



Measuring mobile broadband performance in the UK

4G and 3G network performance

Research Document

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About this document

This document outlines the results of Ofcom's research into the performance of the retail 3G and 4G networks of the UK's four national mobile network operators (MNOs): EE, O2, Three and Vodafone.

Following the conclusion of the 4G spectrum auction in February 2013, Ofcom stated that it would conduct research into the performance of 3G and 4G networks, with the intention of helping consumers understand the performance benefits of 4G over 3G and identifying any differences between MNOs' networks, limited to the locations where all four MNOs' networks are available.

The first research was conducted between March and June 2014, with the second wave of research (summarised in this report) in October and December 2014. In both cases, the research took place in five UK cities where 4G services were offered by all four MNOs. In the first research the tests were delivered in Birmingham, Edinburgh, Glasgow, London and Manchester, while in the second research we tested in Edinburgh, Leeds, London, Newcastle and Poole/Bournemouth.

Our methodology involved using smartphones to measure four key metrics that relate to the experience of using a data connection: download speed, upload speed, web browsing speed (the time taken to load a web page) and latency (measured through ping tests).

To provide context to the results, this report includes 3G and 4G coverage information for each of the MNOs.

We note that network performance is only one element in a consumer's decision to upgrade to a 4G service. This report is part of a wider programme of work by Ofcom into mobile quality of service, which also includes consumers' experience of making and receiving mobile phone calls.

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Section 1

Executive summary

1.1 Introduction

Ofcom's second report on measuring mobile broadband performance provides information about both 4G and 3G mobile network performance in five UK cities, and follows our first report, published in November 2014.¹

Our mobile broadband performance research collects performance data on the UK's four national mobile networks in certain UK cities where both 3G and 4G networks have been deployed by all four mobile network operators (MNOs). The four UK MNOs are EE Limited (EE), Telefónica UK Limited (O2), Vodafone UK (Vodafone) and Hutchison 3G UK (Three).² The research was designed to allow comparison of the performance of 3G and 4G networks on average, by location, and between mobile networks.

The results in this report were collected between October and December 2014 in Edinburgh, Leeds, London, Newcastle and Poole/Bournemouth using unbranded Samsung Galaxy Note 3 smartphone handsets.³ In each city, our testing area was a 4km radius from the mainline train station, which for London was Charing Cross.⁴ It is important to note that the results in this report represent the four mobile broadband performance metrics in the test areas of the five cities in which we tested during Q4 2014.

Such is the dynamic nature of the mobile broadband market, we decided to change some of the test locations from those included in our first report. As such, there were only two cities in which we tested across both phases (Edinburgh and London) so a comparative analysis of the results in both reports is possible only when looking at the data collected in these two cities. However, this is an important comparison to make, as we can see how networks are developing as 4G take-up rises.

The mobile market is changing rapidly, with 4G coverage increasing across the UK. Figure 1 shows Ofcom's estimate of 4G coverage trend for each MNO, while Annex 4 provides further information on coverage data.

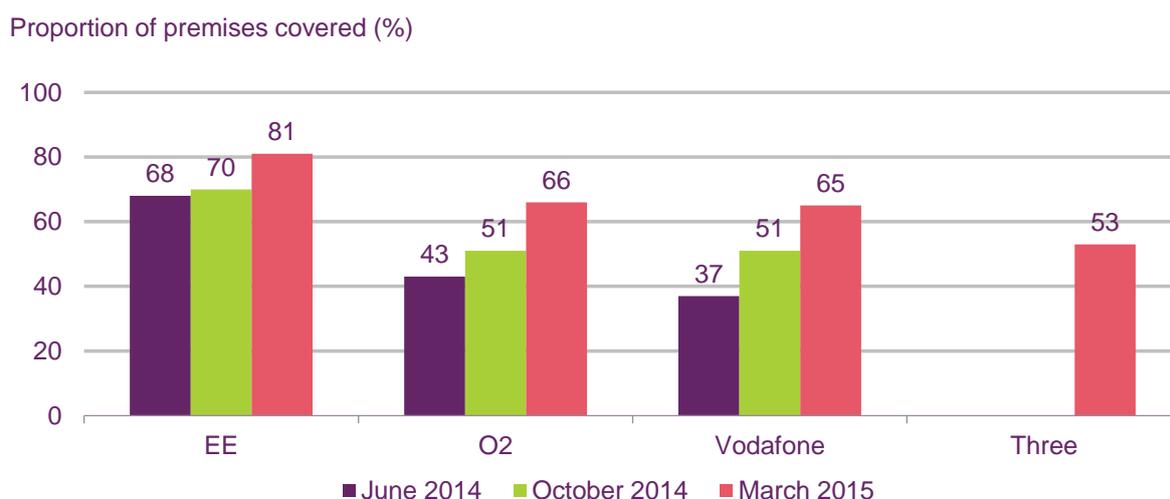
¹ <http://media.ofcom.org.uk/news/2014/3g-4g-bb-speeds/>

² In the rest of this report we will use the abbreviations in brackets.

³ When we selected the test locations, we did not find any cities in Wales or Northern Ireland where all four MNOs had widely-available 4G coverage.

⁴ A 4km radius was used as we considered that this allowed a large enough testing area to avoid any undue clustering of results. See Annex 2 for more information.

Figure 1 Estimated 4G premises coverage, by MNO



Source: Ofcom estimate based on data supplied by operators

1.2 Key findings

We measured performance using four metrics that are relevant to the experience consumers have when accessing different mobile broadband services :⁵

- **Download speed** – the rate at which data can be transferred from the internet to a user’s device (relevant to the downloading files). This is most likely to affect the consumer experience when downloading very large files to a mobile device and when speed is insufficient (under 2Mbit/s) to support high capacity video services.
- **Web browsing speed** – the time that it takes to load a standard web page to a mobile device (relevant to browsing the internet and applications).
- **Upload speed** – the rate at which data can be transferred from the user’s device to the internet (relevant to e.g. sharing of content over social media).
- **Latency** – the responsiveness of the network, measuring the delay of transferring data to and from the user’s device (relevant to e.g. gaming, video calls and web browsing).

These metrics reflect the activities that consumers do more of since upgrading to 4G (browsing the internet, emailing and downloading apps and music rank as the most popular activities)⁶ and the potential attractions of 4G (“surfing the web at speeds nearer to/faster than home broadband” is the biggest attraction⁷ according to YouGov research).

⁵ See further Annex 1 for the methodology that we used in relation to these metrics.

⁶ *Activities people do more of since upgrading to 4G*, YouGov Reports 4G Survey – 4G Users Sample (28 May-6 June 2014)

⁷ *Potential Attractions of 4G*, YouGov Reports 4G Survey – Nationally Representative Sample (23 May-10 June 2014)

We note that the measurements detailed above look at only one aspect of the mobile quality of experience, network performance, with factors such as tariffs, quality of voice calls⁸ and customer service also playing a part.

4G networks performed much better than 3G networks

Our results show that, on average, 4G networks performed much better than 3G networks for all four of the networks measured in the research. These differences were consistent across all mobile operators, and are unsurprising, as we would expect consumers to experience a noticeable improvement in using a mobile broadband service over a 4G network, compared to a 3G network.

Figure 2 4G and 3G fast facts (Q4 2014)

	4G	3G
Download speed		
Average speed (Mbit/s)	14.7	5.9
Probability of a speed greater than 2Mbit/s (%)	97.0	74.8
Web browsing		
Average speed (seconds) (lower is better)	0.72	1.04
Probability of a speed of less than 1 second (%)	83.4	46.7
Upload speed		
Average speed (Mbit/s)	13.6	1.6
Probability of a speed greater than 2Mbit/s (%)	93.8	30.7
Latency		
Average speed (milliseconds) (lower is better)	53.1	63.5
Probability of a speed of less than 0.1 seconds (%)	98.5	85.1

Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: For download and upload speeds, this is the average (mean) of all 4G and 3G tests, while for web browsing and latency, this is the average (median) of all 4G and 3G tests. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Download speeds

HTTP download speed is the rate at which data can be transferred from the internet to a user's device. As well as looking at the average performance results, it is useful to look at the distribution of speeds across our testing.

- EE had the highest average 4G download speed across the cities that we tested, at 18.6Mbit/s. For Vodafone it was 16.4Mbit/s, for O2 13.9Mbit/s and for Three 8.5Mbit/s.
- However, there were significant variations in the range of speeds offered by each MNO. While 37.8% of all 4G tests provided download speeds of under 10Mbit/s, 66.9% of tests for Three were in this range. This compares to 36.2% for O2, 29.9% for Vodafone and 24.8% of test samples for EE. Nearly a third of Three's download

⁸ <http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/consumer-experiences-mobile-phone-calls/>

speeds were under 5Mbit/s (31.4%), compared to 11.0% for O2, 8.7% for Vodafone and 5.8% for EE.

- Comparing results from Q2 to Q4 2014, there was no significant difference in the average 4G download speed in London, while the average 4G download speed in Edinburgh decreased by 12.5%.

Web browsing⁹

Our web browsing speed metric shows the time that it takes to load a standard web page.¹⁰ YouGov's research shows that web-browsing is the activity people do more of than any other activity after upgrading to 4G.¹¹

- Three had the fastest average web browsing speed over 4G, at 0.63 seconds. The average time taken to load a standard web page on O2's network was 0.71 seconds, while there was no significant difference between the 0.76 and 0.77 seconds recorded by Vodafone and EE respectively.
- 83.4% of our test samples provided average 4G web browsing speeds of under one second. This percentage was higher for O2 (93.1%), Vodafone (90.9%) and Three (87.6%) but lower for EE (62.9%). Nearly 30% (29.9%) of EE's web browsing test samples timed out, meaning that the web page failed to download within 15 seconds.
- While the average 4G web browsing speed in London remained unchanged between Q2 and Q4 2014, at 0.72 seconds, it improved in Edinburgh by 10.3% (down from 0.80 seconds, to 0.72 seconds) over the same period.

Upload speeds

Our HTTP upload speed test measures the rate at which data can be transferred from the user's device to the internet. Popular consumer activities such as uploading content to social media sites are directly affected by the upload speed available over mobile broadband, with "using social networking at faster speeds" being the third most popular potential attraction of upgrading to a 4G service, according to the YouGov research.¹²

- EE had the highest average 4G upload speed across the cities that we tested, at 17.6Mbit/s. This was followed by O2 and Vodafone, whose average speeds of 13.2Mbit/s and 13.1Mbit/s respectively were not significantly different, and Three with 9.4Mbit/s.
- Across all of our 4G upload speed test samples, 35.5% were under 10Mbit/s. However, over half (52.6%) of Three's upload speed test samples were under 10Mbit/s, while the figure was less than a third for each of the other MNOs (30.3% for EE, 31.4% for Vodafone and 31.5% for O2). Looking at speeds of under 5Mbit/s, 36.7% of Three's upload speed test samples were within this range, while O2, Vodafone and EE had broadly similar distributions of test samples under 5Mbit/s (11.5%, 11.8% and 12.0% respectively).

⁹ For web browsing, lower results are better. Average results also represent the median result rather than the mean.

¹⁰ For details of the web page we used, see Annex 1.

¹¹ See above n6.

¹² See above n7.

- Average 4G upload speeds increased in both London and Edinburgh between Q2 and Q4 2014, by 9.7% and 7.7 % respectively, to give an average speed of 13.2Mbit/s in each city.

Latency¹³

Latency represents the responsiveness of the network, measured by a 'ping test'; recording the time it takes for a small piece of data to travel to a point and send a response to the user's device. Strong latency performance will improve the consumer experience of video calls and real-time online gaming.

- EE had the lowest average latency on 4G, at 48.4ms. For Three it was 50.9ms, for O2 55.2ms and for Vodafone 59.5ms.
- The distribution of latency test results proved to be fairly consistent across all MNOs, with 86.2% of test samples providing 4G latency speeds of between 40 and 80 milliseconds. Individually, each MNO also saw over 80% of test samples providing latency speeds within this range.
- In London, the average 4G latency performance deteriorated by 2.0% from Q2 to Q4 2014, while in Edinburgh average latency improved by 7.5% across 4G over the same period.

See Annex 1 for further information on understanding and using these results.

1.3 Next steps

Ofcom has an ongoing programme of work focusing on the quality of mobile experience, of which mobile broadband performance plays a part. We aim to undertake further testing of mobile broadband performance in 2015, and publish our third report before the end of the year.

¹³ For latency, lower results are better. Average results also represent the median result rather than the mean.

Section 2

Introduction

2.1 Summary

The objective of this report is to help consumers understand the performance benefits of 3G versus 4G and to identify performance differences between mobile network operators' (MNO) networks, limited to the locations where services from all four MNOs are available.

Our mobile broadband performance research was designed to gather performance data on the UK's four main mobile networks, operated by EE, O2, Vodafone and Three.

