resulting in an enhancement of data rates compared to 4G technology and an improved quality of experience, with content size no longer a barrier to access high quality content. Streaming video experiences, for instance, will have less buffering and content starting instantly.

Ranking methodology

The RootMetrics 5G scoring framework is designed to measure progress towards the 5G standards outlined in IMT-2020, focusing on metrics that are most important to consumer experience and use case application.

To provide an objective view of 5G performance, RootMetrics reviewed a variety of publications and sources in determining what metrics should be evaluated, as well as what performance thresholds should be considered. In addition to the IMT-2020 5G standards, RootMetrics compared recommended performance thresholds for a 5G use case (cloud gaming) and reviewed consumer survey results to better understand expectations from users. Taken together, this multi-faceted approach helped delineate what KPIs are most important while also providing key benchmarks for network comparisons.

Defining what constitutes a 5G experience and the importance of 5G availability

A consumer's 5G experience is built out of a combination of two broad pillars: 1) the network performance delivered while on 5G and 2) how often those 5G networks are actually available.

Assuring that both elements of this 5G equation are considered is especially critical during this growth phase of 5G rollouts and as networks continue to mature. Performance metrics are important but viewing performance without also factoring in availability can create a skewed picture of the 5G experience. After all, an amazing 5G speed only matters to consumers if they can actually access the network consistently.

To that end, the RootMetrics 5G scoring framework first considers how well each network performs across key 5G KPIs (covering speed, reliability, and latency) and then uses the percentage of tests on 5G (availability) as a multiplier. This approach creates a balance that provides a clearer picture into the consumer's 5G experience. It rewards operators that offer the best combination of performance plus availability, while mitigating the impact of an operator excelling in *only* performance or *only* availability.

- An operator with fantastic performance but low availability will have its score impacted negatively by low availability (since, again, if a consumer cannot access the network, that performance is moot).

- Conversely, an operator with high availability but low performance will have its score impacted negatively by its weaker speed, reliability, or latency KPIs.

- An operator cannot score highly by focusing on performance across only a small area or

on wide availability at the expense of stronger performance.

- o This type of mitigation is especially important as different spectrum bands of 5G become available: some spectrum favours broad coverage and some spectrum leads to faster speeds. A true 5G experience must consider both elements, not one at the expense of the other.

- Consumers are thus able to see which operator provides the best overall combination of performance plus availability.

Selection of performance metric

Much of the conversation around 5G focuses on the potential for extremely fast speeds. A March 2020 survey[2] supports the idea that download speeds are at the top of consumers' minds when thinking about 5G. For this reason, RootMetrics weights speeds slightly higher than reliability and latency when evaluating networks.

While speed might be the first thing consumers think of when it comes to 5G, use cases including mobile gaming, augmented or virtual reality, and connected vehicles will also rely on 5G's promise of near-perfect reliability and low latencies.

To capture fully these consumer expectations and use case needs, the following metrics are considered when RootMetrics evaluates 5G networks:

- Download Throughput 5th Percentile (Speed)
- Download Throughput Median (Speed)
- Lite Data Secure Access Speed (Latency)
- Lite Data Secure Access Success (Reliability)
- Lite Data Secure Task Success (Reliability)

Each of these categories is then scored based upon the performance thresholds defined below.

Evaluating availability

5G availability is determined based upon the number of tests RootMetrics recorded on 5G compared to other network technologies:

- Percent of tests on 5G (Availability)

As mentioned above, availability functions as a multiplier within the RootMetrics framework. Once the above performance metrics have been evaluated and the corresponding performance score for each category calculated, 5G availability rates are then factored in as a weighting factor as described above.

The equation is simple and straightforward: the performance of an operator is multiplied by the percentage of tests RootMetrics recorded on 5G.

