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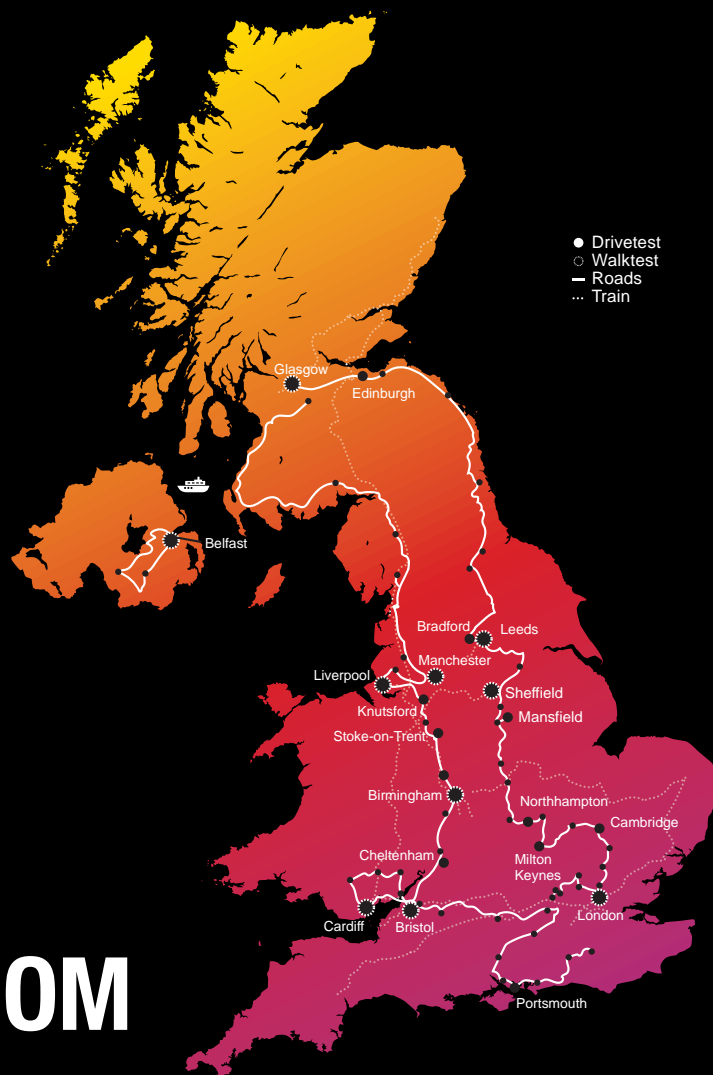
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connect

THE 2021 MOBILE NETWORK TEST IN THE UNITED KINGDOM

For the seventh time, we – the benchmarking expert umlaut and connect magazine – have conducted our tough benchmark of the UK's mobile networks. Once again, we have refined our methodology in the process.

All UK operators have worked hard to expand their 5G coverage and to strengthen their 4G offerings. So we wanted to find out, which of the contenders offers the best performance and the highest reliability of mobile voice and data services.



RESULTS IN A NUTSHELL

EE wins the umlaut connect Mobile Benchmark in the UK for the seventh time. Vodafone maintains the second place. Three manages to conquer the third rank back from O2 and improves its score massively. Although also clearly improving its score, O2 ranks fourth.

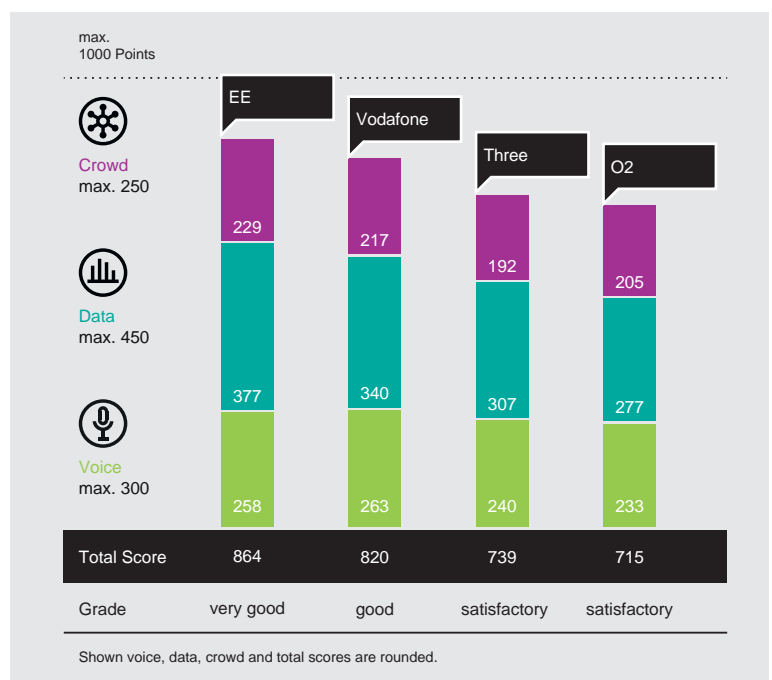
The network benchmarks conducted by umlaut, part of Accenture, and connect are widely accepted as the de-facto industry standard and for being highly objective. The carefully designed methodology of our 2021 benchmark in the United Kingdom represents a holistic approach to network benchmarking. It combines drive tests and walk tests for executing detailed voice and data measurements under controlled circumstances combined with a sophisticated crowd-sourcing methodology. This provides profound insights into the overall coverage of voice, data and 5G services as well as real-world User Download Speeds and Latencies. The drive tests and walk tests allow for the maximum capabilities of the networks to be evaluated. Crowd-sourcing unveils the service quality and performance actually experienced by real users. We have thoroughly weighed these components in order to give a realistic and conclusive assessment of the rated networks' true potential and performance.

EE IS THE OVERALL WINNER, VODAFONE RANKS SECOND. THREE AND O2 IMPROVE THEIR SCORES.

As in our six previous UK benchmarks, the overall winner is EE (in 2016, Vodafone shared the first place with EE). The operator defended its position and earned the grade very good. EE scores best in the Crowd and Data categories, in Voice Vodafone has the lead. As in our three previous benchmarks, Vodafone maintains the second place, showing strong results on all assessed categories. Three manages to distinctly advance its score in comparison to our previous UK benchmark, earning 118 more score points than last time and improving in all three test categories. This also enables this provider to conquer back the third rank from O2, which had surpassed Three in our previous UK benchmark. But while ranking fourth this time, O2 still achieves a clear score gain and improves its results in the Voice and Data categories. In London, EE leads at a gap of ten points ahead of Vodafone, while O2 scores a little higher than Three. In our city comparison, EE leads in seven out of ten considered larger UK cities. Vodafone is a local champion in Belfast and Liverpool, while O2 takes the lead in Bradford. In terms of 5G rollout, all UK operators already show good coverage in the cities. EE offers the highest 5G coverage in all tested scenarios, while in the 5G high band, Three achieves the highest average and maximum data rates in all considered scenarios.

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EE is the winner for the seventh time, Vodafone ranks second. Three takes the third rank back from O2. Three shows massive score gains, but also O2 manages to improve in comparison to our previous benchmark.



Overall Results		EE	Vodafone	Three	O2
Voice	max. 300.00 P.	258	263	240	233
Cities (Drivetest)	135.00	88%	91%	84%	83%
Cities (Walktest)	45.00	90%	94%	92%	87%
Towns (Drivetest)	60.00	92%	93%	84%	82%
Roads (Drivetest)	37.50	88%	80%	62%	67%
Railways (Walktest)	22.50	50%	56%	51%	36%
Data	max. 450.00 P.	377	340	307	277
Cities (Drivetest)	202.50	87%	85%	76%	70%
Cities (Walktest)	67.50	87%	84%	67%	67%
Towns (Drivetest)	90.00	84%	63%	68%	49%
Roads (Drivetest)	56.25	87%	70%	62%	62%
Railways (Walktest)	33.75	53%	45%	37%	36%
Crowd	max. 250.00 P.	229	217	192	205
Crowd	250.00	92%	87%	77%	82%
Connect Rating	max. 1000 P.	864	820	739	715

Percentages and points rounded to integer numbers.
For the calculation of points and totals, the accurate, unrounded values were used.

THE UK OPERATORS

O2 and EE are the largest mobile network operators in the UK, followed by Vodafone, with the smaller Three attacking with aggressive tariffs. Each of the UK's mobile networks offers a high level of 4G coverage, with all four contenders quickly rolling out and expanding their 5G networks.



With almost 32 million mobile subscribers, O2 is the largest mobile network operator. Formerly a subsidiary of British Telecom, O2 plc was purchased by the Spanish telecommunications company Telefónica in 2006. In 2021, O2 entered a 50:50 joint venture with Liberty Global, combining Liberty's brand Virgin Media and O2. The joint company also owns half of the mobile virtual network operator Tesco Mobile which operates on the O2 network in the UK. The operators claim to cover approx. 99 percent of the UK population with 4G. O2 operates its 4G network mainly on 800 MHz with additional 1800, 2100 and 2600 MHz coverage in metropolitan areas. Additionally, O2 provides 2G on 900 MHz and 3G on 900 and 2100 MHz. Like the other UK operators, O2 is operating Voice over LTE (VoLTE) in most of its 4G network. O2 is also continuously rolling out 5G, using its 3500 and 700 MHz spectrum for 5GNR. In late 2021, the company claimed to be live with 5G in over 150 towns and cities, with plans to extend 5G coverage soon to over 215 towns and cities.



With approximately 26 million customers, EE (formerly Everything Everywhere) is the second largest mobile network operator in the UK. Since 2016, EE has been part of the British Telecom Group. EE started offering its 4G service in 2012. Regarding 4G/LTE coverage, EE reports geographic coverage instead of population coverage. They quote Ofcom reporting an 85 percent 4G geographic coverage which equates to more than 99 percent of the population. EE operates its 4G network at 800, 1800, 2100 and 2600 MHz. Additionally, it offers 2G at 1800 and 3G at 2100 MHz. EE operates a growing number of "4G+" cells that support up to 5CA (five carrier frequencies) with up to 1 Gbps under the name "4GEE". Voice over LTE (VoLTE) is available in most of its 4G network. For its 5G deployment, EE uses spectrum at 700, 2100 and 3500 MHz. In 2021, EE announced to offer 5G in more than 160 towns and cities in the UK. The operator plans to cover half of the UK population by early 2023 and the "entire" UK by 2028.