The results in this report were collected between October and December 2014. Ofcom engineers measured the performance of mobile networks across five urban areas in the UK, using unbranded Samsung Galaxy Note 3 smartphones. To provide a robust comparison between 3G and 4G, our measurements were taken in locations where both 3G and 4G networks had been deployed by all four UK MNOs.

Structure of the report:

- Section 1 is the executive summary;
- Section 2 covers our regulatory duties in relation to this research, and the objectives and limitations of this research;
- Section 3 details the results of our testing, looking at average performance across all metrics included in the research, and comparing MNO performance; and
- The annexes to this report detail how to understand and use our results, the testing methodology, the statistical frameworks used to analyse the data that we have collected, and mobile coverage information.

2.2 Our regulatory duties

Ofcom's principal duty under the Communications Act 2003 (the Act), is to further the interests of citizens in relation to communication matters and to further the interests of consumers in relevant markets, where appropriate by promoting competition.

In our 2014-15 Annual Plan (the Plan), we identified *promoting effective competition and informed choice* as a key strategic purpose. Within this, one of the priorities highlighted for 2014-15 was *promoting effective choice for consumers by ensuring that clear and relevant information is readily available*.

Effective competition and informed choice are elements of well-functioning communications markets, and we consider that information about the mobile broadband performance received by 3G and 4G customers will help consumers make informed decisions, and encourage providers to improve their performance.

The Act also sets out that in performing the above duty we must have regard, in particular, to the interests of consumers in respect to choice, price, quality of service and value for money. The Act also requires us to make arrangements to find out about the experiences of consumers on issues relating to electronic communications networks and services and the

way they are provided. One way in which we do this is by carrying out research into these services. Subject to certain exceptions, we have a duty to publish the results of our research, to consider, and to such extent that Ofcom thinks fit, take account of the results in carrying out our functions.

As smartphone take-up and the availability of 4G services grow, it becomes increasingly important that consumers understand the differences between 4G and 3G mobile data services. However, we understand that data network performance is only one part of the mobile quality of experience, with factors such as coverage (see Annex 4), quality of voice calls¹⁴ and customer service also playing a part.

2.3 Objectives

The scope of this research

This research was designed to gather data that would enable us to assess the performance of mobile broadband delivered to consumer smartphones over the four UK MNOs' 4G and 3G networks. The fieldwork for this project was conducted in five UK cities in October and December 2014, with data being compiled from the results of static testing in indoor and outdoor¹⁵ (in-vehicle) locations using consumer handsets.

The five cities in which we tested were chosen from the areas where all four MNOs had launched 4G services. Our testing took place in 50 locations in each city, within a 4km radius of the mainline train station. For London, the central point was Charing Cross station. We tested in an equal number of indoor and outdoor locations to deliver a 50:50 indoor/outdoor testing ratio.

Our testing measured four metrics: download speed, web browsing speed, upload speed and latency.

Outside the scope of this research

This research concentrated on the performance of 3G and 4G networks, as delivered to smartphones, in areas where the four network operators all provided both 3G and 4G services. Factors out of scope for our research included:

- analysis of mobile broadband services delivered to other devices (such as MiFi devices, dongles and tablets);
- comparisons of network performance in urban and rural areas. (To attain a comparable sample across 3G and 4G technologies, we needed to test in areas where all operators had both 3G and 4G coverage. At the time of testing, this was restricted to predominantly urban areas);
- 3G and 4G coverage. (Coverage information is presented in this report to add context to our findings, but this was collected directly from the network operators and is separate from our measurement research);

¹⁴ <http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/consumer-experiences-mobile-phone-calls/>

¹⁵ Our outdoor testing was undertaken in a static vehicle with the handsets mounted to the interior of the window. For ease of understanding, we will be using 'outdoor' in this report to describe this element of our testing.

- the performance of mobile virtual network operators (MVNOs) and resellers;
- mobile voice, mobile messaging and 2G data services;
- drive and other forms of in-motion testing; and
- analysis of public WiFi services. (We note that WiFi services are included in some mobile broadband tariffs and can contribute to the overall quality of experience offered to a consumer).

2.4 Limitations of this research

This report focuses on the relative performance of 4G and 3G networks, in the areas in which we tested, in Q4 2014. Our research did not test coverage, call quality, text messaging or any other aspect of mobile service.

These results provide valuable insight into mobile broadband performance, but there are limitations in our research, including:

- The information presented in this report relates to mobile broadband download speeds, upload speeds, web browsing speeds and latency. Other factors relating to the consumer experience of using mobile services (such as price, traffic management policies, data allowances, customer service, billing etc.) are not covered in this report.
- To a large extent, the performance of mobile broadband services depends on network availability. Although this report includes some coverage information (see Annex 4), the research does not assess levels of network availability, which is dependent on a number of factors including distance from the base station, whether the user is inside a building or outdoors, and whether stationary or in motion.
- The number of people concurrently using a mobile network in the same location can affect service performance, and this, combined with coverage fluctuations, means that the performance available to any individual consumer will vary both by time and by location.
- This report presents information on our recorded results of mobile broadband performance in Q4 2014 in the locations in which we tested. However, the mobile operators are expanding rapidly and optimising their networks, so the speeds and general performance results set out in this report may not represent current or future performance.
- This research is limited to five cities and does not represent UK-wide performance.

Section 3

Our results: mobile broadband network performance

3.1 Introduction

This section of the report sets out the results of our testing, as outlined in Annex 1.

These results represent the network performance at the times when we tested, in the areas in which we took our measurements. Figure 3 shows the dates and locations of our Q4 2014 fieldwork. Details of our fieldwork in Q2 2014 can be found in our first report measuring mobile broadband performance in the UK.¹⁶

Figure 3 Areas and dates of our fieldwork

City	Dates of testing (inclusive)
Edinburgh	28 October to 14 November 2014
Leeds	3 to 14 November and 24 to 28 November 2014
London	28 October to 14 November and 15 to 16 December 2014
Newcastle	24 November to 12 December 2014
Poole / Bournemouth	24 November to 12 December 2014

Note: All of our test sites were chosen within a radius of 4km from the mainline train station (Charing Cross for London) in each of these cities.

To ensure a fair comparison of the four MNOs, we tested each network at the same time at each testing location. The smartphones used were all generic, unbranded and unmodified, were of identical specification and build, and were running the same operating system.

While we intended to test in areas in which all operators had 4G coverage, this was not always possible. Three's roll-out of its 4G service was still not as advanced as those of the other MNOs in Q4 2014, and there were some locations where Three's 4G network was not available. We have examined the data to ensure that no bias has been introduced into the results from this. This process is explained in detail in Annex 3 of this report. The coverage of the four networks as of March 2015 is set out in Annex 4 of this report.

We note that we tested in an equal amount of locations within a 4km radius of the city centre in each of the cities in which we did testing, and did not structure our sample framework to be representative of the geographical make-up of each city.

3.2 Average 4G and 3G HTTP download speeds

The results for HTTP download speed indicate the rate at which data can be transferred from the internet to the user's device using HTTP. This has been measured by downloading

¹⁶ <http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/broadband-speeds/mobile-bb-nov14>

a 2GB file for 30 seconds. After 30 seconds, the connection timed out and the download speed metric was calculated by dividing the amount of data received by 30, to produce a metric of megabits per second (Mbit/s).

These results show the average rate at which data could be downloaded across all of our tests. Our average results take an aggregate of all of our valid 4G and 3G results across all of the networks to produce an average for each technology. The second set of results looks at the average speed of each of the networks in the areas tested, and the distribution of speeds by test sample for each network across 4G and 3G. We also compare our Q4 2014 results with those from Q2 2014 in London and Edinburgh.

Information on how we have processed the raw data from our tests is included in Annex 3 of this report.

4G download speeds were significantly faster than 3G download speeds

On average, across all of the networks in the five cities where we tested, the overall 4G download speed (14.7Mbit/s) was around 2.5 times faster than the 5.9Mbit/s average 3G download speed (Figure 4).

As we tested across some different cities in Q2 and Q4 2014, the overall average results below are not directly comparable to those included in the report covering Q2 2014.

Figure 4 Average 4G and 3G HTTP download speeds, overall: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: Average (mean) of all 4G tests and all 3G tests. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Among the cities where we tested, the highest average 4G download speeds were in Poole/Bournemouth and Newcastle

Averaging the results for all of the networks in each of the cities where we tested shows that the highest average speeds for 4G were in Poole/Bournemouth and in Newcastle, at 15.6Mbit/s and 15.3Mbit/s respectively (with no statistically significant difference between these speeds). The highest average 3G speed among our cities was the 7.1Mbit/s measured in Edinburgh (Figure 5). The lowest average speeds for both 4G and 3G were in London, which had an average 4G download speed of 13.2Mbit/s and an average 3G download speed of 4.4Mbit/s.

Figure 5 Average 4G and 3G HTTP download speeds, by test location: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: Average (mean) of all 4G tests and all 3G tests, by test location. As we tested across some different cities in Q2 and Q4 2014, the total average results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 6 Average 4G and 3G download speeds, by test location: significant differences

	4G faster than:	3G faster than:
Edinburgh	London	Leeds, London, Newcastle, Poole/Bournemouth
Leeds	London	Poole/Bournemouth, London
London	-	-
Newcastle	Edinburgh, Leeds, London	Leeds, London, Poole/Bournemouth
Poole / Bournemouth	Edinburgh, Leeds, London	London

Source: Ofcom
 Note: Differences are significant to a 95% confidence level.

3.3 HTTP download speed on 4G and 3G, by network

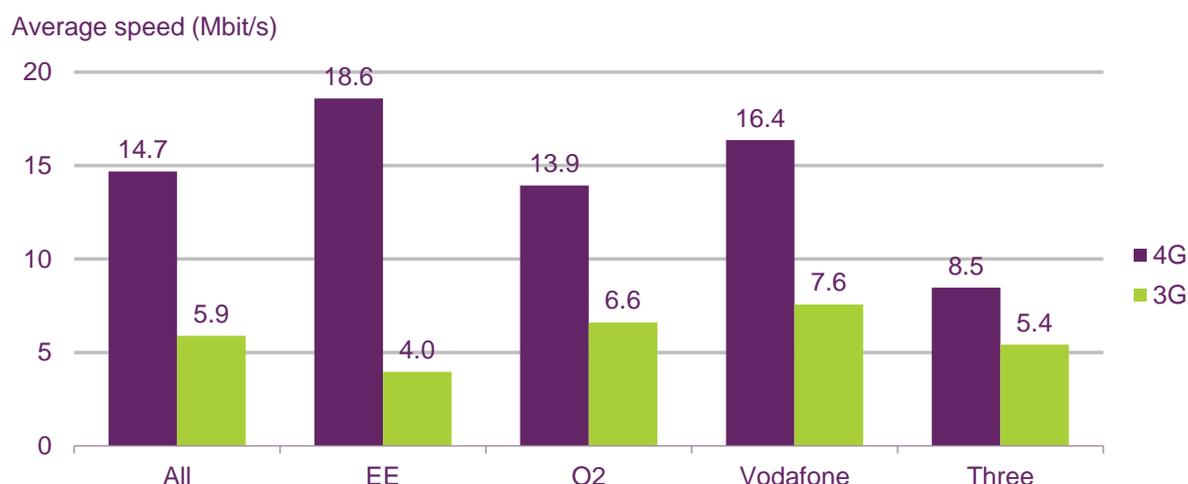
EE had the fastest average download speed in the areas where we tested

The MNO with the fastest average 4G download speed recorded across all of the sample sites in our testing was EE, at 18.6Mbit/s (Figure 7).

Three had the lowest average 4G download speed across the five cities where we tested, at 8.5Mbit/s. For Vodafone, the average 4G download speed was 16.4Mbit/s and for O2 it was 13.9Mbit/s. For EE, O2 and Vodafone, the average 4G download speeds, in the areas where we tested, were more than twice the average 3G speeds.

For 3G download speeds, Vodafone had the fastest average speed with 7.6Mbit/s, followed by O2, which recorded 6.6Mbit/s. The average speed on 3G for Three, at 5.4Mbit/s, was faster than for EE, at 4.0Mbit/s.