Performance Thresholds

The expectation is that 5G technology will move towards ubiquity over the next couple of years. As networks expand and mature, RootMetrics expects performance to continue to improve. When evaluating 5G performance, RootMetrics has therefore taken into consideration key guidelines from IMT-2020[3], including:

- User experienced data rate of 100 Mbps downlink
- Control plane latency of 20ms or less
- 99.9999% reliability

Thresholds for download throughput metrics in the 5G rating are based on the expectation of eventually achieving 100 Mbps at the 5th percentile for download throughput, and more generally the expectation that 5G speeds will be in the hundreds of Mbps (with peak speeds much higher than that). The 100 Mbps mark matches with 5G-specific applications, such as the minimum throughput needed for entry-level VR experience as shown in the recent Ofcom report[4]. This threshold also maps to what RootMetrics has publicised[5], including information that shows consumers how these 5G speeds will impact typical mobile behavior.
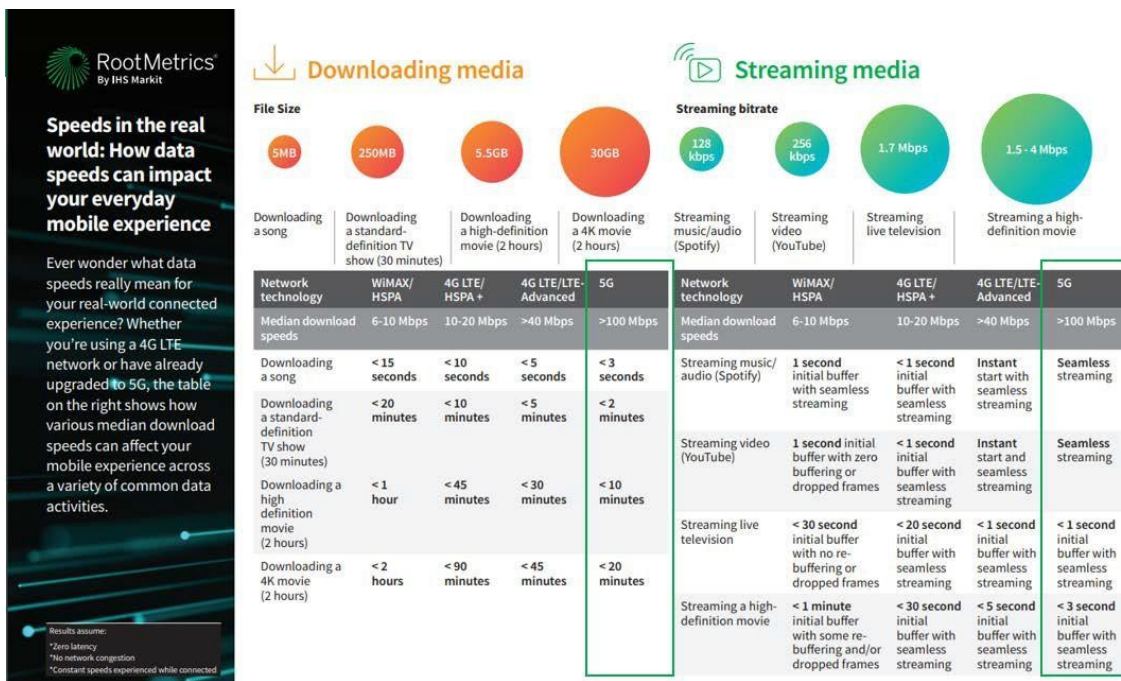
The lower threshold used for the 5th percentile metric was determined by reviewing recommendations associated with mobile cloud gaming as a representative 5G use case. Research across Xbox[6], Google Stadia[7], and others suggests that a minimum speed of 10 Mbps is required to assure a smooth consumer experience for SD gaming. To provide opportunity for further differentiation of networks, a second threshold of 30 Mbps was established and represents a minimum speed needed to support more intensive performance needs for multi-player and/or HD games.

Thresholds for the latency measure of lite data secure access speed, are targeted towards the sub 20ms goal outlined in IMT-2020 with the interim step at a half a star tied to current expectations for latency for smooth performance on mobile gaming platforms. Here too RootMetrics reviewed typical use case latency requirements. Current recommendations from Xbox, for instance, suggest a latency of less than 60ms is required for smooth game play experience. In short, both independent recommendations—the ideal sub 20ms from IMT-2020 and the more achievable 60ms threshold from gaming recommendations—are captured within the RootMetrics star rating framework.

The reliability expectations in IMT-2020 are near perfect at 99.9999%. To account for the early stage of 5G and in acknowledgement that few consumers will have practical impacts from a slightly lower reliability in current use cases the threshold for the reliability metrics was set at 99.5% - still an impressive value when compared to network performance as a whole.