Vodafone UK is part of the international Vodafone Group which is also headquartered in the UK. The Vodafone Group owns and operates networks in 30 countries. Vodafone UK launched 4G/LTE in 2013. With around 17 million mobile subscribers, Vodafone is the third largest mobile network in the UK. In June 2012, Vodafone and O2 signed a deal to "pool" their network technologies, creating a single national grid of 18,500 transmitter sites. Both operators however announced they would continue to use their own independent spectrum. Vodafone operates 4G/LTE at 800, 900, 1500, 1800, 2100 and 2600 MHz and claims to cover 99 percent of the UK population. Additionally, Vodafone offers 2G at 900 MHz and 3G at 900 and 2100 MHz. With "4G+", Vodafone offers up to 1 Gbps – as well as Voice over LTE (VoLTE). By the end of 2021, the operator has deployed 5G in 124 locations across the UK and has announced a further speed up of its 5G roll-out during 2022.



Three UK is a subsidiary of Hutchison Whampoa and launched its mobile service in the UK in 2003. As a relatively young operator Three started as a 3G-only network supplemented by 2G via national roaming. In December 2013, Three began to roll out its 4G/LTE service and expanded it rapidly all over the UK. With about 9.5 million customers, Three is the smallest mobile network operator in the UK. Three offers "4G Advanced" at 800, 1500, 1800 and 2100 MHz as well as 3G on 2100 MHz. The company claims to cover more than 99 percent of the UK's population with at least 3G. Voice over LTE (VoLTE) is available in most of its 4G network. According to the company, "Three's customers use 3.5x more data than the average Brit" – competitive pricing and the availability of unlimited data tariffs will certainly play a part in this. The operator rolls out 5G at 3500 and 3700 MHz and claims to offer more spectrum for its 5G service than any other UK network operator. From 66 towns and cities in February 2020, Three has continuously extended its 5G network coverage.

A CLOSE LOOK AT THE UK NETWORKS

The network benchmarks conducted by umlaut and connect are widely accepted as a completely objective authority. In 2021/2022, we present the umlaut connect Mobile Benchmark in the United Kingdom for the seventh time, further enhancing its methodology.



umlaut, headquartered in Aachen, Germany, is a world leader in mobile network testing. The company was formerly known as P3 communications, changed its name in autumn 2019, and has become a part of Accenture in 2021. umlaut has over 4,300 employees, distributed in over 50 locations all around the world, with a turnover of more than 400 million Euros. umlaut is partnering with the international telecommunications magazine connect, which has 28 years of editorial expertise and is one of the leading test authorities in Europe for telecommunication products and services. Together, we – umlaut and connect – have been conducting the most important network benchmark test in Germany for almost 20 years, extending it to other European

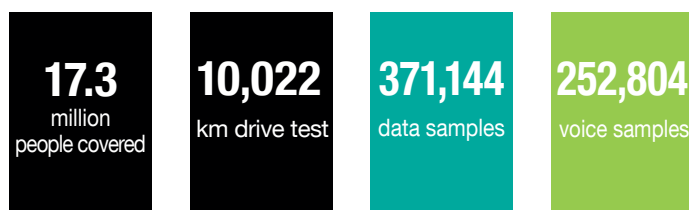
countries since 2009. As the de-facto industry standard, our benchmarking methodology focuses on customer-perceived network quality.

The 2021 umlaut connect Mobile Benchmark in the UK consists of drive tests and walk tests conducted from October 25th to November 15th, 2021. Four drive test cars together covered about 10,000 kilometres, visiting 19 cities and 46 towns. Additionally, two walk test teams visited ten cities and travelled on trains between them. The test areas account for 17.3 million people, or approx. 26 percent of the total population of the UK. In addition, the results of extensive crowdsourcing analyses, considering 24 weeks from end of May to early November 2021 are included in the score.

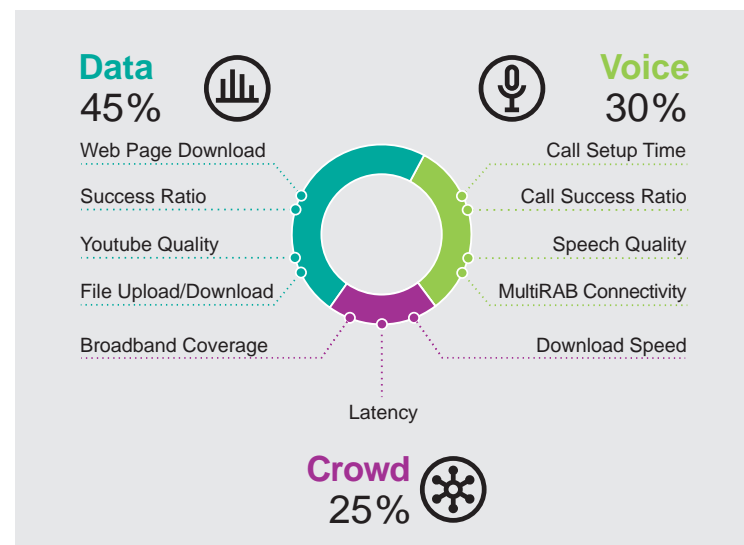
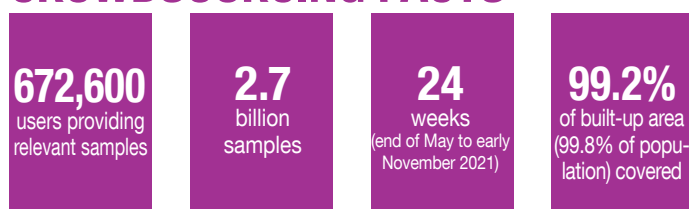
Congratulations to EE for winning the umlaut connect Mobile Benchmark in the UK for the seventh time! Vodafone follows with strong results and a lead in the Voice category. Three deserves acknowledgement for the highest score improvement in this benchmark, while O2 improved in the Voice and Data categories compared to our previous Benchmark. We also see great enhancements in terms of 5G deployment in the UK, with EE offering the best 5G coverage, Vodafone offering strong 5G reliability, Three the highest data rates and O2 a very competitive overall performance. It is visible, that all UK operators have worked hard to expand their 5G coverage and to strengthen their 4G offerings.

Hakan Ekmen, CEO umlaut

DRIVE TEST AND WALK TEST FACTS



CROWDSOURCING FACTS



VOICE

Although messaging, e-mails and social media communications have gained in importance, voice telephony is still important. When taking or placing a phone call, customers expect reliable connections. How do the UK's mobile networks fulfil these expectations?

All four operators in the UK have been supporting Voice over LTE (VoLTE) in their networks since 2018. VoLTE transmits voice calls as data packets over a 4G connection and thus is a clear improvement over the „circuit-switched“ connections in 3G or 2G networks. But with 5G a new challenge arises: For 5G-based telephony, “Voice over 5G“ or “Voice over New Radio“ would be required – but this technology has not yet found its way into the current network implementations. So as before from 4G to 3G, a new kind of fallback is needed – this time from 5G to 4G/VoLTE.

For the voice rating, each drive test car and each walk test team carried one Samsung Galaxy S21+ per operator. The phones in the cars called a counterpart in one of the other cars. The phones carried by the walk test teams in the cities and travelling on trains called a stationary counterpart. The connected testing equipment registered the success ratios, call setup times and speech quality of the test calls. In order to simulate normal smartphone usage, additional data transfers took place in the background of the test calls. Also, the so-called Multirab (Multi Radio Access Bearer) Connectivity denominates whether data connectivity was available during the phone calls. The voice scores account for 30 percent of the total result.

VODAFONE SHOWS THE BEST OVERALL VOICE RESULTS, FOLLOWED AT CLOSE DISTANCE BY EE, WHICH LEADS ON THE ROADS. THREE RANKS THIRD AND O2 FOURTH.

CITIES DRIVE TEST

VODAFONE

VODAFONE SHOWS THE STRONGEST VOICE TESTS RESULTS IN THE DRIVE TESTS IN CITIES, FOLLOWED BY EE

In the larger cities, Vodafone achieves the highest success ratios, closely followed by O2 and then EE. Together with Three, Vodafone also shows the shortest call setup times. EE follows in terms of call setup times, but achieves the best speech quality. Regarding call setup times and speech quality, O2 shows potential for improvement.

CITIES WALK TEST

VODAFONE

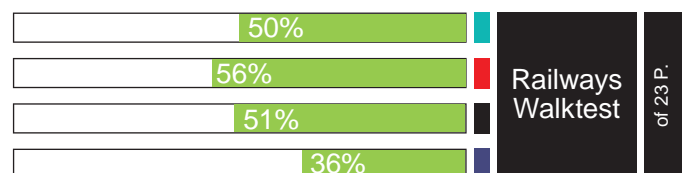
VODAFONE AHEAD IN CITY WALK TESTS, FOLLOWED BY THREE AND THEN EE

In the walk tests conducted in the UK's larger cities, Vodafone takes the lead, providing the best speech quality. Three follows at a close distance, with the shortest call setup times and the highest Multirab connectivity. In terms of call setup times, Three leads, followed by Vodafone and a wider gap by EE. Overall, all contenders score better in the walk tests than in the drive tests.

Voice

300 of 1000 Points

EE
Vodafone
Three
O2



TOWNS DRIVE TEST

VODAFONE

VODAFONE TAKES THE LEAD IN THE VOICE DRIVE TESTS CONDUCTED IN TOWNS, FOLLOWED CLOSELY BY EE

In the drive tests conducted in smaller towns, Vodafone again takes the overall lead, but EE follows at a narrow distance and Three ranks third in this category.

Vodafone provides the highest success ratios and the shortest call setup times. Three shows only slightly longer call setup times and a 100 percent of Multirab connectivity. In the smaller towns, EE leads in terms of speech quality and comes in closely behind Vodafone regarding success ratios. In the success ratios, O2 outranks Three, but comes in fourth overall in the towns.

ROADS DRIVE TEST

EE

EE AHEAD IN VOICE DRIVE TESTS CONDUCTED ON THE UK ROADS. VODAFONE FOLLOWS CLOSELY

While travelling on the connecting roads between the cities and towns, the drive test cars determined the best voice results for EE, followed at a close gap by Vodafone. O2 comes in third, providing higher success ratios and shorter call setup times than Three.

Vodafone provides the shortest call setup times in this scenario, but comes in second behind EE regarding speech quality. In terms of speech quality and Multirab connectivity, Three scores slightly ahead of O2 on the roads. In Multirab connectivity, Vodafone and Three are on a par behind EE.