Figure 7 Average 4G and 3G HTTP download speeds, by provider: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: Average (mean) of all 4G tests and all 3G tests, by operator. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 8 Average 4G and 3G HTTP download speeds, by provider: significant differences

	4G faster than:	3G faster than:
EE	O2, Vodafone, Three	-
O2	Three	EE, Three
Vodafone	O2, Three	EE, O2, Three
Three	-	EE

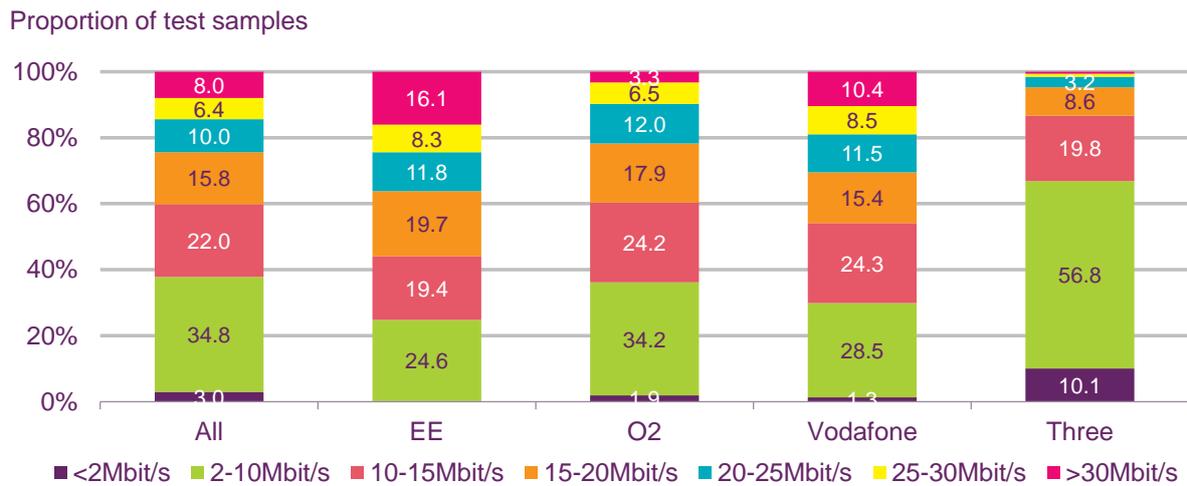
Source: Ofcom
 Note: Differences are significant to a 95% confidence level.

EE and Vodafone had the highest proportion of test samples with a 4G download speed above 30Mbit/s

The distribution of 4G download speeds by network is set out in Figure 9. Three was the only one of our four MNOs for which the majority of 4G download speeds (66.9%) recorded in our testing were under 10Mbit/s. EE (16.1%) and Vodafone (10.4%) had the greatest percentage of test locations showing average download speeds faster than 30Mbit/s. For O2, 29.9% of test samples produced speeds between 15Mbit/s and 25Mbit/s.

Further analysis of the distribution of download speeds over 4G can be found in the chart pack accompanying this report.

Figure 9 Distribution of 4G HTTP download speeds, by network: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Vodafone had the largest proportion of 3G download speeds higher than 2Mbit/s

Vodafone had the largest proportion of 3G download speeds higher than 2Mbit/s, at 81.5%, followed by O2, at 76.4%, Three at 72.2% and EE at 69.0% (Figure 10).

Further analysis of the distribution of download speeds over 3G can be found in the chart pack accompanying this report.

Figure 10 Distribution of 3G HTTP download speeds, by network: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

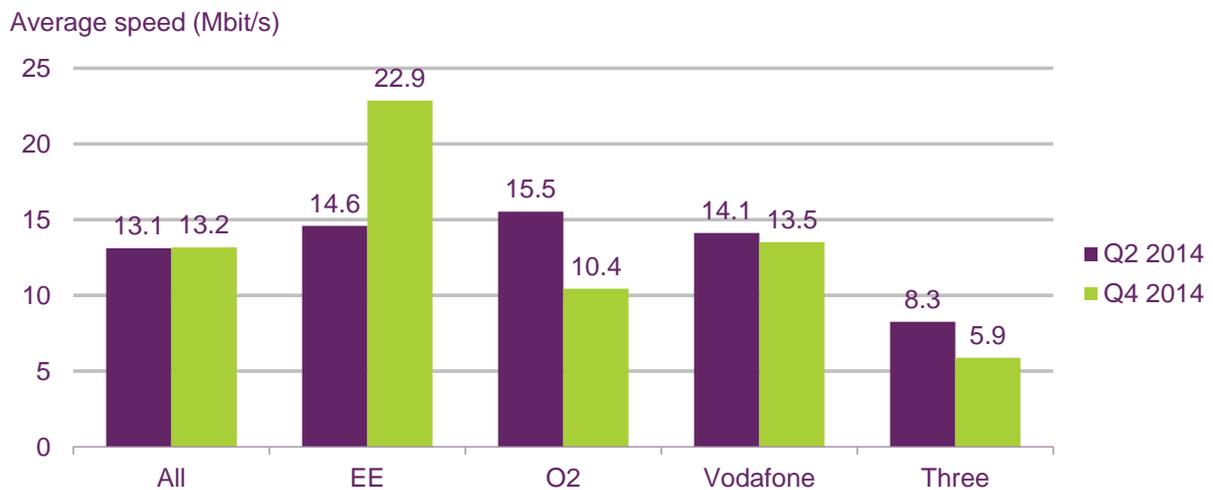
3.4 HTTP download speed on 4G and 3G: London and Edinburgh

There was no statistically significant difference in the overall average 4G download speeds in London between Q2 and Q4 2014

In London, the overall average 4G download speed of 13.2Mbit/s in Q4 2014 was not significantly different to the 13.1Mbit/s average speed recorded in Q2 2014 (Figure 11).

EE was the only network to see an increase in download speeds in London between Q2 and Q4 2014 (up by 56.6% from 14.6Mbit/s to 22.9Mbit/s). Vodafone's 4G average speed in London in Q4, at 13.5Mbit/s, was not significantly different from the 14.1Mbit/s average in Q2 2014. O2 saw a 32.8% (5.1Mbit/s) drop in average 4G download speed over the same period. Three also had a decrease in average download speed, down by 28.8% to 5.9Mbit/s from Q2 to Q4 2014.

Figure 11 Average 4G HTTP download speeds, by provider, in London



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 12 Average 4G HTTP download speeds, by provider, in London: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Faster	Three	O2, Vodafone, Three
O2	Slower	EE, Vodafone, Three	Three
Vodafone	No significant difference	Three	O2, Three
Three	Slower	-	-

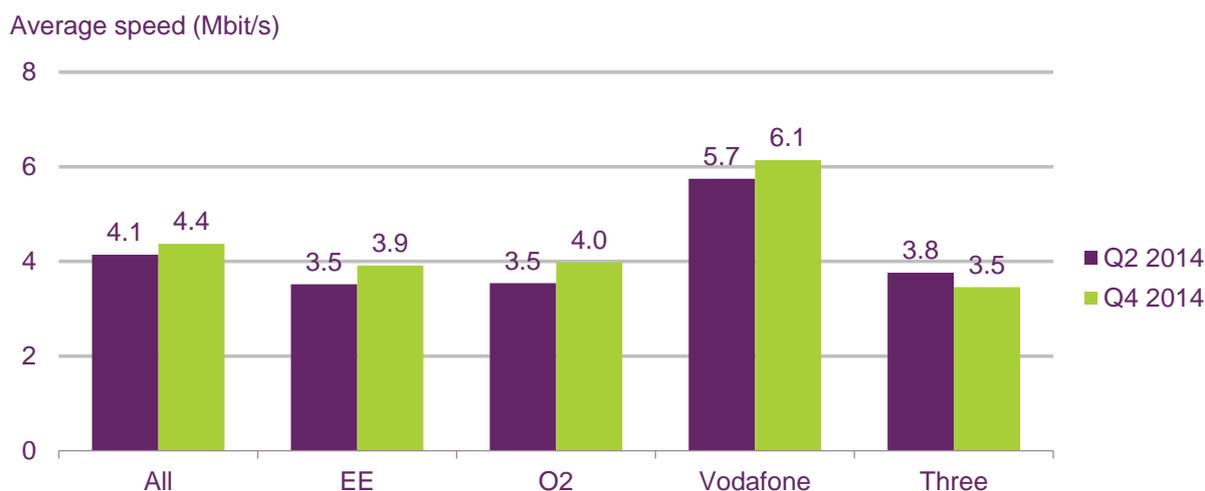
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Total average 3G download speed increased by 5.6% in London between Q2 and Q4 2014

The average 3G download speed across all MNOs increased by 5.6% in London, from 4.1Mbit/s to 4.4Mbit/s, between Q2 and Q4 2014 (Figure 13). Almost all MNOs experienced increases in their average download speeds over this period (EE up 11.2%, O2 up 12.4% and Vodafone up 6.9%), with the exception of Three, which saw no statistically significant change between Q2 and Q4 2014.

Figure 13 Average 3G HTTP download speeds, by provider, in London



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 14 Average 3G HTTP download speeds, by provider, in London: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	Faster	-	Three
O2	Faster	-	Three
Vodafone	Faster	EE, O2, Three	EE, O2, Three
Three	No significant difference	-	-

Source: Ofcom

Note: Differences are significant to a 95% confidence level.

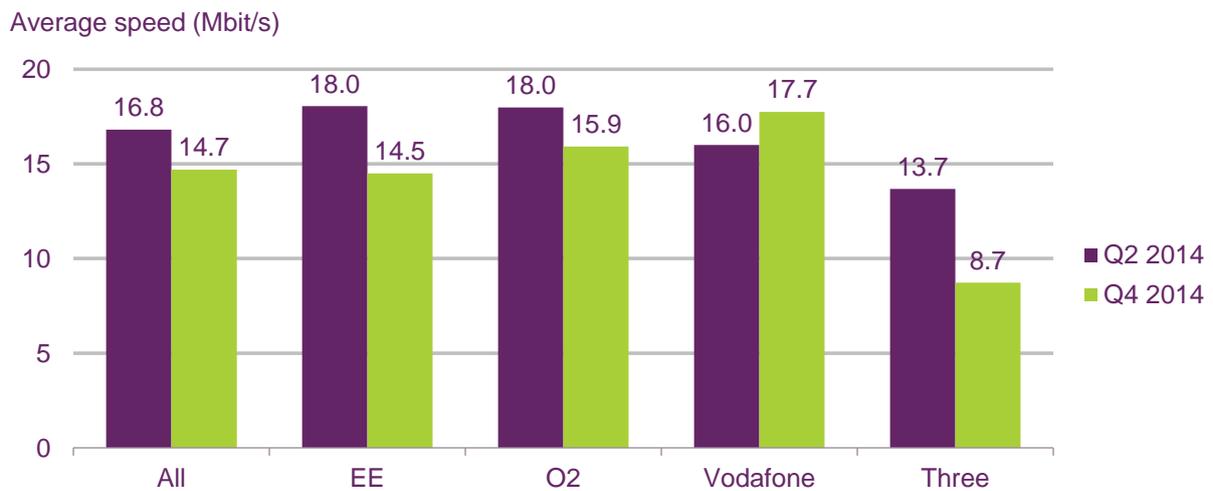
In Edinburgh, the total average 4G download speed decreased by 12.5%

In Edinburgh, there was a 12.5% decrease in the average 4G download speed across all operators between Q2 and Q4 2014, down from 16.8Mbit/s to 14.7Mbit/s (Figure 15).

Vodafone was the only MNO to see an increase in average 4G download speed in Edinburgh; from Q2 to Q4 2014 (up by 10.9% to 17.7Mbit/s). All other MNOs had decreases

in average 4G download speeds in Q4 2014 compared to Q2 2014, with Three experiencing the largest fall of 36.2% (5.0Mbits).

Figure 15 Average 4G HTTP download speeds, by provider, in Edinburgh



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 16 Average 4G HTTP download speeds, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Slower	Vodafone, Three	Three
O2	Slower	Vodafone, Three	EE, Three
Vodafone	Faster	Three	EE, O2, Three
Three	Slower	-	-

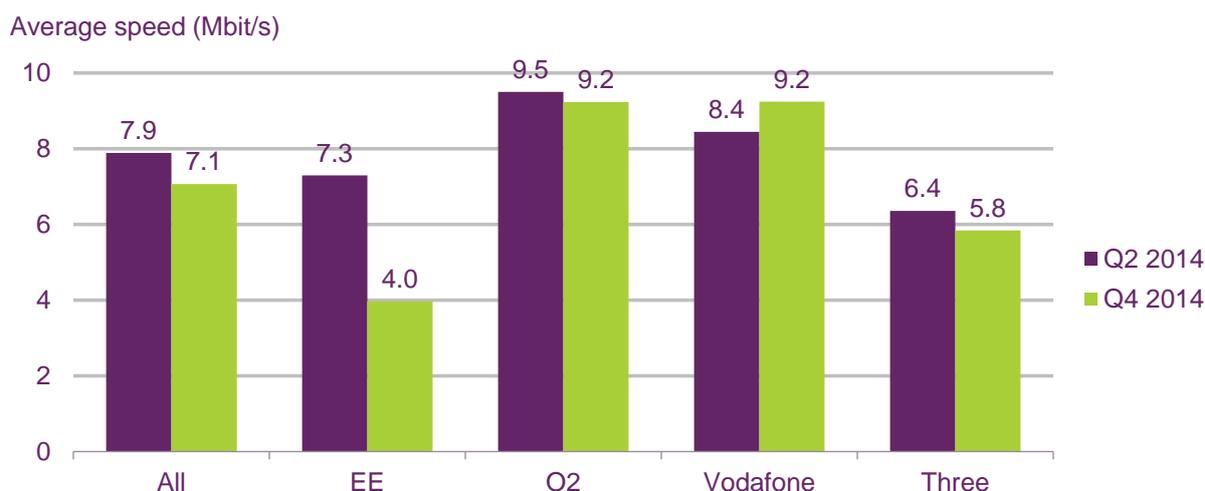
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Total average 3G download speed in Edinburgh fell by 10.4% between Q2 and Q4 2014

The average 3G download speed across all MNOs fell by 10.4% in Edinburgh between Q2 and Q4 2014, down from 7.9Mbit/s to 7.1Mbit/s (Figure 17). Vodafone was the only MNO to experience an increase in download speed over this period, with its average 3G download speed rising by 9.4% to 9.2Mbit/s. EE's average download speed decreased by 45.6% over the same period, while O2 had no significant change. Three saw its average 3G download speed fall over this period, by 8.2% to 5.8Mbit/s.