National aggregation

As of the second half of 2021, 5G rollout in the UK has been primarily concentrated in the metro areas. Due to the relative lack of 5G seen in national drive route testing, the national rollup calculation for 5G metrics includes only testing from RootMetrics' Metro testing across UK's top 16 metros. All 5G data tests from across the 16 metros are used to calculate the national level metrics. There is no weight applied in this aggregation.

Rating Framework and quick metric summary

As shown below, EE delivered the joint best 5G performance in UK testing for H1 2023. Whilst they did achieve the highest 5G Score - RootMetrics determines a winner by having at least a 1 point difference in score. In this situation both EE and Three have a joint win for the UK's Best 5G Network, meaning EE has the claim to the UK's Unbeatable 5G Network.

Availability: 5G availability is the gateway for consumers to access enhanced mobile network experience promised by this new technology and acts as a multiplier of the other performance metrics within the RootMetrics framework.

5th percentile: 5th Percentile speeds experienced on 5G provide a measure of minimum performance required to provide access great media content quickly or great gaming experiences on the go.

Median download throughput: Median download speeds > 100Mbps provide consumers faster access to higher quality media on the go, enable enterprise organisations to work from anywhere, and deliver enhanced mobile broadband to consumers in the home who may not have access to fixed broadband.

LDRS and latency: Improved latency enables quicker responses and lag-free applications and sets the stage for future 5G use cases such as autonomous cars and more.

Reliability: A consistent user experience requires high access reliability to connect to the service and task reliability to receive the necessary data to operate the service.

References:

[1] https://www.ofcom.org.uk/__data/assets/pdf_file/0011/211115/report-emerging-technologies.pdf

[2] https://www.ansys.com/-/media/ansys/corporate/resourcelibrary/brochure/ansys-5g-survey-infographic.pdf?la=en&hash=4A18E71A92731D76D4B52763E46CAC0AC5391A93

[3] https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/060R1e.pdf and https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/S01-1_Requirements%20for%20IMT-2020_Rev.pdf

[4] https://www.ofcom.org.uk/__data/assets/pdf_file/0011/211115/report-emerging-technologies.pdf

[5] https://www.rootmetrics.com/en-US/content/speeds-in-the-real-world-infographic

[6] https://support.xbox.com/en-US/help/games-apps/cloud-gaming/about-cloud-gaming#about-cellular-gameplay

[7] https://support.google.com/stadia/answer/9607891?hl=en

5G National & Metro Level Results

	5th Percentile Download Speed (Mbps)	Median Download Speed (Mbps)	Latency (ms)
EE	19.9	144.6	51
Virgin Media O2	5.4	75.1	49
Three	8.9	202.2	46.5
Vodafone	9.2	131.5	55.5

	LDRS Access Success	LDRS Task Success	Percentage of Tests on 5G
EE	99.7%	99.9%	50.6%
Virgin Media O2	99.6%	99.6%	48.1%
Three	99.7%	99.7%	54.3%
Vodafone	99.7%	99.7%	39.6%

| Operator	Availability Multiplier	Performance Score	5G Score
EE	50.6%	96.4	48.8
O2	48.1%	67.7	32.6
Three	54.3%	88.9	48.3
Vodafone	39.6%	86.7	34.3

Belfast - *Tested 22/05/2023 - 26/05/2023*
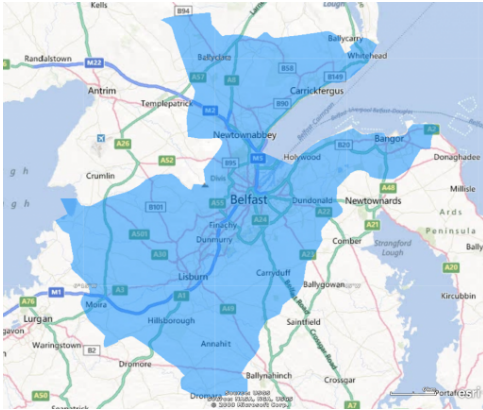
Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	191.5	28.4	53	99.9%	100.0%	50.6%	50.3
O2	109.0	3.9	50.5	99.9%	99.9%	54.9%	41.7
Three	124.1	9.0	51	99.7%	99.9%	45.3%	39.2
Vodafone	191.1	23.9	58.5	99.7%	99.9%	37.8%	37.3