RAILWAYS WALK TEST

VODAFONE

VODAFONE AHEAD IN UK TRAINS, THREE RANKS SECOND. AND EE FOLLOWS AT CLOSE DISTANCE

For the third time in the UK, we have also examined the quality of voice calls conducted in trains. While the results have improved since our previous benchmark, they are still by far weaker than in the other categories. Again, Vodafone takes a lead when it comes to voice calls on the UK railways, offering still the highest success ratios. Three ranks second with equal call setup times and the best Multirab connectivity. EE follows at close distance with the best speech quality. O2 is behind when it comes to voice calls on trains.

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VOICE RESULTS AT A GLANCE

Vodafone achieves the highest score in the voice discipline, leading in the drive tests and walk test conducted in the bigger cities as well as in the smaller towns. On the connecting roads, EE takes the overall lead, closely followed by Vodafone. Three shows good results in the the walk tests conducted in the larger cities. When travelling on trains, all four contenders show considerably weaker results, with Vodafone still leading, while Three and EE are following.

Operator	EE	Vodafone	Three	O2
Cities (Drivetest)				
Success Ratio (%)	98.4	98.9	97.8	98.7
Call Setup Time P90 (s)	2.5	1.9	1.9	2.8
Speech Quality P10 (MOS-LQO)	4.1	4.0	3.8	3.3
Multirab Connectivity (%)	99.9	99.9	99.8	99.3
Towns (Drivetest)				
Success Ratio (%)	99.2	99.4	97.9	98.7
Call Setup Time P90 (s)	2.5	2.0	2.2	2.9
Speech Quality P10 (MOS-LQO)	4.1	3.9	3.7	3.3
Multirab Connectivity (%)	99.9	99.7	100.0	99.3
Roads (Drivetest)				
Success Ratio (%)	98.2	96.2	92.5	94.5
Call Setup Time P90 (s)	2.8	2.6	3.5	3.3
Speech Quality P10 (MOS-LQO)	3.8	3.4	3.1	2.9
Multirab Connectivity (%)	99.7	98.7	98.7	98.0
Cities (Walktest)				
Success Ratio (%)	98.9	99.2	99.0	99.0
Call Setup Time P90 (s)	2.3	1.8	1.6	2.6
Speech Quality P10 (MOS-LQO)	4.3	4.4	3.9	3.6
Multirab Connectivity (%)	99.0	99.7	99.8	99.3
Railways (Walktest)				
Success Ratio (%)	88.9	89.4	88.5	85.9
Call Setup Time P90 (s)	3.8	3.1	3.1	4.0
Speech Quality P10 (MOS-LQO)	3.5	3.4	3.0	2.8
Multirab Connectivity (%)	97.2	97.3	97.8	97.5



DATA

With the volume of transmitted data permanently growing, data connectivity constantly becomes more important. Which operator in the UK manages best to meet the increasing demand?

All four UK networks claim to cover a large part of the population with their 4G/LTE services – the claimed percentages range in the high nineties. Their constant race for the best coverage and the highest data rates has helped to establish an overall very good availability of 4G in the UK. Now the race continues regarding 5G – and again, there is a fierce competition among the four network operators to lead the field regarding this new mobile network technology.

The commercial deployment of 5G in the UK has come so far that we assume this standard as a given in the data tests of this year's umlaut connect Mobile Benchmark in the UK. So, the Samsung S21+ smartphones carried by each of our four drive test cars and also by the two walk test teams were configured to prefer 5G – whenever this technology is available, it should also be used for our data measurements.

But also in terms of 4G/LTE, the mobile network technology has come a long way. In many areas where there is no 5G yet, the test smartphones could still benefit from the combined use of currently up to five LTE carrier frequencies, "5CA", which is currently only supported by EE and can also deliver up to 1 Gbps download data rates.

umlaut's testing rewards fast throughputs as well as the networks' availability and stability. In order to assess typical performance as well as peak speeds, we consider two values: the minimum data rate that is available in 90 percent of the cases, and additionally the peak data rate that is surpassed in 10 percent of the cases. Web page and file downloads or file uploads reward fast speeds, while the determination of success ratios and assessing Youtube payouts concentrate on reliability aspects.

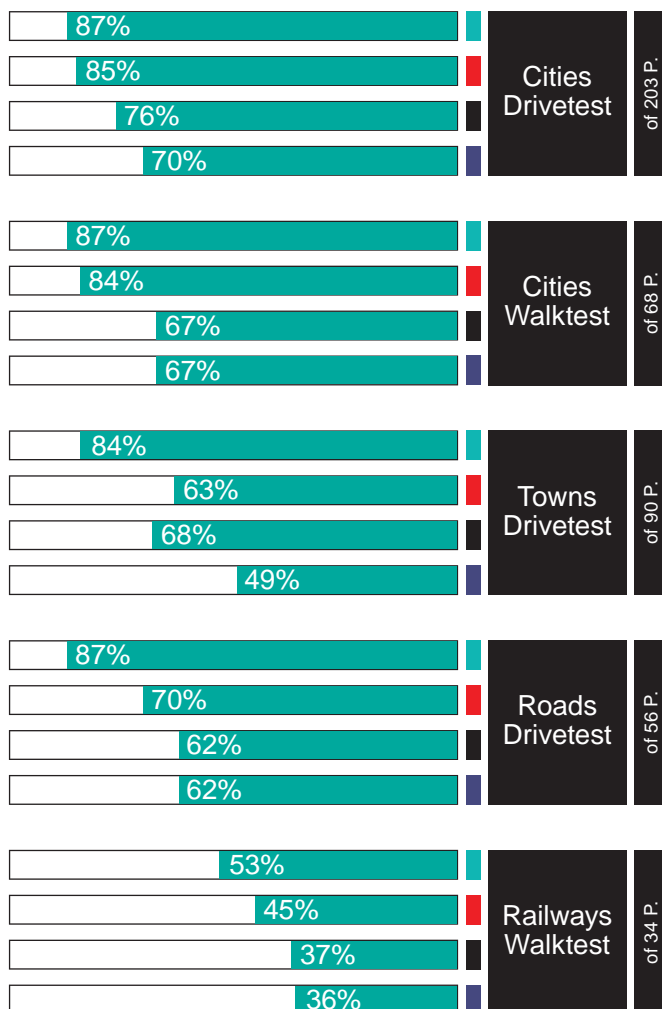


EE IS THE
CLEAR WINNER
IN THE DATA
DISCIPLINE,
VODAFONE
RANKS SECOND.
THREE
FOLLOWS
AT SOME
DISTANCE,
WHILE O2
RANKS FOURTH.

Data

450 of 1000 Points

■ EE
■ Vodafone
■ Three
■ O2



CITIES DRIVE TEST

EE

EE LEADS IN DATA DRIVE TESTS, VODAFONE FOLLOWS CLOSELY

In the drive tests conducted in 19 larger cities, EE leads by a narrow margin, followed by Vodafone.

Three achieves a solid third position, while O2 ranks fourth. On the level of individual KPIs, EE and Vodafone are in a neck-and-neck race. In some aspects such as the success ratios of web page downloads, they are on a par. In some such as most of the Youtube results, EE is ahead – in other such as download and upload success ratios, Vodafone leads the field. O2 keeps pace well, but ranks fourth overall in this scenario.

CITIES WALK TEST

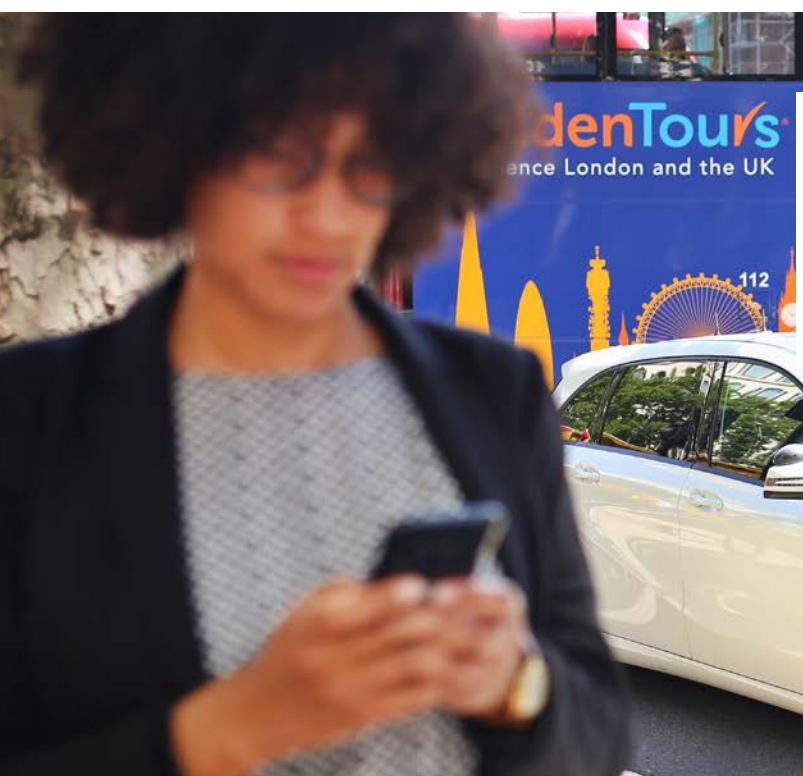
EE

EE AHEAD OF VODAFONE ALSO IN BIG CITY DATA WALK TESTS

In the overall results of the walk tests conducted in Belfast, Birmingham, Bristol, Cardiff, Glasgow, Leeds, Liverpool, Greater London, Manchester and Sheffield, EE scores ahead of Vodafone, but at a relatively close distance. The gap to Three and O2 is more distinct, with these two operators scoring overall on a par in the big city data walk tests. Three shows high data rates in many of the data disciplines, but falls back in the Youtube tests – along with O2, which also shows a relatively weak Youtube performance in all tested scenarios.