Figure 17 Average 3G HTTP download speeds, by provider, in Edinburgh



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 18 Average 3G HTTP download speeds, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	Slower	Three	-
O2	No significant difference	EE, Vodafone, Three	EE, Three
Vodafone	Faster	EE, Three	EE, Three
Three	Slower	-	EE

Source: Ofcom

Note: Differences are significant to a 95% confidence level.

3.5 Web browsing speed on 4G and 3G as an overall average

The results for web browsing speed indicate the time that it takes to completely load a web page. This has been measured by downloading an ETSI standard mKepler web page and recording the length of time that this took to complete.

These results show the average time in which a web page could be completely loaded across all of our tests, measured in seconds. The first results take an aggregate of all of our valid 4G and 3G results across all of the networks to produce an average for each technology. The second set of results for web browsing speed look at the average speed of each of the networks in the areas in which we tested, for each network across 4G and 3G. Our final set of results compares the performance between Q2 2014 and Q4 2014 in London and Edinburgh.

The results for web browsing followed a non-standard statistical distribution, so the averages below are calculated as the median rather than the mean. Using the median in a skewed distribution reduces the effect of a small number of high or low results influencing the averages.

Information on how we have processed the raw data from our tests is included in Annex 3 of this report.

The time taken to load a web page was lower on 4G than on 3G

The average time taken to completely load a standard web page on 4G was 0.72 seconds, compared to 1.04 seconds over 3G (Figure 19).

As we tested across some different cities in Q2 and Q4 2014, the overall average results below are not directly comparable to those included in the report covering Q2 2014.

Figure 19 Average 4G and 3G web browsing speeds overall: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

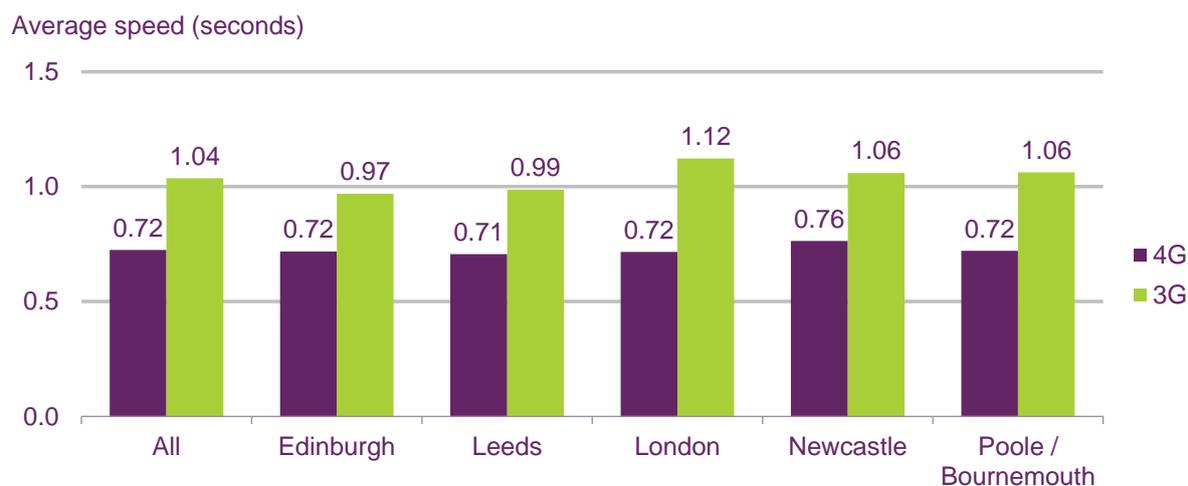
Note: Average (median) of all 4G tests and all 3G tests. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Leeds had the fastest 4G web browsing speed while London had the slowest 3G web browsing speed

Across all of the networks and the cities that we tested, our results show that Leeds had the fastest average 4G web browsing speed, taking an average of 0.71 seconds to load a standard web page (Figure 20). The slowest average 4G web browsing speed was in Newcastle, where it took an average of 0.76 seconds to load a web page. Edinburgh, London and Poole/Bournemouth all had average 4G browsing speeds of 0.72 seconds.

The fastest average 3G web browsing speeds were in Edinburgh and Leeds, at 0.97 seconds and 0.99 seconds respectively, with no statistically significant difference between the two average speeds. The slowest average 3G web browsing speed was recorded in London, where it took 1.12 seconds to load a standard web page.

Figure 20 Average 4G and 3G web browsing speed, by test location: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: Average (median) of all 4G tests and all 3G tests, by test location. As we tested across some different cities in Q2 and Q4 2014, the total average results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 21 Average time taken to load a web page on 4G and 3G, by test location: significant differences

	4G faster than:	3G faster than:
Edinburgh	Newcastle	London, Newcastle, Poole/Bournemouth
Leeds	Edinburgh, London, Newcastle, Poole/Bournemouth	London, Newcastle, Poole/Bournemouth
London	Newcastle	-
Newcastle	-	London
Poole / Bournemouth	Newcastle	London

Source: Ofcom
 Note: All differences are calculated to a 95% confidence level.

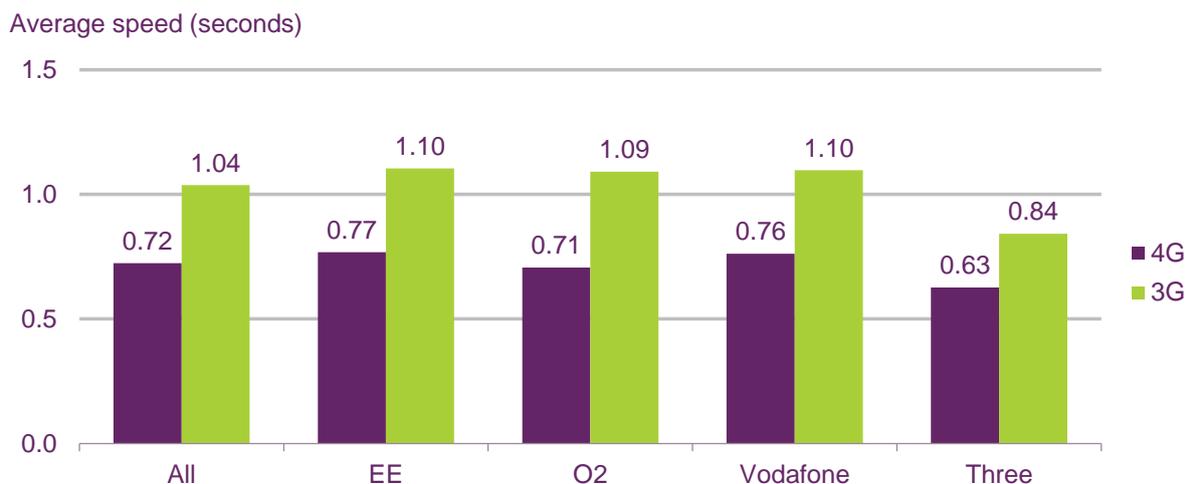
3.6 Web browsing speed on 4G and 3G, by network

Three recorded the fastest time to load a web page, both on 4G and 3G

The time taken to load a standard web page on 4G for Three was 0.63 seconds, the fastest of all the networks we tested (Figure 22). O2 had the second fastest 4G web browsing speed at 0.71 seconds, while there was no statistically significant difference between the browsing speeds of EE and Vodafone (at 0.77 seconds and 0.76 seconds respectively).

Three's 3G web browsing speed, at 0.84 seconds, was also the fastest that we tested and the only average less than a second across all of the networks. There was no statistically significant difference between the average 3G web browsing speeds on the other three networks; the overall average 3G browsing speed across all four networks was 1.04 seconds.

Figure 22 Average 4G and 3G web browsing speed, by provider: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: Average (median) of all 4G tests and all 3G tests, by operator. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 23 Average 4G and 3G web browsing speeds, by provider: significant differences

	4G faster than:	3G faster than:
EE	-	-
O2	EE, Vodafone	-
Vodafone	-	-
Three	EE, O2, Vodafone	EE, O2, Vodafone

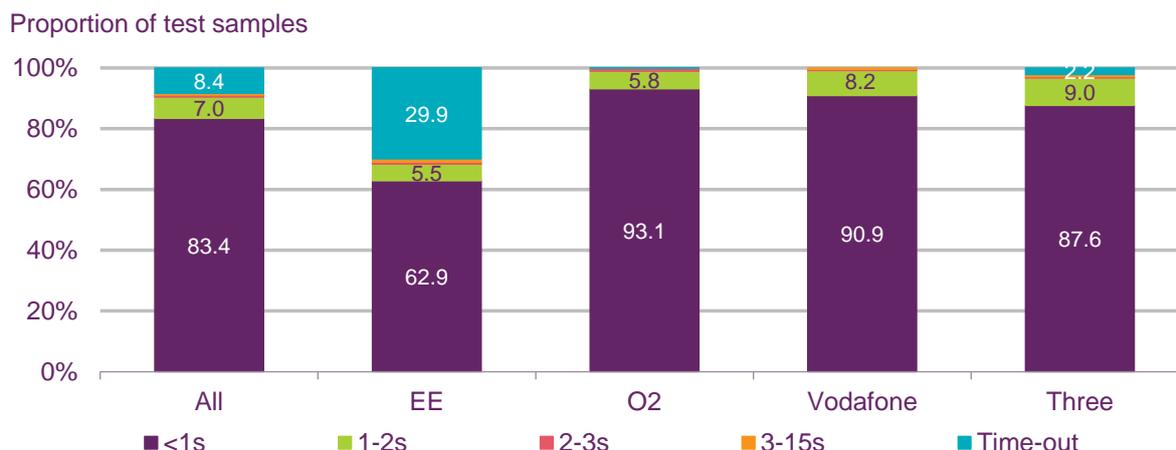
Source: Ofcom
 Note: All differences are calculated to a 95% confidence level.

Across all four MNOs, 83.4% of all 4G test samples provided a web browsing speed of less than a second

For O2 (93.1%), Vodafone (90.9%) and Three (87.6%), over 85% of the test samples resulted in a 4G web browsing speed of less than a second (Figure 24). This figure was 62.9% for EE, with the web page failing to download within 15 seconds during 29.9% of our test samples.

Further analysis of the distribution of web browsing speeds over 4G can be found in the chart pack accompanying this report.

Figure 24 Distribution of 4G web browsing speeds, by network: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance. The tests timed out when the web page failed to download after 15 seconds.

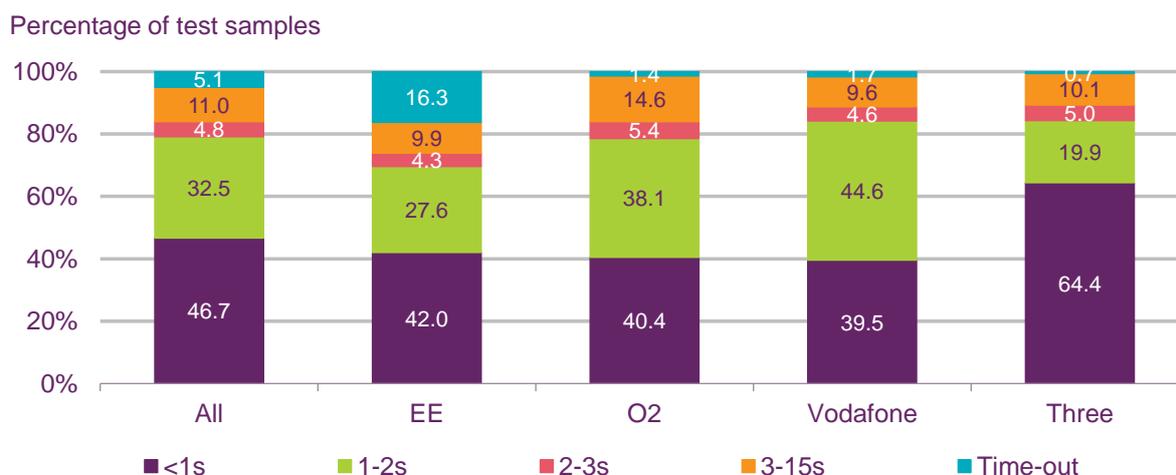
Three’s 3G web browsing speed was less than one second for 64.4% of our test samples

Across all 3G networks, 46.7% of our test samples provided a web browsing speed of less than one second, with another 32.5% providing browsing speeds between one and two seconds (Figure 25). Three had the largest proportion of 3G web browsing speeds that were less than one second, with 64.4% of our test samples producing such a result, followed by EE at 42.0%.