Birmingham - *Tested 02/06/2023 - 06/06/2023*
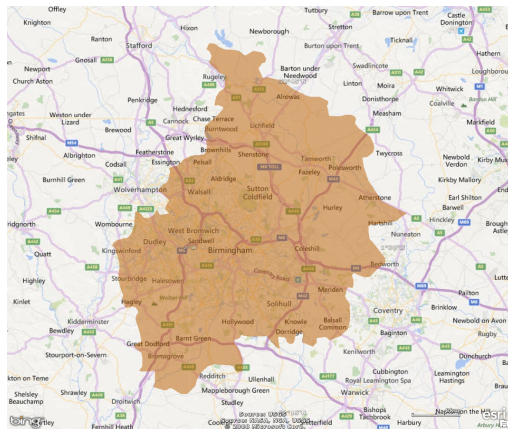
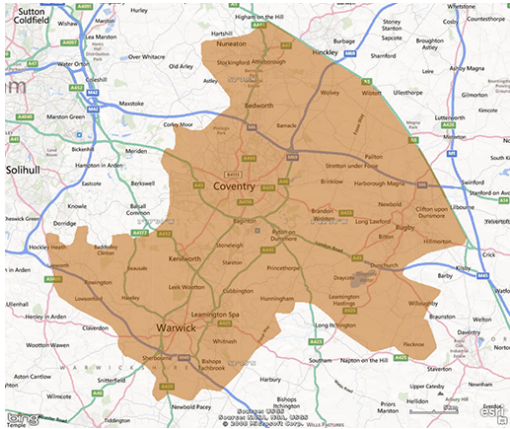| Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	168.8	25.8	48	99.9%	100.0%	47.7%	47.2
O2	100.6	5.0	41	99.5%	99.7%	38.3%	28.1
Three	277.8	6.5	43	99.9%	99.7%	66.5%	57.0
Vodafone	121.4	9.5	56	99.6%	99.4%	46.7%	39.1

Bristol - *Tested 09/02/2023 - 13/02/2023*
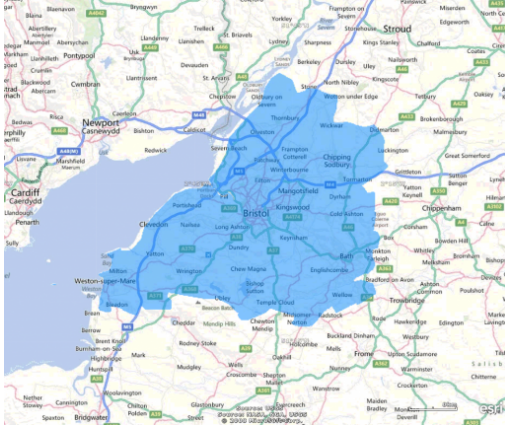
Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	143.4	15.4	49.25	99.8%	100.0%	56.1%	53.2
O2	83.1	3.6	47.75	98.7%	98.6%	36.3%	19.0
Three	185.5	16.4	45	99.4%	99.7%	44.6%	42.0
Vodafone	133.0	5.7	53	99.9%	99.7%	61.1%	49.7

Cardiff - *Tested 11/05/2023 - 14/05/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	206.6	34.9	49.5	99.8%	99.9%	65.6%	65.1
O2	138.5	6.9	39.25	99.3%	99.4%	45.9%	36.4
Three	280.2	9.8	45.5	99.7%	99.0%	50.8%	43.3
Vodafone	144.4	8.5	50.5	99.9%	99.6%	54.7%	47.7

Coventry - *Tested 25/01/2023 - 15/02/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	101.2	21.7	54.5	99.8%	100.0%	31.3%	28.8
O2	73.1	5.9	58	99.6%	99.9%	60.6%	42.0
Three	244.4	13.0	42	99.6%	99.5%	44.0%	40.7
Vodafone	258.0	36.0	51	99.3%	99.9%	15.0%	14.4