Data Cities (Drivetest)	EE	Vodafone	Three	O2
Web-Page Download				
Success Ratio (%)	99.2	99.2	98.2	98.0
Overall Session Time (s)	1.7	1.6	1.9	1.8
File Download (10 MB)				
Success Ratio/Avg. Session Time (%/s)	99.8/2.3	99.9/4.0	99.6/5.1	99.0/5.3
90%/10% faster than (Mbps)	21.7/118.4	10.0/138.8	7.6/149.3	6.3/125.0
File Upload (5 MB)				
Success Ratio/Avg. Session Time (%/s)	99.6/4.9	99.8/4.8	99.3/5.6	99.6/6.0
90%/10% faster than (Mbps)	3.7/39.4	4.1/41.2	3.4/46.7	3.2/27.2
File Download (7 Seconds)				
Success Ratio (%)	99.2	99.3	99.1	98.1
10% faster than (Mbps)	294.8	280.5	391.3	207.5
Speed > 5Mbps / 20Mbps (%)	99.6/94.7	97.6/86.7	95.7/80.5	93.5/74.5
File Upload (7 Seconds)				
Success Ratio (%)	99.0	99.0	98.4	97.3
10% faster than (Mbps)	58.8	60.4	62.6	31.9
Speed > 2Mbps / 5Mbps (%)	96.9/87.0	96.7/89.7	94.7/81.9	94.1/81.2
Youtube				
Success Ratio/Start Time (%/s)	98.6/1.6	97.4/1.6	93.8/1.6	92.8/1.5
Average Video Resolution (p)	1075	1070	1064	1054
Youtube live				
Success Ratio/Start Time (%/s)	97.5/1.6	97.8/1.6	95.8/1.9	93.5/2.1
Average Video Resolution (p)	1080	1080	1080	1080
Youtube 4K Smartphone				
Success Ratio/Start Time (%/s)	99.0/1.6	96.8/1.5	90.0/1.6	89.4/1.6
Average Video Resolution (p)	2042	1884	1950	1894

Data Cities (Walktest)	EE	Vodafone	Three	O2
Web-Page Download				
Success Ratio (%)	99.1	98.7	97.4	97.6
Overall Session Time (s)	1.7	1.5	1.9	1.8
File Download (10 MB)				
Success Ratio/Avg. Session Time (%/s)	99.5/2.1	99.1/3.4	98.5/6.2	98.1/4.8
90%/10% faster than (Mbps)	25.4/116.6	12.0/123.9	5.6/175.1	7.4/144.4
File Upload (5 MB)				
Success Ratio/Avg. Session Time (%/s)	99.3/4.2	99.2/4.0	98.7/5.8	98.7/6.0
90%/10% faster than (Mbps)	5.2/38.4	5.6/41.2	3.0/49.7	3.5/26.5
File Download (7 Seconds)				
Success Ratio (%)	99.1	99.4	98.2	97.4
10% faster than (Mbps)	294.8	288.2	273.2	275.6
Speed > 5Mbps / 20Mbps (%)	99.7/95.7	98.6/92.7	94.1/75.8	91.7/78.0
File Upload (7 Seconds)				
Success Ratio (%)	98.8	99.1	97.9	97.1
10% faster than (Mbps)	56.7	66.1	67.6	32.8
Speed > 2Mbps / 5Mbps (%)	96.3/90.9	98.0/92.7	93.4/81.0	94.9/84.9
Youtube				
Success Ratio/Start Time (%/s)	98.7/1.5	97.9/1.5	90.9/1.5	87.8/1.4
Average Video Resolution (p)	1073	1071	1061	1047
Youtube live				
Success Ratio/Start Time (%/s)	98.3/1.6	95.2/1.5	91.5/1.8	92.6/2.2
Average Video Resolution (p)	1080	1080	1080	1079
Youtube 4K Smartphone				
Success Ratio/Start Time (%/s)	97.8/1.6	95.6/1.4	87.7/1.5	86.4/1.5
Average Video Resolution (p)	2047	1891	1906	1936



TOWNS DRIVE TEST

EE

EE AHEAD IN DATA DRIVE TESTS IN SMALLER TOWNS, WITH THREE RANKING SECOND

In the data drive tests that our measurement cars performed in 46 smaller towns, EE takes a clear lead with the highest success ratios and overall good results. In this scenario, however, Three manages to take the second rank from Vodafone by offering slightly higher success rates and also faster data throughputs in many of the tested disciplines. Still, Vodafone follows not too far behind Three in the smaller town, while the gap between O2 and Vodafone is more distinct.

ROADS DRIVE TEST

EE

EE LEADS ON CONNECTING ROADS, WITH A HIGHER PERFORMANCE LEVEL ON THE ROADS THAN IN THE TOWNS

The lead of EE on the connecting roads covered by our test cars, is quite distinct. Remarkably, EE even scores a little higher in this scenario than in the smaller towns. Vodafone follows at a distinct distance on the second rank, due to good success ratios and decent data rates. Three and O2 share the third rank in the drive tests on the roads – but again at a distinct distance to the second-ranking Vodafone. Particularly their success ratios show potential for improvement.



DATA RESULTS AT A GLANCE

In the Data discipline, EE is leading the field in all tested scenarios. Vodafone ranks second – at an only narrow distance in the big cities and a more distinct gap on rural roads. Three takes the second rank from Vodafone in the smaller towns. When travelling by train, EE offers the best data results, but still at a relatively low level. All four UK operators still have much to do in terms of supplying data connectivity on railways. Regarding their 5G deployments, all UK operators have made much progress with EE leading in coverage in the bigger cities and Three offering the highest data rates.

Data Towns (Drivetest)	EE	Vodafone	Three	O2
Web-Page Download				
Success Ratio (%)	99.6	97.5	98.0	94.7
Overall Session Time (s)	1.6	2.0	2.0	2.3
File Download (10 MB)				
Success Ratio/Avg. Session Time (%/s)	99.9/3.3	98.8/9.7	98.9/6.1	98.3/11.8
90%/10% faster than (Mbps)	13.7/105.5	3.4/68.4	6.7/70.7	2.7/54.9
File Upload (5 MB)				
Success Ratio/Avg. Session Time (%/s)	99.6/4.8	99.7/6.6	98.6/7.7	98.9/8.5
90%/10% faster than (Mbps)	4.2/35.1	3.2/23.6	2.4/26.1	2.1/18.3
File Download (7 Seconds)				
Success Ratio (%)	99.1	98.3	99.2	95.5
10% faster than (Mbps)	175.6	109.8	135.6	62.1
Speed > 5Mbps / 20Mbps (%)	97.3/84.2	83.3/54.6	94.9/72.9	77.0/37.3
File Upload (7 Seconds)				
Success Ratio (%)	98.7	97.6	97.1	96.9
10% faster than (Mbps)	52.4	29.4	31.6	20.0
Speed > 2Mbps / 5Mbps (%)	96.4/89.8	95.0/78.4	91.3/74.0	88.5/69.2
Youtube				
Success Ratio/Start Time (%/s)	97.6/1.6	89.4/1.6	95.0/1.6	82.1/1.6
Average Video Resolution (p)	1073	1044	1058	1023
Youtube live				
Success Ratio/Start Time (%/s)	96.3/1.6	91.9/1.9	94.8/2.3	83.4/2.5
Average Video Resolution (p)	1080	1080	1080	1080
Youtube 4K Smartphone				
Success Ratio/Start Time (%/s)	96.9/1.7	87.2/1.6	89.9/1.5	77.9/1.6
Average Video Resolution (p)	2013	1651	1821	1640

Data Roads (Drivetest)	EE	Vodafone	Three	O2
Web-Page Download				
Success Ratio (%)	98.9	95.7	94.4	93.8
Overall Session Time (s)	1.8	2.1	2.9	2.2
File Download (10 MB)				
Success Ratio/Avg. Session Time (%/s)	99.2/3.6	99.5/11.3	98.3/10.2	96.2/11.9
90%/10% faster than (Mbps)	13.2/92.8	3.0/55.6	3.7/57.0	2.8/44.2
File Upload (5 MB)				
Success Ratio/Avg. Session Time (%/s)	99.3/5.6	98.4/8.3	96.6/12.4	97.6/7.9
90%/10% faster than (Mbps)	3.5/31.1	2.2/21.3	1.4/22.0	2.5/21.1
File Download (7 Seconds)				
Success Ratio (%)	97.4	97.6	96.4	94.5
10% faster than (Mbps)	127.2	71.0	102.0	48.4
Speed > 5Mbps / 20Mbps (%)	98.2/84.1	83.9/42.3	89.4/55.5	81.6/36.2
File Upload (7 Seconds)				
Success Ratio (%)	97.7	95.6	92.3	95.5
10% faster than (Mbps)	45.4	26.7	26.4	22.0
Speed > 2Mbps / 5Mbps (%)	92.6/82.2	90.4/71.3	75.9/53.6	88.5/70.6
Youtube				
Success Ratio/Start Time (%/s)	98.0/1.6	89.0/1.5	90.1/1.5	77.9/1.6
Average Video Resolution (p)	1072	1047	1038	1021
Youtube live				
Success Ratio/Start Time (%/s)	95.1/1.8	93.2/2.2	88.5/2.9	81.8/2.6
Average Video Resolution (p)	1080	1080	1078	1080
Youtube 4K Smartphone				
Success Ratio/Start Time (%/s)	93.9/1.6	88.9/1.5	85.1/1.5	83.6/1.6
Average Video Resolution (p)	2011	1529	1657	1670

Data Railways (Walktest)	EE	Vodafone	Three	O2
Web-Page Download				
Success Ratio (%)	89.3	85.4	82.9	80.6
Overall Session Time (s)	2.3	2.6	3.1	2.8
File Download (10 MB)				
Success Ratio/Avg. Session Time (%/s)	93.7/6.6	93.0/13.8	91.5/12.7	86.7/15.3
90%/10% faster than (Mbps)	5.4/99.5	2.2/75.1	2.5/80.8	1.9/79.2
File Upload (5 MB)				
Success Ratio/Avg. Session Time (%/s)	91.0/12.1	89.8/15.2	83.2/19.9	89.1/14.1
90%/10% faster than (Mbps)	1.1/25.7	1.0/18.1	0.8/22.1	1.1/17.5
File Download (7 Seconds)				
Success Ratio (%)	90.5	89.6	87.9	88.1
10% faster than (Mbps)	208.7	172.8	224.7	129.9
Speed > 5Mbps / 20Mbps (%)	91.8/73.4	79.5/52.7	80.6/54.5	68.2/32.8
File Upload (7 Seconds)				
Success Ratio (%)	82.0	81.3	73.4	76.3
10% faster than (Mbps)	39.8	25.2	23.6	17.5
Speed > 2Mbps / 5Mbps (%)	78.1/59.5	82.8/63.3	68.6/45.3	79.1/54.7
Youtube				
Success Ratio/Start Time (%/s)	80.2/1.5	72.9/1.5	73.1/1.5	66.2/1.5
Average Video Resolution (p)	1047	1020	1007	998
Youtube live				
Success Ratio/Start Time (%/s)	78.9/2.0	72.2/2.5	71.7/2.8	59.6/2.6
Average Video Resolution (p)	1080	1080	1080	1076
Youtube 4K Smartphone				
Success Ratio/Start Time (%/s)	78.9/1.5	77.4/1.5	68.4/1.6	63.0/1.6
Average Video Resolution (p)	1841	1495	1613	1495

RAILWAYS WALKTEST

EE

EE AND VODAFONE AHEAD IN TRAINS – WITH MUCH POTENTIAL FOR IMPROVEMENT

The tests performed in UK's trains reveal much potential for improvement. Even EE, who reach the highest score in this scenario, only achieve 53 percent of the possible score points in this scenario. Vodafone follows at some distance, with Three and O2 further behind. While the score gap between EE and Vodafone is distinct, the performances of Three and O2 rank quite close together in this discipline.