EE had the largest proportion of test samples where the web page failed to download within 15 seconds over a 3G connection, at 16.3%. This happened for less than 2% of the test samples for each of the other three MNOs.

Further analysis of the distribution of web browsing speeds over 3G can be found in the chart pack accompanying this report.

Figure 25 Distribution of 3G web browsing speeds, by network: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance. The tests timed out when the web page failed to download after 15 seconds.

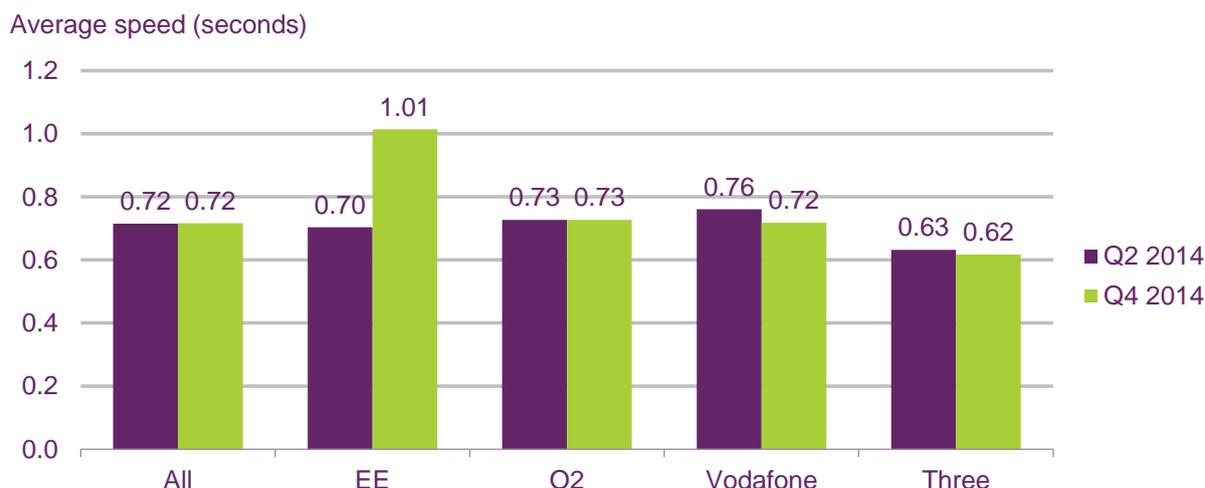
3.7 Web browsing speed on 4G and 3G: London and Edinburgh

Total average 4G web browsing speed in London was unchanged, at 0.72 seconds, in Q4 2014

In London, there was no statistically significant difference between the average 4G web browsing speeds in Q2 2014 and Q4 2014, both at 0.72 seconds (Figure 26). EE saw the most significant change in results over this period; its average web browsing speed was slower (at 1.01 seconds (up by 44.0%) in Q4 2014) than the 0.70 seconds recorded in Q2 2014.

Vodafone and Three recorded faster average web browsing speeds in Q4 2014 than in Q2 (down by 5.7% and 2.4% respectively), while O2 had no statistically significant change over the same period.

Figure 26 Average 4G web browsing speeds, by provider, in London (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 27 Average 4G web browsing speeds, by provider, in London: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Slower	O2, Vodafone	-
O2	No significant difference	Vodafone	EE
Vodafone	Faster	-	EE
Three	Faster	EE, O2, Vodafone	EE, O2, Vodafone

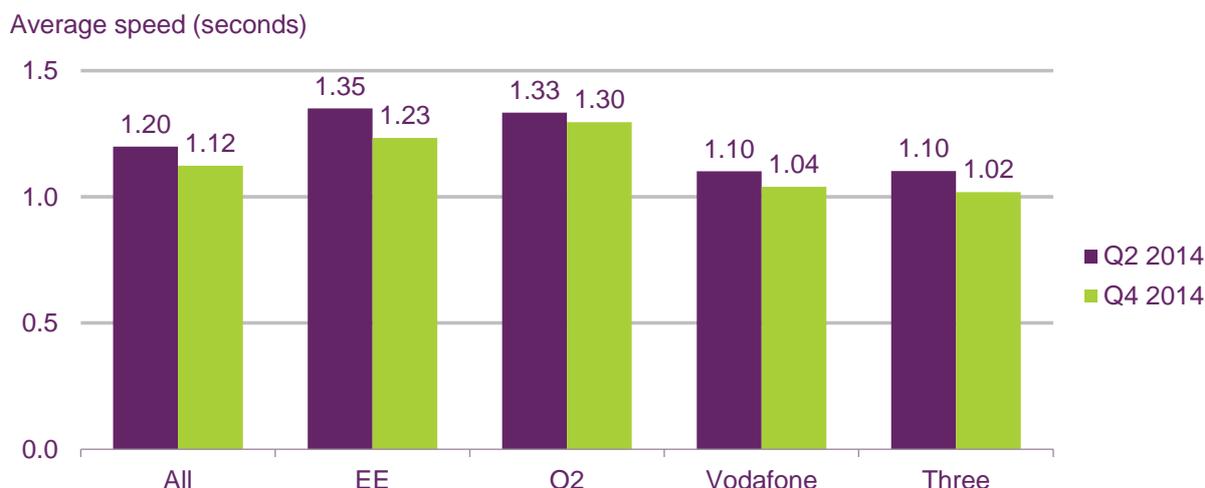
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

The overall average 3G web browsing speed in London was faster in Q4 than in Q2 2014

The overall average web browsing speed over 3G in London was faster in Q4 2014, at 1.12 seconds (down by 6.3%), than the 1.20 seconds recorded in Q2 2014 (Figure 28). Individually, each MNO had faster average 3G web browsing speeds in London in Q4 2014, with the exception of O2, which experienced no statistically significant change (EE down 8.7%, Vodafone down 5.5%, Three down 7.5%).

Figure 28 Average 3G web browsing speeds, by provider, in London (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 29 Average 3G web browsing speeds, by provider, in London: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	Faster	-	-
O2	No significant difference	-	-
Vodafone	Faster	EE, O2	EE, O2
Three	Faster	EE, O2	EE, O2

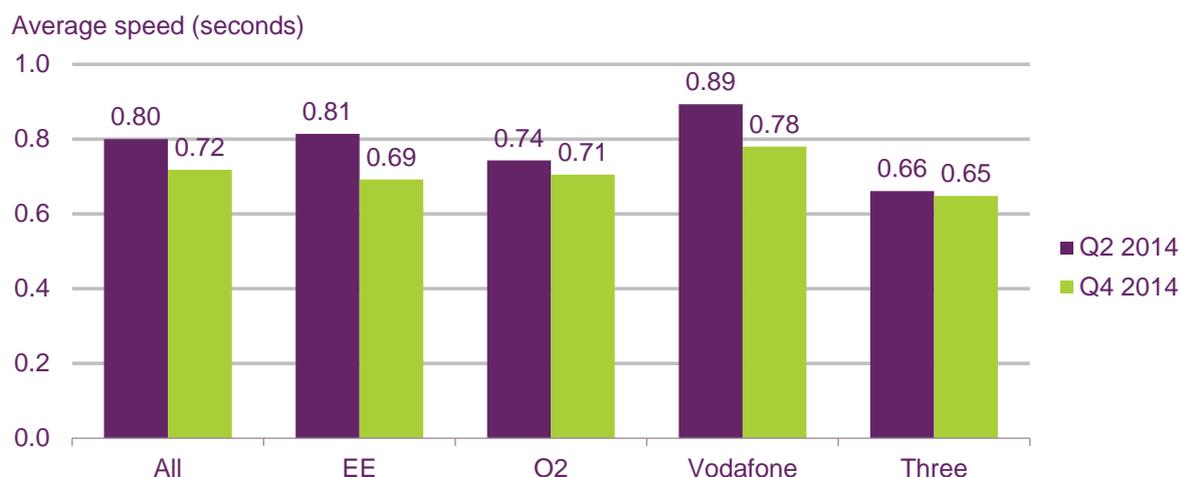
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

In Edinburgh, the overall average 4G web browsing speed was more than 10% faster in Q4 2014 than in Q2 2014

In Edinburgh, the overall average 4G web browsing speed in Q4 2014 was 0.08 seconds faster (down by 10.3% at 0.72 seconds) than the average of 0.80 seconds in Q2 2014 (Figure 30). Individually, each MNO experienced faster web browsing speeds in Q4 2014 than in Q2 2014, with the exception of Three, which had no statistically significant change in the average web browsing speed over the same period.

Figure 30 Average 4G web browsing speeds, by provider, in Edinburgh (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 31 Average 4G web browsing speeds, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Faster	Vodafone	Vodafone
O2	Faster	EE, Vodafone	Vodafone
Vodafone	Faster	-	-
Three	No significant difference	EE, O2, Vodafone	O2, Vodafone

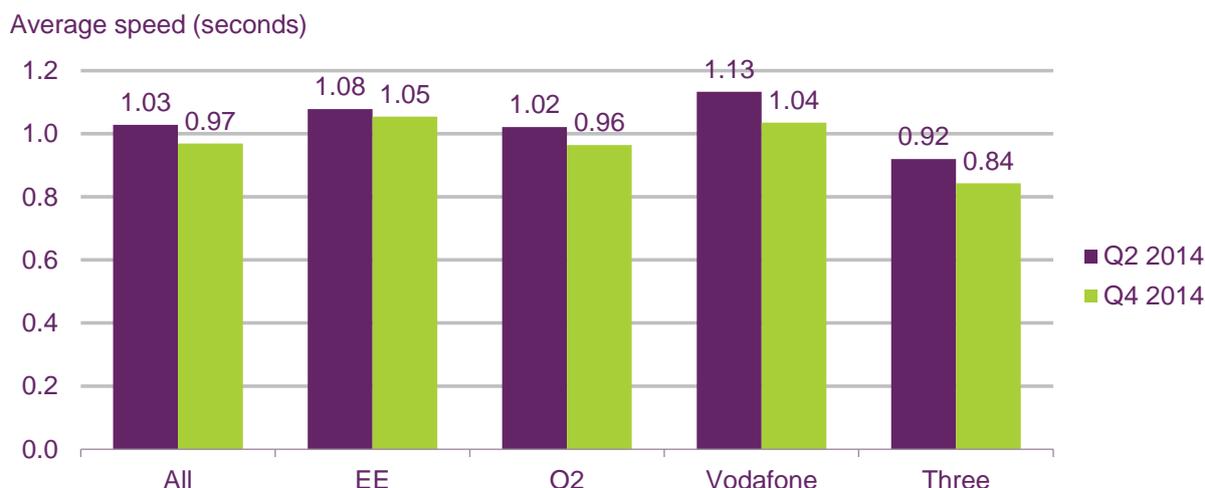
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Average 3G web browsing speed improved in Edinburgh between Q2 and Q4 2014

Similar improvements can be seen in the comparative results for web browsing speed over 3G in Edinburgh, with both the overall average speed and the average speeds for O2, Vodafone and Three being faster in Q4 2014 than in Q2 2014 (Figure 32). EE's results were not significantly different over the same period.

Figure 32 Average 3G web browsing speeds, by provider, in Edinburgh (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 33 Average 3G web browsing speeds, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	No significant difference	-	-
O2	Faster	EE, Vodafone	EE, Vodafone
Vodafone	Faster	-	-
Three	Faster	EE, O2, Vodafone	EE, O2, Vodafone

Source: Ofcom

Note: Differences are significant to a 95% confidence level.

3.8 HTTP upload speed on 4G and 3G as an overall average

The results for HTTP upload speed indicate the rate at which data can be transferred from the user's device using HTTP. This has been measured by uploading 100MB of data from the device for 15 seconds. The volume of data uploaded is then divided by the time taken, producing a metric of megabits per second (Mbit/s).

These results show the average rate at which data could be uploaded across all of our tests. The first results take an aggregate of all of our valid 4G and 3G results across all of the networks and locations, to produce an average for each technology. The second set of results for upload speed look at the average speed of each of the networks in the areas where we tested, and the distribution of recorded speeds for each network across 4G and 3G. Finally, we look at the performance changes between Q2 2014 and Q4 2014 in London and Edinburgh.