Edinburgh - *Tested 04/03/2023 - 07/03/2023*
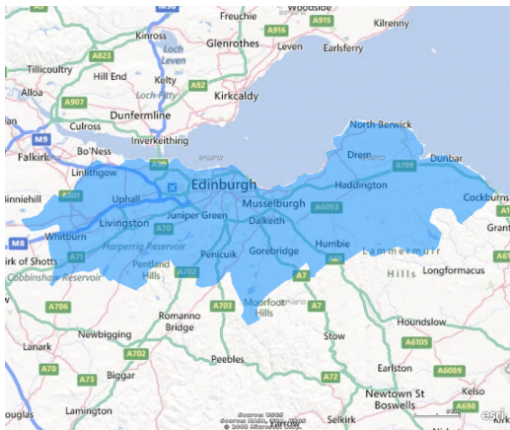
Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	157.2	31.0	59	99.7%	100.0%	47.2%	46.3
O2	61.0	4.4	42.5	99.8%	99.7%	64.6%	40.3
Three	201.0	18.8	41.5	99.6%	99.9%	49.4%	47.8
Vodafone	137.8	18.0	51.75	99.1%	100.0%	23.9%	21.6

Glasgow - *Tested 14/03/2023 - 18/03/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	132.7	20.2	56	99.7%	100.0%	54.0%	51.6
O2	100.3	7.8	43.5	99.4%	99.8%	32.8%	25.7
Three	199.9	9.0	59.5	99.8%	99.9%	59.6%	53.8
Vodafone	100.4	7.0	55.5	99.8%	99.4%	42.7%	32.9

Hull - *Tested 07/06/2023 - 11/06/2023*
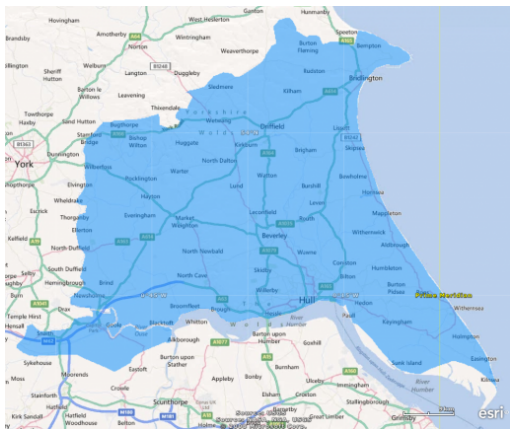
Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	132.6	13.0	49.5	99.5%	99.9%	36.6%	33.3
O2	70.9	5.5	43.5	99.8%	99.8%	45.2%	31.0
Three	210.1	2.2	52.5	99.2%	99.4%	51.3%	36.8
Vodafone	145.2	11.2	63	99.3%	99.4%	43.2%	37.1

Leeds and Bradford - *Tested 24/02/2023 - 28/02/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	141.9	16.6	47	99.8%	99.9%	50.7%	48.3
O2	55.7	6.8	42	100.0%	99.6%	53.9%	35.0
Three	219.6	13.8	51.5	99.9%	100.0%	58.8%	56.4
Vodafone	154.9	9.5	47.5	99.9%	99.8%	23.3%	21.0

Leicester - *Tested 01/06/2023 - 05/06/2023*
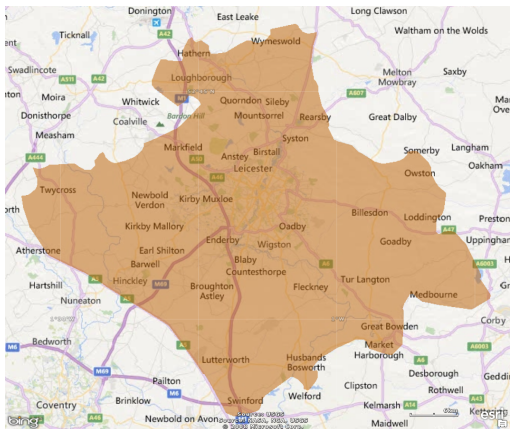
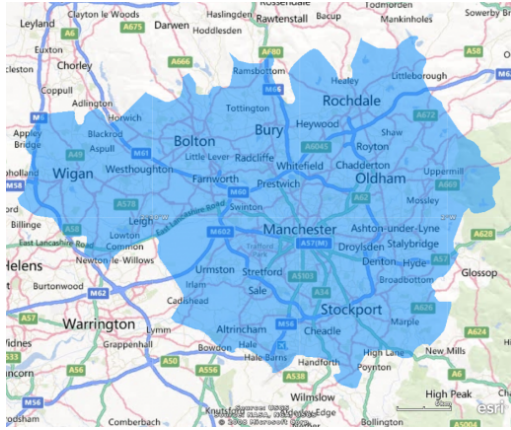| Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	158.9	26.9	50	99.6%	99.8%	43.3%	42.0
O2	57.7	4.8	60	99.4%	99.8%	56.4%	34.0
Three	349.8	14.0	56.5	99.9%	100.0%	59.4%	57.2
Vodafone	312.3	31.1	57.5	99.8%	100.0%	24.5%	24.4