But all in all, there remains much to be done in terms of data connectivity on railways in the UK.

CONSIDERABLE ADVANCEMENTS IN TERMS OF 5G ROLLOUT IN THE UK

In comparison to our previous umlaut connect Mobile Benchmark in the UK, when the deployment of 5G had only just started, all four operators have come quite far. Particularly, they already show a strong 5G penetration in the cities, with more than 50 percent of the tested areas covered by this technology.

EE is ahead regarding the combination of 5G coverage and success ratios. For this operator, all data samples considered in our assessment were gathered in the 3.5 GHz frequency band ("5G high band"). Vodafone and O2 are the only operators offering a noteworthy level of 5G deployment using "Dynamic Spectrum Sharing" (DSS) which distributes the available spectrum between 4G and 5G depending on current demand.

But the number of samples collected via this transition technology in these two networks during the drive tests and walk tests are not too high: Vodafone shows 1.4 percent of the collected 5G data samples with DSS and O2 0.62 percent. This observation emphasises that the UK operators concentrate on rolling out 5G on the higher frequency bands, which allow for higher data rates at the cost of limited signal reach per mobile radio cell.

5G

EE AND VODAFONE VERY CLOSE TOGETHER IN 5G. THREE AND O2 FOLLOW, WITH OVERALL BALANCED 5G PERFORMANCES

Based on their deployment strategy, EE shows the highest availability in the Cities. Three is ahead with the highest shares in the towns, on the roads and in the trains. Vodafone follows at a narrow distance, and while O2 ranks fourth in this consideration, it still achieves 5G shares of above 50 percent in the bigger cities. Above that, it is particularly noteworthy that in all four UK networks, the 5G share on trains was considerably higher than on the connecting roads.

As a representative example, below we look at the results of samples with 5G in the 7 second Download tests. Here, Three achieves the highest data rates, while Vodafone shows the best success ratios. As these exemplary values show, EE and Vodafone are very close together regarding their 5G deliveries. Three and O2 follow at some distance, but present overall comparable 5G performances.

Data rates 7s Download	EE				O2				Three				Vodafone			
Samples with 5G	Share	Success Ratio	Average (Mbps)	10% faster than (Mbps)	Share	Success Ratio	Average (Mbps)	10% faster than (Mbps)	Share	Success Ratio	Average (Mbps)	10% faster than (Mbps)	Share	Success Ratio	Average (Mbps)	10% faster than (Mbps)
Cities – Drivetest	67.1%	99.4%	166.0	321.4	53.2%	99.6%	139.8	246.1	61.1%	99.4%	212.2	460.9	60.6%	99.4%	174.3	307.9
Cities – Walktest	80.2%	99.5%	159.8	307.2	59.8%	100.0%	171.4	306.9	67.4%	99.8%	156.2	298.7	69.7%	100.0%	178.9	318.2
Towns – Drivetest	13.8%	100.0%	125.3	254.2	4.2%	97.4%	131.0	233.7	18.7%	99.4%	171.4	366.2	3.9%	100.0%	192.0	320.1
Roads – Drivetest	8.5%	100.0%	122.4	253.3	2.1%	100.0%	119.9	182.0	11.5%	98.4%	156.1	373.6	2.8%	100.0%	148.2	273.5
Trains – Walktest	28.2%	98.9%	162.1	341.4	23.7%	100.0%	105.7	180.9	31.0%	96.5%	187.7	380.4	26.0%	100.0%	141.1	264.3
Samples with 5G-DSS																
Cities – Drivetest	–	–	–	–	1.1%	100.0%	26.6	46.6	–	–	–	–	1.7%	100.0%	60.0	100.0
Cities – Walktest	–	–	–	–	0.7%	100.0%	9.8	16.1	–	–	–	–	0.4%	100.0%	39.7	59.5
Towns – Drivetest	–	–	–	–	–	–	–	–	–	–	–	–	2.5%	100.0%	41.0	71.2
Roads – Drivetest	–	–	–	–	–	–	–	–	–	–	–	–	0.7%	100.0%	25.7	41.1
Trains – Walktest	–	–	–	–	–	–	–	–	–	–	–	–	0.3%	100.0%	17.2	17.2

CROWD

672,600 users from the UK have contributed around 2.7 billion measurement samples between end of May and early November, 2021. We have conducted a thorough analysis of this extensive data set, using an even more refined crowdsourcing methodology compared to previous years.

While the drive tests and walk tests determine the peak performance of the examined networks, crowdsourcing can add important dimensions such as time, geography or variety in devices and tariff plans – if done in the right way. A detailed description of our crowdsourcing methodology can be found on page 17. A total of 672,600 mobile phone users in the UK have provided relevant samples to our crowd data. The test area of our crowdsourcing represents 99.2 percent of the built-up area of the UK and 99.8 percent of the UK's population.

EE TAKES
THE LEAD IN
THE CROWD
EVALUATION,
AHEAD OF
VODAFONE.
O2 COMES IN
THIRD, AND
THREE RANKS
FOURTH.

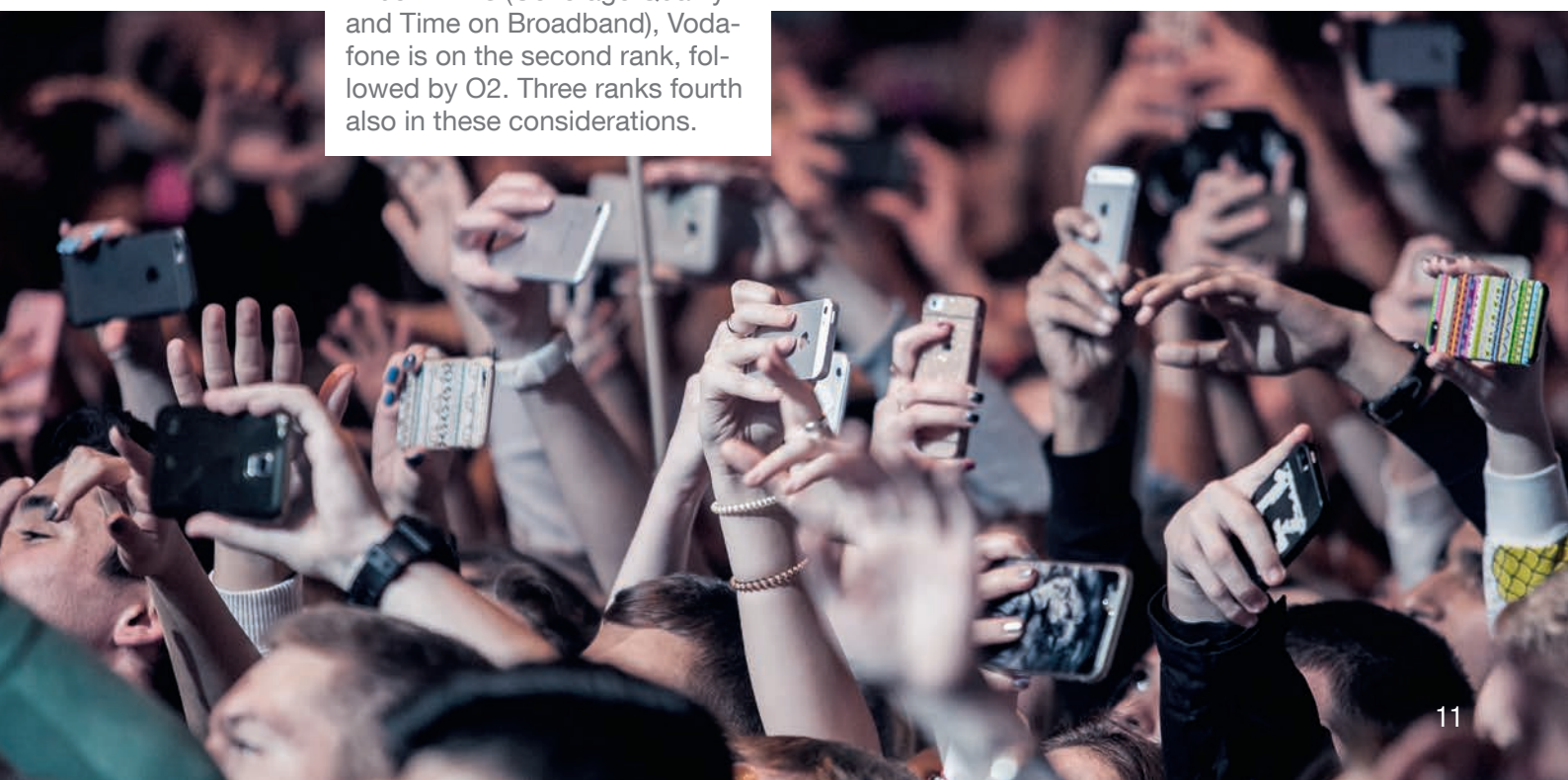
COVERAGE

EE

EE LEADS IN COVERAGE QUALITY. IN COVERAGE REACH, EE AND O2 ON A PAR, AND VODAFONE RANKS THIRD

In terms of Coverage Reach (the recorded 3G, 4G or 5G coverage related to the overall summation of all coverage areas), EE and O2 are on a par, followed by Vodafone and Three. But EE offers the best Coverage Quality (the ratio of all Evaluation Areas to the "common footprint") and also the best Time on Broadband (how often an average user had 4G or 5G reception). In both KPIs (Coverage Quality and Time on Broadband), Vodafone is on the second rank, followed by O2. Three ranks fourth also in these considerations.