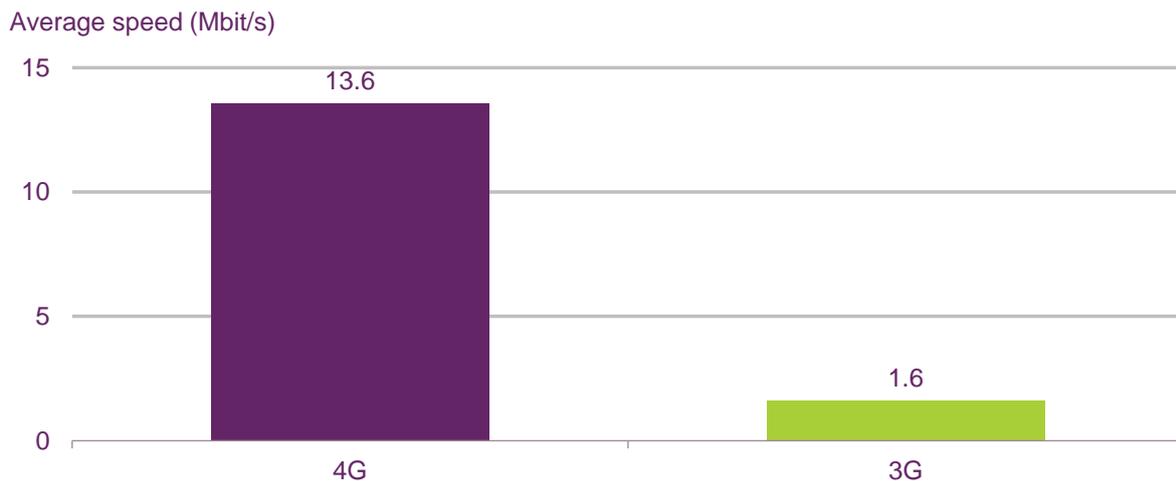
Information on how we have processed the raw data from our tests is included in Annex 3 of this report.

4G upload speeds were more than eight times faster than those over 3G

Across all of the networks in the five cities where we tested, the overall average 4G upload speed was significantly faster than the average 3G upload speed (Figure 34). The average 4G upload speed was 13.6Mbit/s, while the average 3G upload speed was 1.6Mbit/s.

As we tested across some different cities in Q2 and Q4 2014, the overall average results below are not directly comparable to those included in the report covering Q2 2014.

Figure 34 Average 4G and 3G HTTP upload speeds, overall: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: Average (mean) of all 4G tests and all 3G tests. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

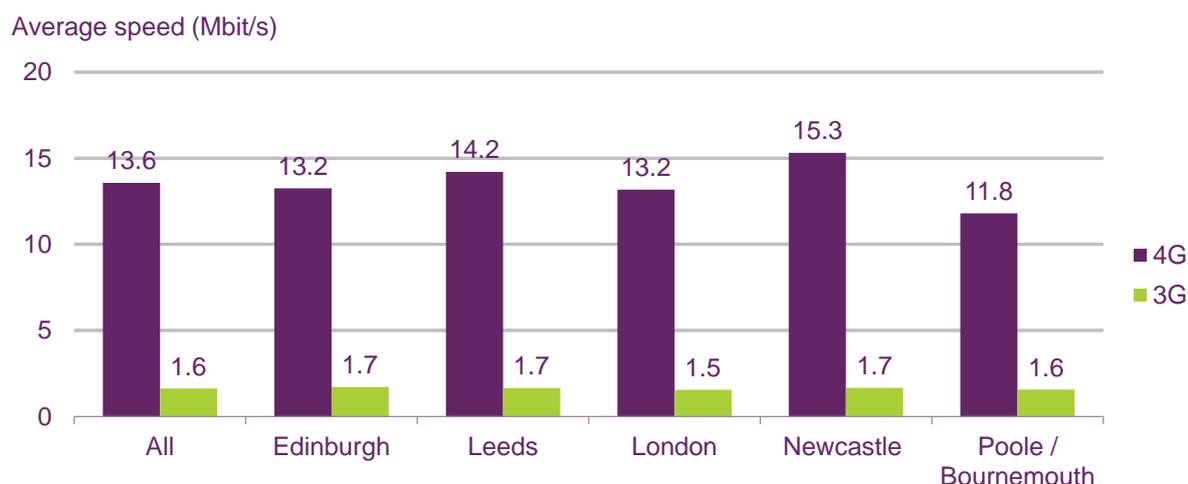
Newcastle had the highest average 4G upload speed among the five cities we tested

Averaging the results for all of the networks in each of the cities where we tested shows that the highest average 4G upload speed was in Newcastle, at 15.3Mbit/s, while our test locations in Poole/Bournemouth had the lowest average 4G upload speeds, at 11.8Mbit/s (Figure 35).

Edinburgh had the fastest average 3G upload speed of all our cities, with Leeds and Newcastle having an average upload speed only marginally less.¹⁷ London and Poole/Bournemouth had the lowest average 3G upload speeds.

¹⁷ See Figure 36.

Figure 35 Average 4G and 3G HTTP upload speeds, by test location: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: Average (mean) of all 4G tests and all 3G tests, by test location. As we tested across some different cities in Q2 and Q4 2014, the total average results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 36 Average 4G and 3G HTTP upload speeds, by test location: significant differences

	4G faster than:	3G faster than:
Edinburgh	Poole/Bournemouth	Leeds, London, Newcastle, Poole/Bournemouth
Leeds	Edinburgh, London, Poole/Bournemouth	London, Poole/Bournemouth
London	Poole/Bournemouth	-
Newcastle	Edinburgh, Leeds, London, Poole/Bournemouth	London, Poole/Bournemouth
Poole / Bournemouth	-	-

Source: Ofcom

Note: Differences are significant to a 95% confidence level. Although our 3G figures show Edinburgh, Leeds and Newcastle as having average speeds of 1.7Mbit/s, our significant difference testing shows Edinburgh as being faster than Leeds and Newcastle, when looking at the test results to multiple decimal places (1.72, 1.66 and 1.65 respectively).

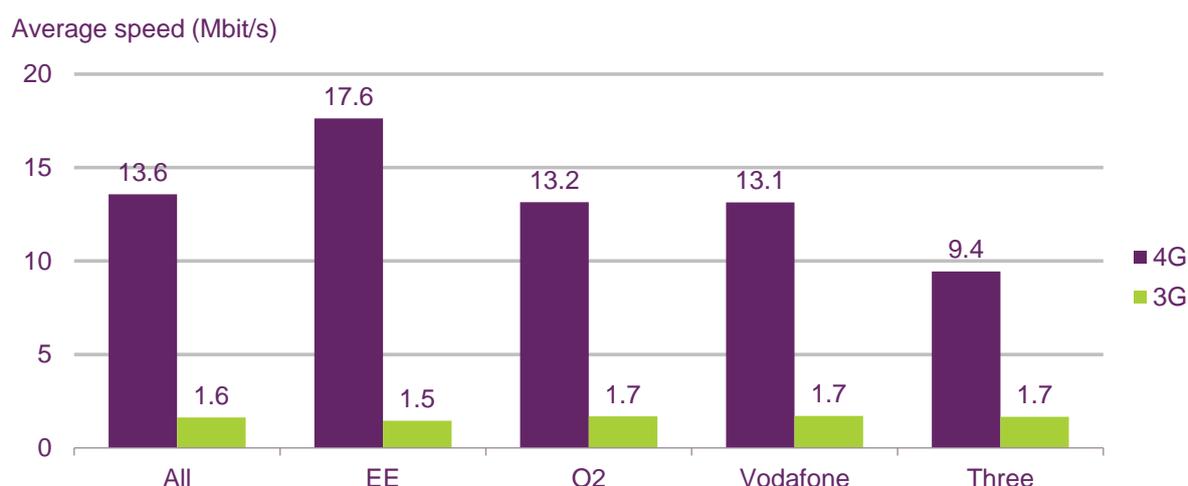
3.9 HTTP upload speed on 4G and 3G, by network

EE had the highest average 4G upload speed in the areas where we tested

EE's upload speeds over 4G were the highest of the four networks, at 17.6Mbit/s. (Figure 37). O2 and Vodafone recorded upload speeds of 13.2Mbit/s and 13.1Mbit/s respectively (no statistically significant difference), while Three had an average upload speed of 9.4Mbit/s.

There was less variation between the MNOs for average 3G upload speeds than there was for average 4G upload speeds; the 1.7Mbit/s average 3G upload speeds recorded for Vodafone, O2 and Three were faster than the 1.5Mbit/s average for EE.

Figure 37 Average 4G and 3G HTTP upload speeds, by provider: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: Average (mean) of all 4G tests and all 3G tests, by operator. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 38 Average 4G and 3G HTTP upload speeds, by provider: significant differences

	4G faster than:	3G faster than:
EE	O2, Vodafone, Three	-
O2	Three	EE
Vodafone	Three	EE, Three
Three	-	EE

Source: Ofcom
 Note: All differences are calculated to a 95% confidence level. Although our 3G figures show Vodafone and Three as having average speeds of 1.7Mbit/s, our significant difference testing shows Vodafone as being faster than Three when looking at the test results to multiple decimal places (1.71Mbit/s compared to 1.66Mbit/s).

Nearly two-thirds (64.5%) of test samples provided 4G upload speeds higher than 10Mbit/s

Three had the lowest proportion of test samples where its 4G upload speed was higher than 10Mbit/s in our testing, with 47.4% falling into this category (Figure 39). This compared to 69.7% for EE, 68.7% for Vodafone and 68.5% for O2.

EE recorded more 4G test speeds greater than 25Mbit/s than any of the other MNOs, at 27.5%. This compared to 0.1% for each of the other MNOs respectively.

Further analysis of the distribution of upload speeds over 4G can be found in the chart pack accompanying this report.

Figure 39 Distribution of 4G HTTP upload speeds, by network: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

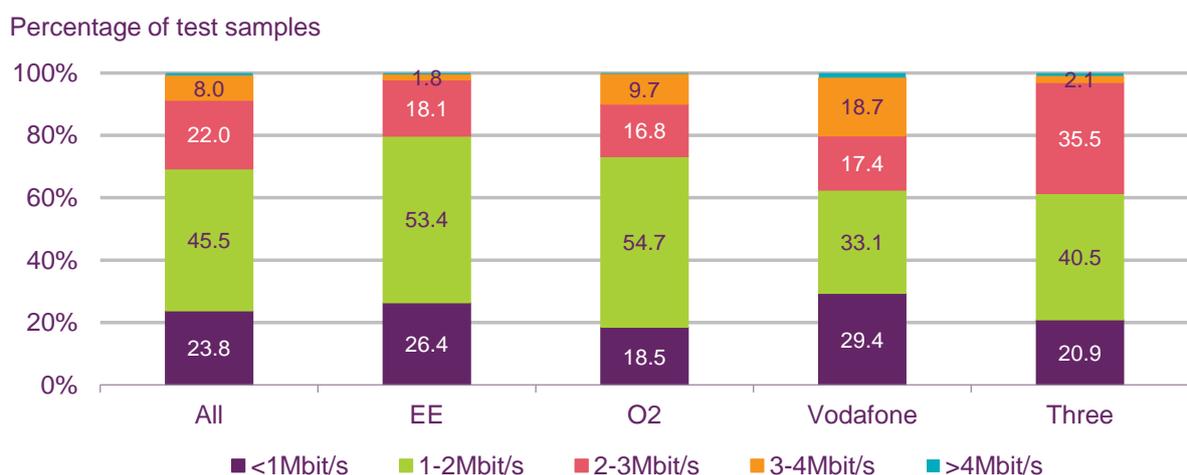
Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Over 90% of our 3G upload speed test samples were under 3Mbit/s across all four MNOs

Upload speeds over 3G were significantly lower than on 4G, with 91.3% of our test samples being under 3Mbit/s (Figure 40). Vodafone had the highest proportion of 3G upload speeds higher than 3Mbit/s (20.1%) and lower than 1Mbit/s (29.4%) among the four MNOs.

Further analysis of the distribution of upload speeds over 3G can be found in the chart pack accompanying this report.

Figure 40 Distribution of 3G HTTP upload speeds, by network: Q4 2014



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

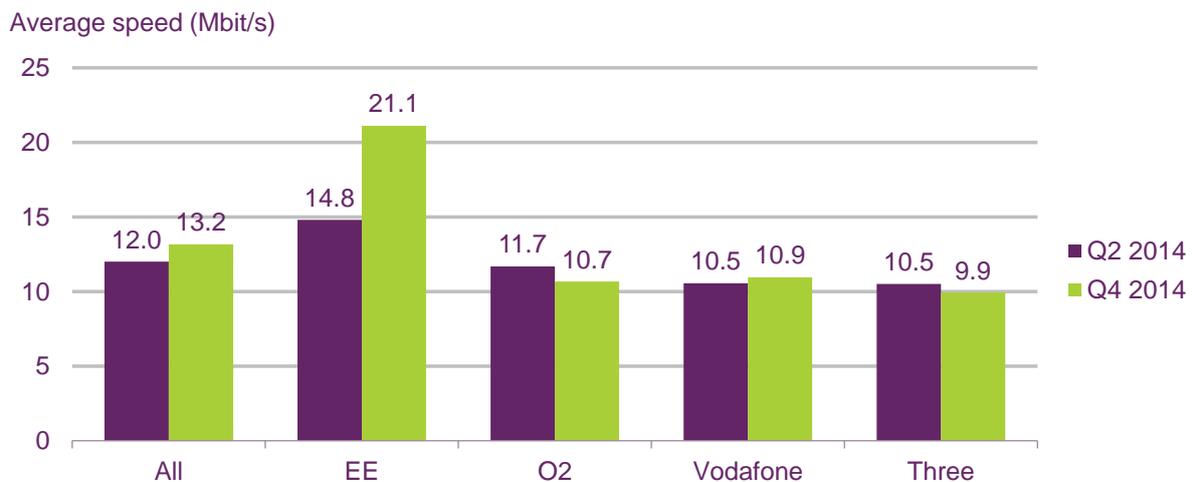
3.10 HTTP upload speed on 4G and 3G: London and Edinburgh

There was a 9.7% increase in overall average 4G upload speed in London between Q2 and Q4 2014

Overall average 4G upload speed across all MNOs increased by 9.7% (1.2Mbit/s) in London between Q2 and Q4 2014, up from 12.0Mbit/s to 13.2Mbit/s (Figure 41). This was driven by the 42.6% (6.3Mbit/s) increase in average upload speeds for EE over this period and a smaller, 3.8% (0.4Mbit/s), increase for Vodafone.