Liverpool - *Tested 31/03/2023 - 03/04/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	171.1	24.6	50	99.9%	99.9%	64.9%	64.0
O2	90.7	7.2	42.5	99.8%	99.5%	57.8%	44.0
Three	237.2	16.7	45	99.6%	99.8%	64.8%	62.6
Vodafone	114.9	9.9	52.5	99.8%	99.8%	67.8%	58.8

London - *Tested 13/04/2023 - 21/04/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	148.0	15.7	50	99.7%	99.9%	51.2%	48.7
O2	60.0	6.1	55	99.1%	99.6%	46.7%	28.0
Three	177.2	7.7	37	99.4%	99.7%	52.2%	44.1
Vodafone	99.7	8.2	60	99.8%	99.7%	53.6%	43.5

Manchester - *Tested 24/04/2023 - 28/04/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	156.5	22.4	49.5	99.8%	100.0%	61.4%	60.2
O2	130.2	4.7	42	99.6%	99.3%	43.2%	32.7
Three	252.7	13.1	48.25	99.7%	99.8%	58.9%	55.7
Vodafone	101.3	6.2	59	99.6%	99.3%	56.9%	42.1

Newcastle - *Tested 21/05/2023 - 25/05/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	80.1	11.5	65.5	99.5%	99.8%	48.0%	38.1
O2	63.4	3.8	41.5	99.9%	99.7%	55.6%	34.6
Three	165.2	4.6	59	99.7%	99.9%	45.8%	37.2
Vodafone	131.5	23.0	50.25	99.8%	99.5%	24.1%	22.7

Nottingham - *Tested 31/01/2023 - 03/02/2023*

Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	121.9	21.0	55	99.2%	100.0%	49.0%	44.6
O2	51.7	7.8	60	99.9%	100.0%	44.5%	29.6
Three	162.8	6.9	46	99.6%	99.5%	67.6%	56.3
Vodafone	232.7	32.2	53.75	99.5%	99.9%	9.5%	9.3

Sheffield - *Tested 17/02/2023 - 24/02/2023*
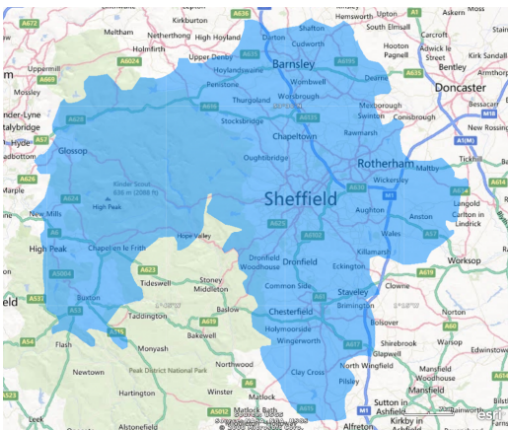
Carrier	Median Download Speed (Mbps)	5th Percentile Download Speed (Mbps)	Latency (ms)	LDRS Access Success	LDRS Task Success	5G Availability	5G Score
EE	136.9	22.1	49	99.8%	99.9%	52.2%	50.4
O2	70.5	6.9	42	99.8%	99.4%	38.3%	26.4
Three	147.3	12.4	46	99.9%	100.0%	52.8%	49.3
Vodafone	182.1	16.1	52	100.0%	100.0%	20.8%	20.3