Operators	EE	Vodafone	Three	O2
Broadband Coverage				
Coverage Quality (%)	96.1	92.0	84.5	89.4
Coverage Reach (%)	96.6	94.6	92.8	96.6
Time on Broadband (%)	95.7	93.9	87.8	92.1
Download Speed				
Basic Internet Class(%)	93.7	92.4	91.5	90.5
HD Video Class (%)	78.3	73.6	69.4	66.3
UHD Video Class (%)	21.4	15.4	15.4	15.4
Latency				
Gaming Class (%)	87.1	70.8	47.7	63.0
OTT Voice Class (%)	96.3	96.3	92.7	95.4



DOWNLOAD SPEEDS

EE

EE TAKES THE LEAD IN ALL DOWNLOAD SPEED CLASSES, FOLLOWED BY VODAFONE

In our crowdsourced assessment of Download Speeds, EE achieved the best results in all considered speed classes.

In the Basic Internet sub-category, 93.7 percent of EE's samples have throughputs above 2 Mbps, closely followed by Vodafone with 92.4 percent, Three follows on third rank with 91.5 percent and O2 ranks fourth with 90.5 percent.

In "HD Video" (above 5 Mbps), EE leads again with 78.3 percent of the samples fulfilling this requirement, followed by Vodafone with 73.6 percent. At a wider gap, Three achieves 69.4 percent, and O2, 66.3 percent.

In the most demanding sub-category, "UHD Video", EE manages to achieve 21.4 percent, while the three competitors share the second position with 15.4 percent.

LATENCY

EE

EE AHEAD IN THE LATENCY METRIC, FOLLOWED BY VODAFONE AND THEN O2

In our examinations of Latency, EE is the leader in the Gaming category by showing 87.1 percent of the samples below 50 ms, followed by Vodafone with 70.8 percent and O2 with 63 percent.

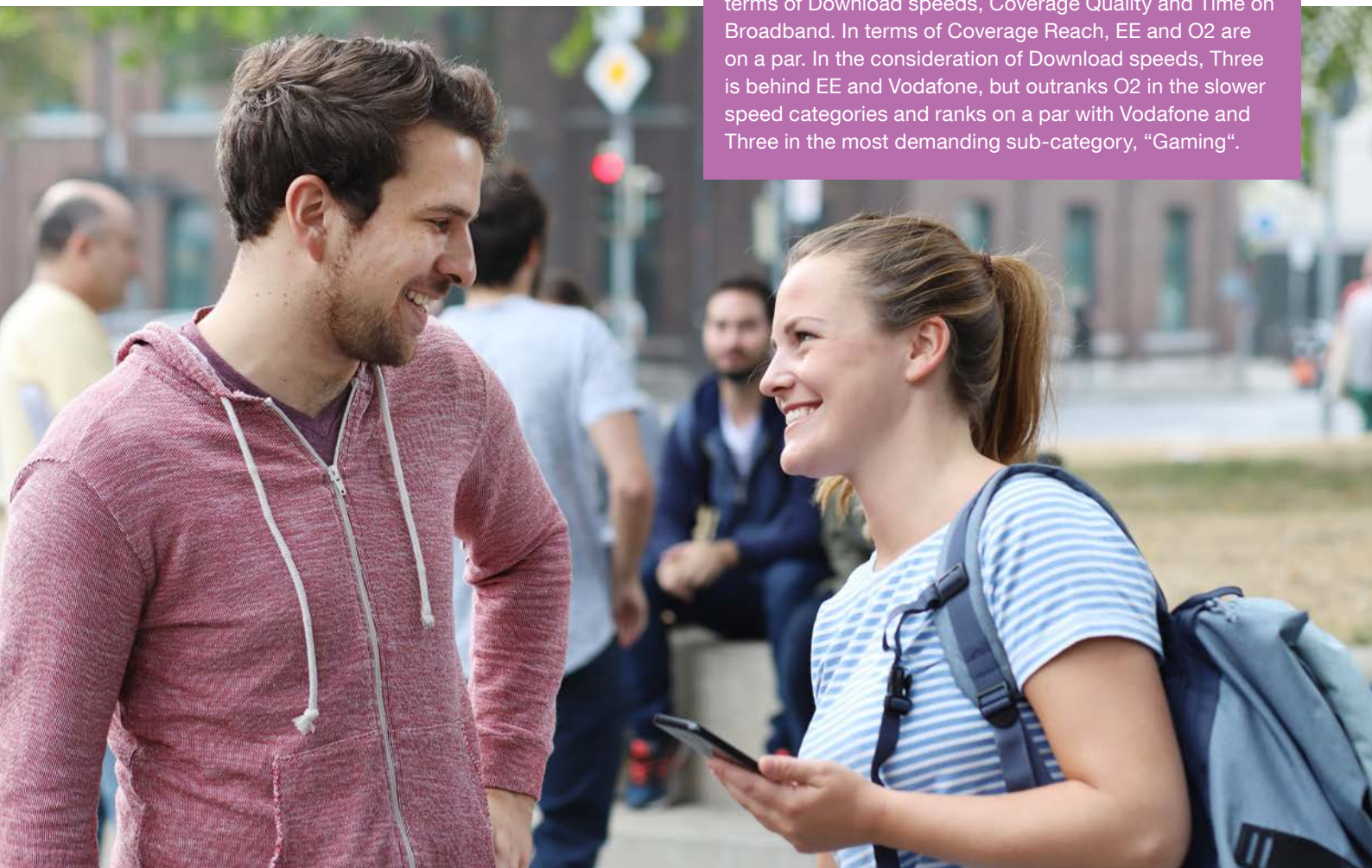
In the more demanding Gaming category, only 47.7 percent of the samples gathered in the Three network are below the threshold of 50 ms.

In the "OTT Voice" category, EE and Vodafone are on par with 96.3 percent of their samples below 100 ms, closely followed by O2 with 95.4 percent. Three remains in fourth position with 92.7 percent of the samples showing a latency below 100 ms.



CROWD RESULTS AT A GLANCE

In the crowdbased score, EE takes the overall lead in all three categories, followed by Vodafone in the overall crowd assessment. Vodafone is on a par with EE in the "OTT Voice" latency examinations and is also strong in terms of Download speeds, Coverage Quality and Time on Broadband. In terms of Coverage Reach, EE and O2 are on a par. In the consideration of Download speeds, Three is behind EE and Vodafone, but outranks O2 in the slower speed categories and ranks on a par with Vodafone and Three in the most demanding sub-category, "Gaming".



RELIABILITY

The assessment of Reliability is another way to look at the results of our voice and data drivetests and walktests as well as at those of our crowd analyses. This approach concentrates on the compulsory basics instead of the highest peaks of a network's performance.

Reliability is not an additional category of our tests, but rather a different angle of viewing the results: For each KPI, our scoring distinguishes between "Qualifiers" (the expected basic performance) and "Differentiators" (the additional performance that exceeds the expected basics). Our look at Reliability limits itself to the Qualifiers – thus conveying an impression of the standards, a user can reasonably expect from a mobile network. The reference values in this representation are therefore only the subset of score points which we assigned to the Qualifiers. The resulting scores state the reliability with which an operator offers its network services.

EE ALSO LEADS IN THE RELIABILITY ASSESSMENT. VODAFONE IS AHEAD IN VOICE. O2 ACHIEVES HIGHER SCORES THAN THREE IN THE RELIABILITY OF THE VOICE DRIVE TESTS AND OF THE CROWDSOURCING.

RELIABILITY

EE LEADS IN RELIABILITY, VODAFONE AHEAD IN VOICE, O2 SURPASSES THREE IN RELIABILITY IN THE VOICE DRIVE TESTS AND IN CROWDSOURCING

The scores resulting from our special look at Reliability mostly correspond to the overall ranking. As in the overall result, in the Voice category Vodafone also reaches a slightly higher score in the Reliability assessment in comparison to EE.

Also, O2 reaches more score points than Three in the Voice category – coming from the Voice drive tests tests – as well as in the Crowdsourcing. These results support a view that O2 focuses a little more on the widespread availability of its services, while Three shines in the domain of peak performances.

Operator		EE	Vodafone	Three	O2
Voice	max. 165 points	138	141	123	133
Drivetest	128	87%	88%	75%	84%
Walktest	37	72%	75%	72%	67%
Data	max. 227 points	198	184	167	148
Drivetest	176	91%	84%	78%	68%
Walktest	51	76%	71%	57%	56%
Crowd	max. 138 points	125	122	112	118
Crowd	138	91%	89%	81%	86%
Total	max. 529 points	461	447	402	399
Grade		very good	good	good	good

RELIABILITY LONDON

EE LEADS IN RELIABILITY ASSESSMENT FOR LONDON, VODAFONE FOLLOWS AS "CO-BEST" AT A VERY NARROW GAP. O2 AHEAD OF THREE IN THE LONDON RELIABILITY SCORES

The Reliability assessment for London refers to an even smaller maximum score, as the road, town and railway tests are omitted. In the hotly contested capital, EE still takes the lead – but the gap to Vodafone is narrow.

Vodafone is ahead in the Voice category, leading in the drive tests and scoring on a par with EE in the walktests. In Data, EE is ahead by a very narrow margin. Overall, both contenders are very good in terms of their Reliability score for London. O2 scores ahead of Three in this consideration mainly due to stronger Voice results.

Operator		EE	Vodafone	O2	Three
Voice	max. 99 points	86	88	85	62
Drivetest	74	84%	86%	84%	57%
Walktest	25	96%	96%	90%	82%
Data	max. 136 points	122	118	98	98
Drivetest	102	89%	88%	72%	77%
Walktest	34	91%	82%	71%	55%
Crowd	max. 138 points	125	123	119	120
Crowd	138	91%	89%	87%	87%
Total	max. 373 points	333	329	302	280
Grade		very good	very good	good	good

LONDON

Traditionally, umlaut and connect take a closer look at the UK's capital to see how the operators cover this lively centre of business, politics and culture.



Greater London is by far the most densely populated area in the UK and also a vibrant business capital. This also makes the nation's capital an especially demanding terrain for deploying and maintaining a mobile network. For this reason, we regularly take a closer look to see how the performance in the capital compares to the rest of the United Kingdom.

So, as in our previous umlaut connect Mobile Benchmarks for the UK, we have filtered the results of the drive tests and walk tests as well as the crowd results obtained in the London area in order to separate them from the nationwide values. As these city scores neither contain the results of the drive tests conducted in the smaller towns and on the connecting roads nor the walk test results from the trains, we have adapted the maximum achievable points accordingly to a total of 700.