In contrast, O2 and Three recorded slightly slower average upload speeds in London in Q4 2014 than in Q2 (O2 down 8.7%, Three down 5.4%).

Figure 41 Average 4G HTTP upload speeds, by provider, in London



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 42 Average 4G HTTP upload speeds, by provider, in London: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Faster	O2, Vodafone, Three	O2, Vodafone, Three
O2	Slower	Vodafone, Three	Three
Vodafone	Faster	-	Three
Three	Slower	-	-

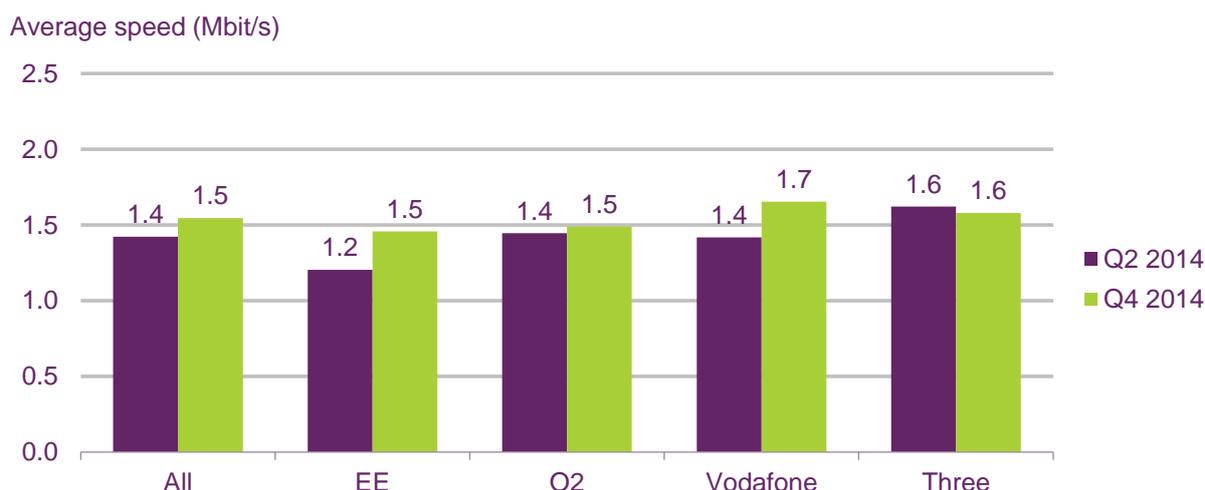
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Overall average 3G upload speed increased by 8.9% in London between Q2 and Q4 2014

There was an 8.6% (0.1Mbit/s) increase in the average 3G upload speed in London between Q2 and Q4 2014 (Figure 43). EE and Vodafone both saw increases in their average 3G upload speed over the same period (up 21.1% and 16.6% respectively), while O2 and Three experienced no statistically significant change.

Figure 43 Average 3G HTTP upload speeds, by provider, in London



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 44 Average 3G HTTP upload speeds, by provider, in London: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	Faster	-	-
O2	No significant difference	EE	-
Vodafone	Faster	EE	EE, O2
Three	No significant difference	EE, O2, Vodafone	EE, O2

Source: Ofcom

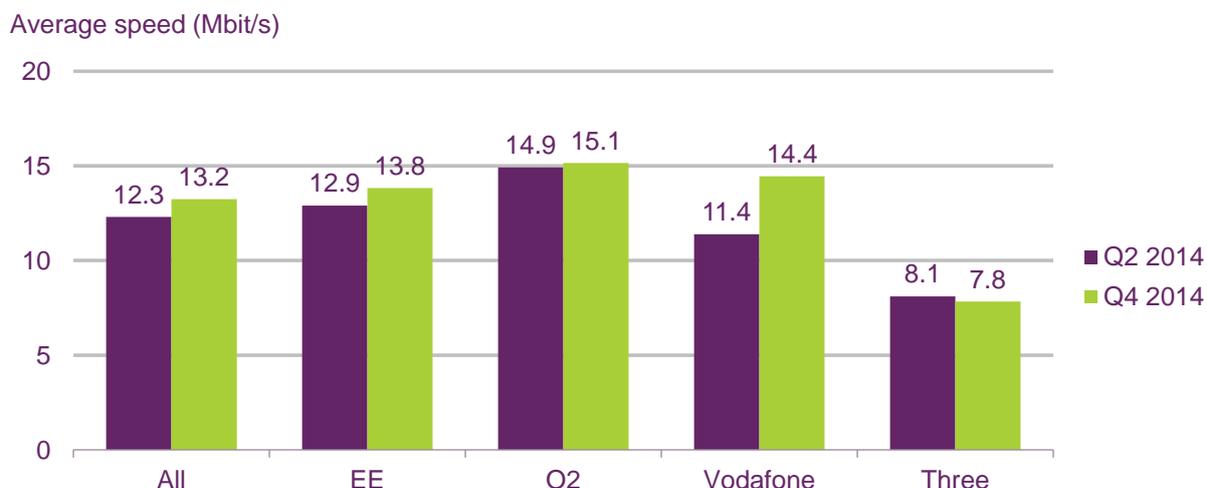
Note: Differences are significant to a 95% confidence level.

In Edinburgh, the total average upload speed over 4G increased by 7.7% between Q2 and Q4 2014

In Edinburgh, the average 4G upload speed in Q4 2014 across all MNOs was 7.7% higher, at 13.2Mbit/s, than the 12.3Mbit/s average in Q2 2014 (Figure 45). Vodafone experienced the largest increase in average 4G upload speed in Edinburgh, up by 26.9% (3.0Mbit/s) to average 14.4Mbit/s in Q4 2014. EE also had an increase in speed over the same period (up

by 7.2%), while there was no significant difference in the average speeds for O2 and Three between Q2 and Q4 2014.

Figure 45 Average 4G HTTP upload speeds, by provider, in Edinburgh



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 46 Average 4G HTTP upload speeds, by provider, in Edinburgh

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Faster	Vodafone, Three	Three
O2	No significant difference	EE, Vodafone, Three	EE, Vodafone, Three
Vodafone	Faster	Three	Three
Three	No significant difference	-	-

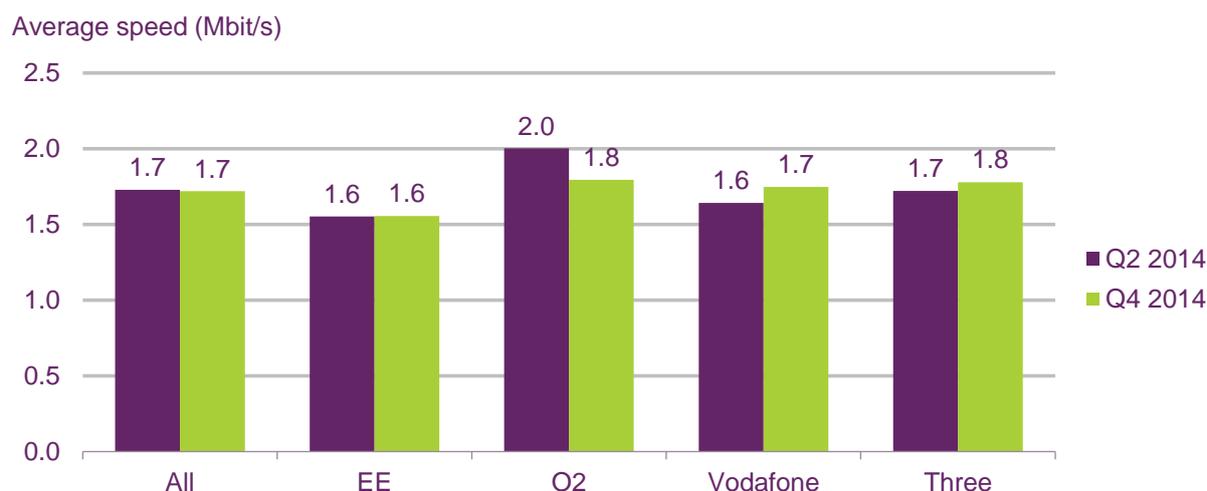
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Overall average 3G upload speed was unchanged at 1.7 Mbit/s in Edinburgh in Q4 2014

There was no statistically significant difference between the overall average 3G upload speeds in Edinburgh in Q2 and Q4 2014 (Figure 47). Vodafone experienced the only significant increase in average 3G upload speed among the MNOs over this period, up by 6.4% (0.1Mbit/s) to 1.7Mbit/s, while O2 was the only MNO to experience a decrease in average 3G upload speed over the same period (down by 10.4%).

Figure 47 Average 3G HTTP upload speeds, by provider, in Edinburgh



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (mean) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 48 Average 3G HTTP upload speeds, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	No significant difference	-	-
O2	Slower	EE, Vodafone, Three	EE
Vodafone	Faster	-	EE
Three	No significant difference	EE	EE

Source: Ofcom

Note: Differences are significant to a 95% confidence level.

3.11 Latency on 4G and 3G as an overall average

The results for latency indicate the responsiveness of the network. Latency is measured as the time between sending a signal and receiving a response. We measured latency in our testing by sending a series of ICMP (internet control message protocol) ping tests.

These results show the average round-trip time¹⁸ of the data sent, across all of our ICMP ping tests. The first results take an aggregate of all of our valid 4G and 3G results across all of the networks to produce an average for each technology. The second set of results for latency looks at the average result for each of the networks in the areas where we tested, for each network across 4G and 3G. Finally, we compare the results across 4G and 3G from Q2 2014 to Q4 2014 in both London and Edinburgh.

The results for ping followed a non-standard statistical distribution, so the averages below are calculated as the median rather than the mean. Using the median in a skewed

¹⁸ The round trip time is the time between sending a packet data to a server and receiving a response.

distribution reduces the effect of a small number of high or low results overly influencing the averages.

Information on how we have processed the raw data from our tests is included in Annex 3 of this report.

4G networks had lower latency than 3G networks

Across all of our test locations, as an average of all the networks we tested, latency on 4G was 53.1 milliseconds (ms), while it was 63.5ms over 3G (Figure 49).

As we tested across some different cities in Q2 and in Q4 2014, the overall average results below are not directly comparable to those included in the report covering Q2 2014.

Figure 49 Average 4G and 3G latency overall: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

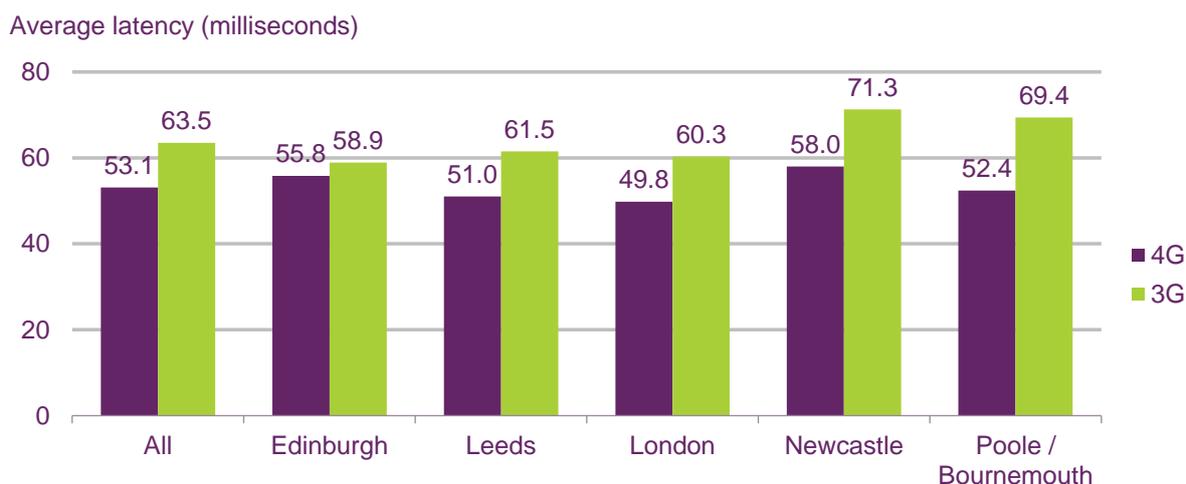
Note: Average (median) of all 4G tests and all 3G tests. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

The lowest average 4G latency was measured in London

The lowest average latency over 4G, at 49.8ms, was measured in London (Figure 50). This was followed by Leeds, at 51.0ms, and Poole/Bournemouth, at 52.4ms. Latency was highest over 4G in Newcastle, where the average was 58.0ms.