5G Coverage Metro Results

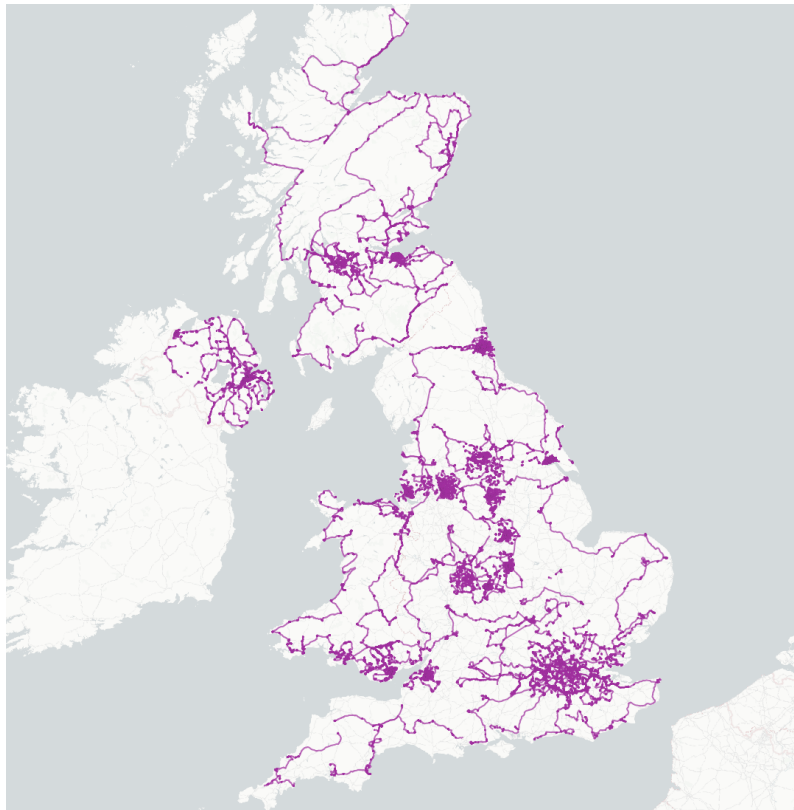| Market	EE 5G% coverage	O2 5G% coverage	Three 5G% coverage	Vodafone 5G% coverage
Belfast	35.20%	54.90%	36.50%	34.50%
Birmingham	43.90%	40.80%	69.10%	46.30%
Bristol	53.90%	29.80%	42.00%	55.80%
Cardiff	60.70%	37.80%	51.20%	48.80%
Coventry	16.10%	59.30%	42.90%	9.30%
Edinburgh	45.50%	66.90%	56.20%	19.30%
Glasgow	53.30%	28.50%	57.70%	38.70%
Leeds	22.90%	39.60%	44.90%	38.40%
Leicester	48.20%	54.40%	59.00%	22.50%
Liverpool	38.50%	52.70%	64.20%	20.20%
London	56.50%	51.20%	60.70%	62.50%
Manchester	52.40%	46.30%	54.90%	53.50%
Newcastle	56.40%	35.80%	58.50%	50.80%
Nottingham	40.50%	58.40%	45.20%	19.20%
Sheffield	48.80%	35.90%	64.40%	5.80%
Hull	44.20%	31.10%	48.00%	16.50%

Why are these results robust?

RootMetrics uses scientific methodologies to design tests, measure activities, and collect data about mobile network performance that are representative of a consumer's mobile experience within a given market. RootMetrics then employs statistical techniques to verify and validate the results. This approach ensures all operators are measured on a level playing field, removes unintentional bias, and allows RootMetrics to provide actual, in-the-field data that confirms or challenges performance numbers that are otherwise only theoretical or based on ideal conditions. Weighting and stratification methods ensure that test data correctly represents the overall national population distribution.

We measure network reliability, accessibility, and speed performance across the activities that consumers use their smartphones for on a daily basis, like browsing webpages, using apps, making calls, and sending texts. Our methodology is designed to ensure that our tests measure performance across a wide range of real-world situations that consumers experience while using their smartphones on a daily basis. For example: we collect samples during periods of high and low congestion; we measure performance across variations in speed, from standing still to driving on the highway; and we perform tests whether coverage is poor or excellent or somewhere in between. We test each network head-to-head in these situations to make comparisons easy and assure all networks are measured on a level playing field.

Methodological Facts from RootMetrics' UK tests conducted between Jan and Jun 2023:

- 538,780 tests across the UK
- 24,109 miles driven
- 4 nations visited
- 16 of the largest metropolitan areas (Eurostat 'Large Urban Zones' [LUZs]) included