EE LEADS IN LONDON TOO, VODAFONE RANKS SECOND. ALL FOUR NETWORKS PERFORM BETTER IN THE CAPITAL THAN NATIONWIDE

The overall ranking in the London area is the same as in the nationwide assessment. EE leads the field in the capital, showing slightly stronger voice and crowdsourcing results compared to the evaluation for the whole United Kingdom. In the data category, EE however falls a little behind its nationwide result in the drive tests. The walk tests basically reveal the same level performance as in the rest of the UK. Vodafone ranks second in London, also performing somewhat stronger in the voice and crowdsourcing disciplines compared to its nationwide results. In the data tests, similar to EE, Vodafone's scores are also a little lower than in the nationwide assessment.

STRONG CROWD RESULTS FOR O2 AND THREE IN LONDON

The same is also true for O2 which achieves the third position in the capital: In the voice and crowdsourcing it is a little stronger, the data tests performed in London score a little behind its nationwide result.

Three ranks fourth in the capital. Its voice results are a little behind the nationwide assessment. In the data tests, Three performs a little stronger in the walk tests conducted in London, but falls a little behind its result in the rest of the UK regarding the data drive tests. In the crowdsourcing analyses, Three again achieved a somewhat higher score than nationwide.



LONDON RESULTS AT A GLANCE

As can be expected in this densely populated area, all four UK networks score a little higher in London than in the overall, nationwide assessment. Such as in the whole UK, EE is also the winner in the capital. Compared to the nationwide results, EE scores a little better in the voice and crowdsourcing disciplines, but falls somewhat behind in the data assessment. The same is true for the second-ranking Vodafone and the third-placed O2. Three ranks fourth in the capital with its voice score a little behind the UK results. In the data tests, Three performs a little stronger in the London walk tests and a little weaker in the drive tests.

Overall Results London		EE	Vodafone	O2	Three
Voice	max. 180 P.	161	165	154	138
Cities (Drivetest)	135	88%	90%	85%	73%
Cities (Walktest)	45	94%	95%	89%	87%
Data	max. 270 P.	232	225	183	195
Cities (Drivetest)	203	85%	84%	68%	76%
Cities (Walktest)	68	87%	81%	66%	62%
Crowdsourced Quality	max. 250 P.	232	225	219	215
Crowd	250	93%	90%	88%	86%
Total	max. 700 P.	625	615	556	548

Percentages and points rounded to integer numbers.
For the calculation of points and totals, the accurate, unrounded values were used.

THE UK'S LARGEST CITIES

For the inhabitants of the other large cities in the UK, it is interesting to see how the different operators perform in their areas. Therefore, we performed additional analysis for ten large cities all over the United Kingdom.

As interesting as the focus on the densely populated London area is, the inhabitants of other large UK cities and the capitals of the other nations besides England have their own perspective on network performance and availability. In order to also provide valuable insights for their inhabitants, we have additionally analysed the performances of the four operators in ten large cities of the UK.

When comparing the individual results, it must however be taken into account that we did non conduct walk tests in Belfast and Edinburgh – and thus have adapted the amount of maximum obtainable points accordingly.

different as can be seen from the bar charts shown below. Overall, EE leads in seven out of ten cities (plus London). With the exception of Cardiff, the two top contenders rank relatively close together.



SAME RANKING AS NATIONWIDE IN BIRMINGHAM, BRISTOL, CARDIFF AND MANCHESTER

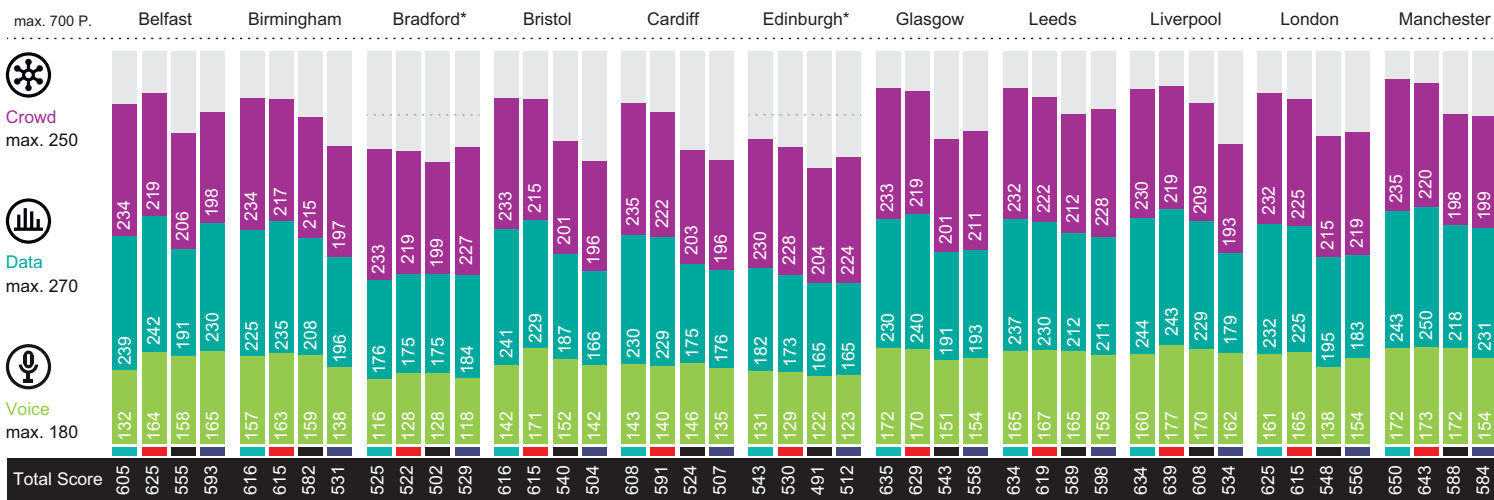
The same ranking as in the nationwide assessment can be seen in Birmingham, Bristol, Cardiff and Manchester. In these cities, EE is the leader, followed by Vodafone. Three ranks third, and O2 fourth – although the gaps between the four contenders are somewhat

VODAFONE LOCAL CHAMPION IN BELFAST AND LIVERPOOL. O2 AHEAD OF THREE IN BELFAST, EDINBURGH, GLASGOW AND LEEDS

In Belfast, Vodafone takes the lead with strong data and crowd results and in Liverpool due to a distinct advance in Voice. EE ranks second in both cities. O2 outranks Three in Belfast as well as in Edinburgh, Glasgow and Leeds.

O2 LOCAL CHAMPION IN BRADFORD

And in the Metropolitan Borough City of Bradford, West Yorkshire, O2 takes the position of a local champion: Here, the operator ranks first ahead of EE and a closely succeeding Vodafone. Three follows at some distance but with still respectable results and exactly the same scores as Vodafone in the voice and data categories.



* Drivetest only, max. 587 P. — Shown scores are rounded.

Cities: Belfast (W), Birmingham (W), Bradford, Bristol (W), Cambridge, Cardiff (W), Cheltenham, Darlington, Edinburgh, Glasgow (W), Leeds (W), Liverpool (W), London (W), Manchester (W), Mansfield, Milton Keynes, Northampton, Portsmouth, Stoke on Trentn; (W) designates walk test cities. A walk test has also been conducted in Sheffield.

Towns: Abergavenny, Alsager, Armagh, Banbridge, Berwick upon Tweed, Bishop's Stortford, Bolsover, Bromsgrove, Catterick Garrison, Chepstow, Chichester, Chippenham, Chorley, Chorleywood, Cramlington, Daventry, Dumfries, Dunscoft (Hatfield), East Grinstead, Epping, Fleet, Gerrads Cross, Horsham, Kendal, Knutsford, Larkhall, Locks Heath, Merthyr Tydfil, Monmouth, Narborough, Newbury, Penrith, Potters Bar, Rickmansworth, Saffron Walden, Shepshed, Skelmersdale, South Normanton, St Neots, Tewkesbury, Tranent, Wellingborough, Welwyn Garden City, Winchester, Windsor, Yate.

TESTING METHODOLOGY

The methodology of the umlaut connect Mobile Benchmark is the result of almost 20 years of testing mobile networks. Today, network tests are conducted in more than 120 countries. Our methodology was carefully designed to evaluate and objectively compare the performance and service quality of mobile networks from the users' perspective.

The umlaut connect Mobile Benchmark in the United Kingdom comprises of the results of extensive voice and data drive tests and walk tests as well as a sophisticated crowdsourcing approach.

DRIVE TESTS AND WALK TESTS

The drive tests and walk tests in the UK took place between October 25th and November 15th, 2021. All samples were collected during the day, between 8.00 a.m. and 10.00 p.m. The network tests covered inner-city areas, outer metropolitan and suburban areas. Measurements were also taken in smaller towns and cities along connecting highways. The connecting routes between the cities alone covered about 1,365 kilometres per car – 54,62 kilometres for all four cars. In total, the four vehicles together have covered about 10,022 kilometres.

The combination of test areas has been selected to provide representative test results across the UK's population. The areas selected for the 2021 test account for 17.3 million people, or roughly 26 percent of the total population

of the United Kingdom. The test routes are shown on page 1 of this report, all visited cities and towns are listed in the box on the right.

The four drive-test cars were equipped with arrays of Samsung Galaxy S21+ smartphones for the simultaneous measurement of voice and data services.

VOICE TESTING

One smartphone per operator in each car was used for the voice tests, setting up test calls from one car to another („mobile-to-mobile“). The walk test team also carried one smartphone per operator for the voice tests. In this case, the smartphones called a stationary (smartphone) counterpart. The audio quality of the transmitted speech samples was evaluated using the HD-voice capable and ITU standardised so-called POLQA wideband algorithm. All smartphones used for the voice tests were set to “5G preferred” mode. In addition, they were set to “VoLTE preferred”. As Voice over 5G/Voice over New Radio is not yet supported in current 5G networks, this means that the

devices would perform a fallback from 5G to 4G in order to establish voice calls.

In the assessment of call setup times we also rate the so-called P90 value. Such values specify the threshold in a statistical distribution, below which 90 percent of the gathered values are ranging. For speech quality, we publish the P10 value (10 percent of the values are lower than the specified threshold), because in this case higher values are better.

In order to account for typical smartphone-use scenarios during the voice tests, background data traffic was generated in a controlled way through injection of data traffic (HTTP downloads). In the process, we also recorded Multi-RAB connectivity – the use of several “radio access bearers” for the background data connections.

The voice scores account for 30 percent of the total results.

DATA TESTING

Data performance was measured by using four more Galaxy S21+ in each car – one per operator. Their radio access technology was also set to 5G preferred mode.

For the web tests, they accessed web pages according to the widely recognised Alexa ranking.

In addition, the static “Kepler” test web page as specified by ETSI (European Telecommunications Standards Institute) was used. In order to test the data service performance, files of 10 MB for



Each drive test vehicle carried eight smartphones for conducting the voice and data tests.



A special control system monitors the smartphones and logs the measurement values they collect.



The walktest teams use trolleys in which powerful rechargeable batteries feed the test smartphones.

download and and 5 MB for upload were transferred from or to a test server located in the cloud. In addition, the peak data performance was tested in uplink and downlink directions by assessing the amount of data that was transferred within a seven seconds time period.

The Youtube measurements take into account the “adaptive resolution” of the video platform: Youtube dynamically adjusts the played resolution to the available bandwidth. The rating therefore considers the average image resolution or number of lines of the videos. In addition, the video rating is based on the success rate, the time until playback starts and the proportion of video playbacks that went through without interruption.

All the tests were conducted with the best-performing mobile plan available from each operator. Data scores account for 45 percent of the total results.

CROWDSOURCING

Additionally, umlaut conducted crowd-based analyses of the UK’s networks which contribute 25 percent to the end result. They are based on data gathered between calendar week 21 (end of May) until calendar week 44 (early November), 2021.

In the process, a total of 2.7 billion samples from more than 672,600 users were evaluated. The area of the UK covered by these crowdsourcing analyses covers approx. 200,300 square km and 99.2 percent of the UK’s built-up areas, which correspond to approx. 99.8% of the population.

For the collection of crowd data, umlaut has integrated a background diagnosis process into more than 1000 diverse Android apps. If one of these applications is installed on the end-user’s phone and the user authorizes the background analysis, data collection takes place 24/7, 365 days a year. Reports are generated for every hour and sent daily to umlaut’s cloud servers. Such reports occupy just a small number of bytes per message and do not include any personal user data.

This unique crowdsourcing technology allows umlaut to collect data about real-world experience wherever and whenever customers use their smartphones.

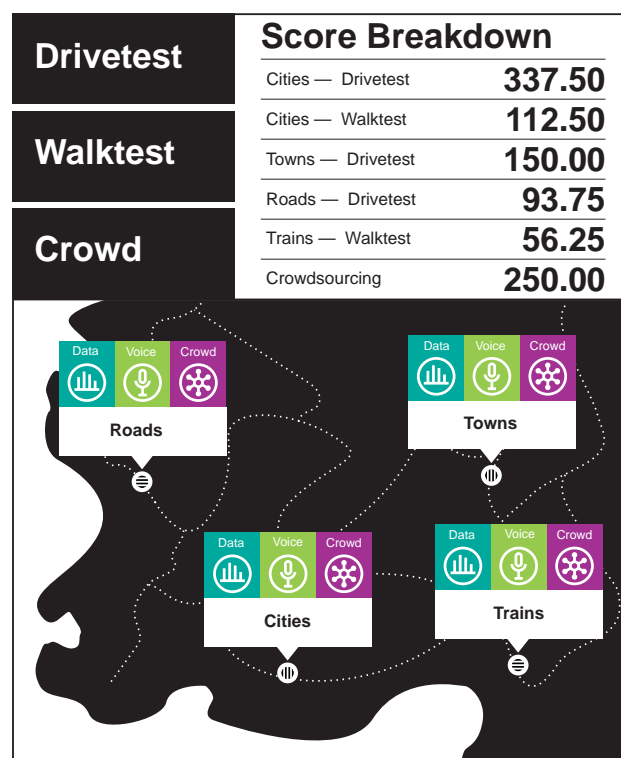
NETWORK COVERAGE

In order to assess the “Coverage Reach“, the test area is divided by a grid of 2x2 km tiles (“Evaluation Areas” or EAs for short). A minimum number of users and measured values must be available for an EA to be considered in the analysis.

For the evaluation, umlaut awards one point per EA if the network under consideration offers 3G coverage. Three points are awarded if 4G or 5G is available in the EA. The number of points achieved in this way is then divided by the total number of points that can be achieved (three points per EA in the “common footprint” – i.e. the area of the country covered by all tested mobile network operators).

In addition, we look at the “Coverage Quality“. It puts the percentage of EAs in which a user had 4G or 5G coverage in relation to all EAs in the common footprint.

A third KPI for broadband quality is “Time on Broadband“. It tells us how often an individual user had 4G or 5G reception in the period under consideration – regardless of the EAs in which the samples were recorded. For this purpose, umlaut sets the samples that show 4G/5G coverage in relation to the total number of all samples. Important: The percentage values determined and published for all three parameters reflect the respective degree of fulfilment – they do not correspond to the percentage of 4G/5G mobile coverage in an area or in relation to the overall population.



DATA RATES AND LATENCIES

The data rates determined are included in the crowd score at 30%, the latencies at 20%. The investigation of these parameters is also carried out independently of the EAs and thus concentrates on the experience of each individual user. Samples that were recorded via WiFi or when flight mode was activated, for example, are filtered out before further analysis.

In order to take into account the fact that many mobile phone tariffs throttle the usable data throughput, umlaut has defined three application-related speed classes: “Basic internet” requires a minimum of 2 Mbps, “HD video” requires 5 Mbps and “UHD video” requires 20 Mbps. For a sample to be valid, a minimum amount of data must also have flowed in a 15-minute period.

Similarly, the latency of the data packets is also assigned to an application-related class: Roundtrip times up to 100 ms are sufficient for “OTT voice services“, less than 50 ms qualify a sample for “gaming“.

In the evaluation, umlaut assigns the speeds and latencies determined in the samples to one of these classes. “Basic internet” then accounts for 55% of the data rate rating, “HD video” for 33.8% and “UHD video” for 11.3%. “OTT voice” services account for 55% of the latency rating and gaming for 45%.

CONCLUSION

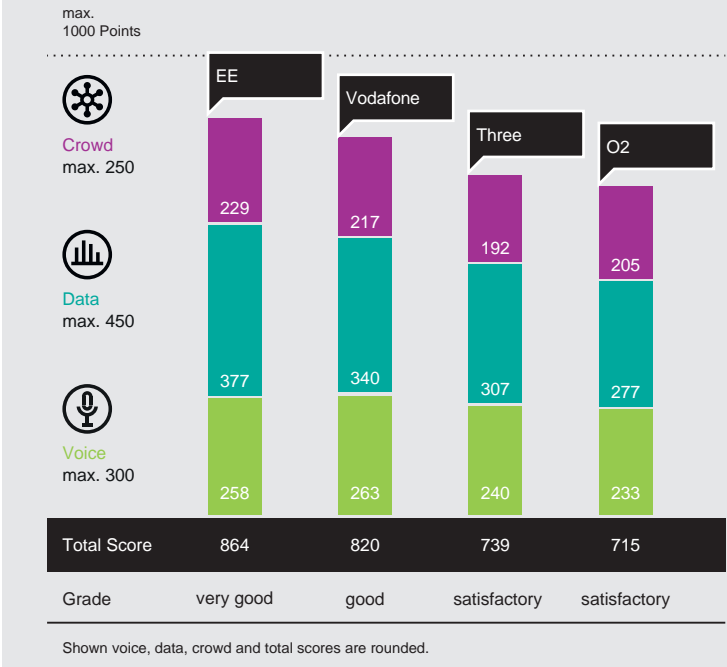
EE wins for the seventh time. Vodafone maintains the second place. Three takes back the third rank from O2, showing massive score gains. But also O2 manages to improve over our previous benchmark in the UK.

The overall winner of the 2021 umlaut connect Mobile Benchmark in the UK is EE – for the seventh time (in 2016, EE shared the first place with Vodafone). EE scores best in the Data and Crowd categories, while Vodafone has the lead in Voice. Still, the second-ranking Vodafone shows also strong results in the other categories.

Three manages to distinctly advance its score in comparison to our previous UK benchmark, improving in all three test categories. In doing so, Three also wins back the third rank from O2, which had taken this position in our previous UK benchmark. Although ranking fourth this time, O2 still achieves a clear score gain and improves its results in the Voice and Data categories.

In London, EE leads at a gap of ten points ahead of Vodafone, while O2 scores a little higher than Three. In our city comparison, EE leads in seven out of ten considered larger UK cities. Vodafone is a local champion in Belfast and Liverpool, while O2 takes the lead in Bradford.

In terms of 5G rollout, all UK operators already show good coverage in the cities. EE offers the highest 5G coverage in all tested scenarios, while in the 5G high band, Three achieves the highest average and maximum data rates in all scenarios except for the walk tests conducted in the big cities.



Overall Results		EE	Vodafone	Three	O2
Voice	max. 300.00 P.	258	263	240	233
Cities (Drivetest)	135.00	88%	91%	84%	83%
Cities (Walktest)	45.00	90%	94%	92%	87%
Towns (Drivetest)	60.00	92%	93%	84%	82%
Roads (Drivetest)	37.50	88%	80%	62%	67%
Railways (Walktest)	22.50	50%	56%	51%	36%
Data	max. 450.00 P.	377	340	307	277
Cities (Drivetest)	202.50	87%	85%	76%	70%
Cities (Walktest)	67.50	87%	84%	67%	67%
Towns (Drivetest)	90.00	84%	63%	68%	49%
Roads (Drivetest)	56.25	87%	70%	62%	62%
Railways (Walktest)	33.75	53%	45%	37%	36%
Crowd	max. 250.00 P.	229	217	192	205
Crowd	250.00	92%	87%	77%	82%
Connect Rating	max. 1000 P.	864	820	739	715

Percentages and points rounded to integer numbers.
For the calculation of points and totals, the accurate, unrounded values were used.



1

As in our previous UK Benchmarks, EE is the winner. The second largest operator in the UK manages to hold its high performance levels and scores best in our Data and Crowd disciplines of our evaluation. In terms of 5G deployment, EE made clear advancements and offers the highest coverage in all scenarios.



2

Vodafone defends the second place which it has been holding since 2017, after having scored on a par with EE in 2016. The operator leads our comparison in the Voice category and also shows strong results in Data and Crowd. Its 5G deployment is strong in the cities and keeps up in trains, but is capable of development in rural areas.



3

The smallest UK operator managed to make its way to the third rank by this time achieving the biggest score improvement over the results of our previous benchmark. There is some room for improvement in its Crowd results. In our 5G assessments, Three convinces with particularly fast data rates.



4

The now biggest mobile operator in the UK ranks fourth, but shows strength in our Crowd analyses. In the city comparisons, O2 is a local champion in Bradford. Compared to our previous benchmark, O2 improved in Voice and Data. In terms of 5G, its results are already strong in the cities, but in need of development in rural areas.