Over 3G, the lowest average latency was in Edinburgh, at 58.9ms. There was no statistically significant difference between the average latency in Newcastle and in Poole/Bournemouth; both had the highest latency among our cities (at 71.3ms and 69.4ms respectively).

Figure 50 Average 4G and 3G latency, by test location: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: Average (median) of all 4G tests and all 3G tests, by test location. As we tested across some different cities in Q2 and Q4 2014, the total average results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 51 Average 4G and 3G latency, by test location: significant differences

	4G faster than:	3G faster than:
Edinburgh	Newcastle	Leeds, London, Newcastle, Poole/Bournemouth
Leeds	Edinburgh, Newcastle, Poole/Bournemouth	Newcastle, Poole/Bournemouth
London	Edinburgh, Leeds, Newcastle, Poole/Bournemouth	Newcastle, Poole/Bournemouth
Newcastle	-	-
Poole / Bournemouth	Edinburgh, Newcastle	-

Source: Ofcom

Note: All differences are calculated to a 95% confidence level.

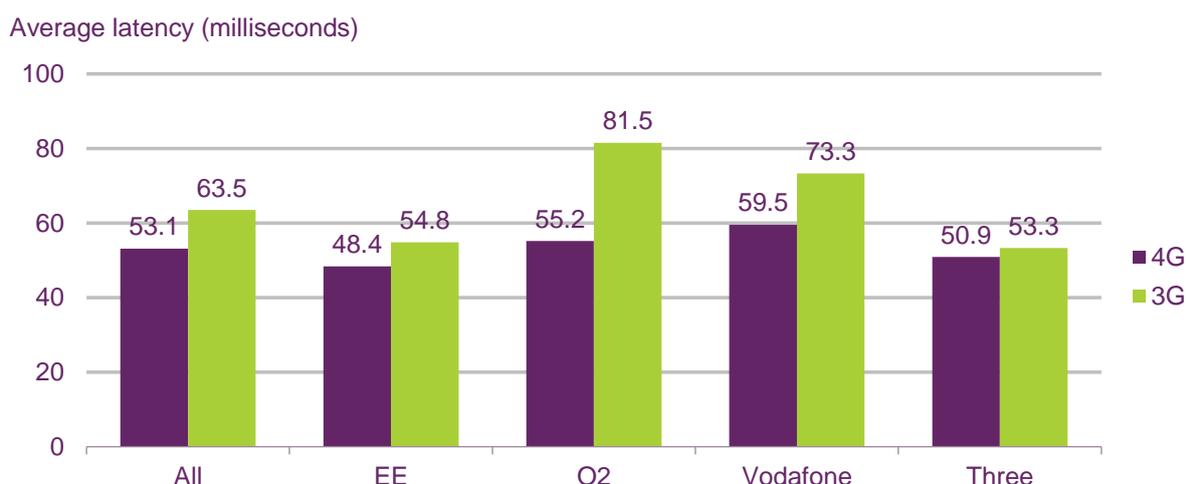
3.12 Latency on 4G and 3G, by network

EE had the lowest latency on 4G

At 48.4ms, average latency on EE's 4G network was lower than on any other MNO's network (Figure 52). There was no statistically significant difference between Three's and EE's average 3G latency (53.3ms and 54.8ms respectively), with these networks having the joint average lowest latency over 3G.

Latency was lower on 4G than on 3G for all networks. Three had the smallest difference between the average latencies found on 3G and 4G, while O2 had the largest difference between the two technologies; its average 4G latency (55.2ms) was 26.3ms lower than its average 3G latency (81.5ms).

Figure 52 Average 4G and 3G latency, by provider: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: Average (median) of all 4G tests and all 3G tests, by operator. As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Figure 53 Average 4G and 3G latency, by provider: significant differences

	4G faster than:	3G faster than:
EE	O2, Vodafone, Three	O2, Vodafone
O2	Vodafone	-
Vodafone	-	O2
Three	O2, Vodafone	O2, Vodafone

Source: Ofcom
 Note: All differences are calculated to a 95% confidence level.

Three's 4G latency was the most consistent of all the networks

Across all four of the UK's 4G networks, 68.9% of test samples resulted in a latency of between 20 and 60ms (Figure 54). EE had the highest proportion of test samples with a latency of 20 to 40ms, at 13.5%. Three's latency was the most consistent of all four networks, with 79.0% of its test samples having a latency of between 40 and 60ms.

Further analysis of the distribution of latency over 4G can be found in the chart pack accompanying this report.

Figure 54 Distribution of 4G latency, by network: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

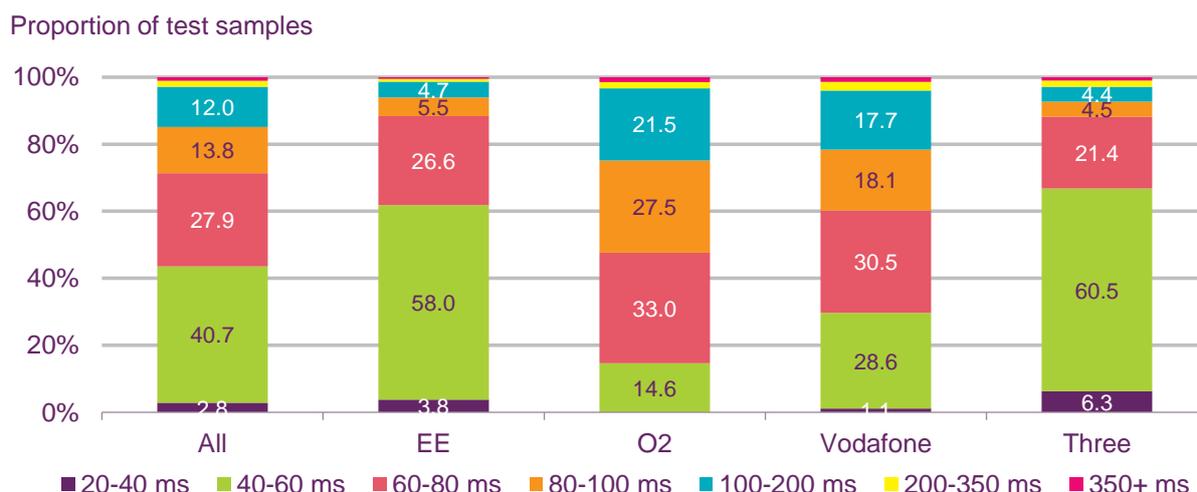
Over two thirds (66.8%) of 3G latency results for Three were less than 60ms

Across all 3G test samples, 71.4% of test locations resulted in latency lower than 80ms, with 43.5% being below 60ms (Figure 55).

Three had the highest proportion of results lower than 60ms (66.8%), followed by EE (61.8%). O2 had the highest proportion of results that were higher than 100ms (24.9%), followed by Vodafone, which had 21.6% of test samples with a latency of 100ms or more.

Further analysis of the distribution of latency over 3G can be found in the chart pack accompanying this report.

Figure 55 Distribution of 3G latency, by network: Q4 2014 (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

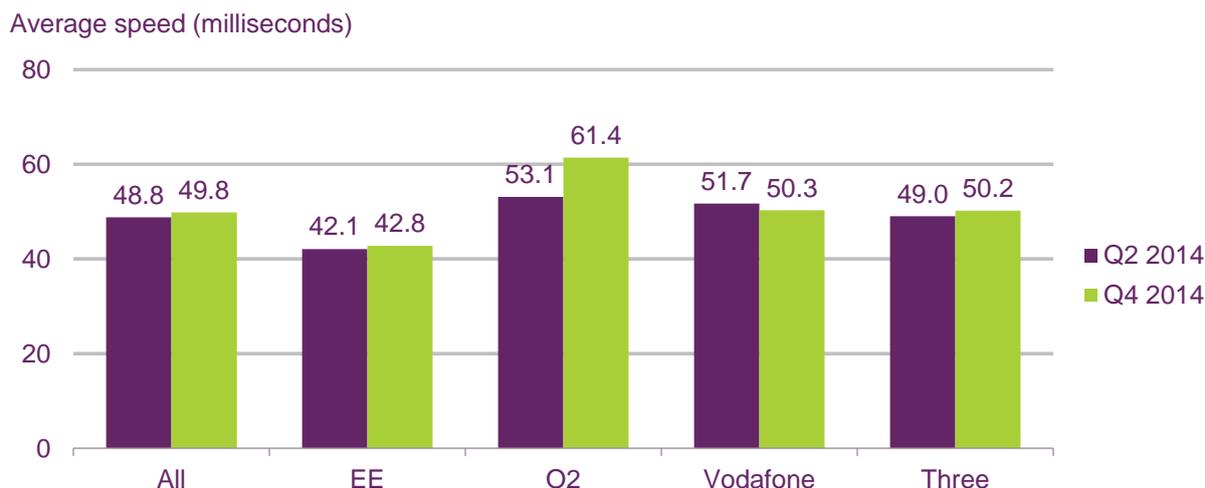
Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

3.12 Latency on 4G and 3G: London and Edinburgh

Total average 4G latency increased by 2.0% in London between Q2 and Q4 2014

There was a 2.0% (1.0ms) increase in the average 4G latency in London between Q2 and Q4 2014 (Figure 56). There were increases in the average latency for O2 and Three over the same period (up 15.6% and 2.4% respectively), while EE and Vodafone experienced no statistically significant difference between Q2 and Q4 2014.

Figure 56 Average 4G latency, by provider, in London (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 57 Average 4G latency, by provider, in London: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	No significant difference	O2, Vodafone, Three	O2, Vodafone, Three
O2	Slower	-	-
Vodafone	No significant difference	O2	O2
Three	Slower	O2, Vodafone	O2

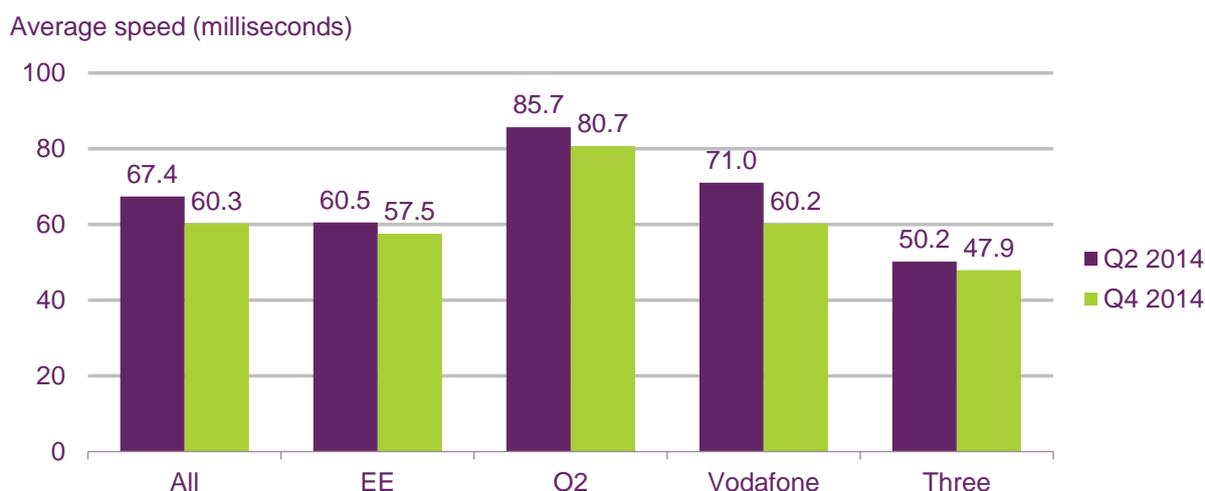
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

All four MNOs recorded lower average latency over 3G in London in Q4 2014

In London, the total average 3G latency was 10.5% lower in Q4 2014 (at 60.3ms) than the 67.4ms recorded in Q2 2014 (Figure 58). Individually, each MNO had a significant performance improvement over this period (EE by 5.0%, O2 by 5.8%, Vodafone by 15.2% and Three by 4.6%).

Figure 58 Average 3G latency, by provider, in London (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 59 Average 3G latency, by provider, in London: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	Faster	O2, Vodafone	O2, Vodafone
O2	Faster	-	-
Vodafone	Faster	O2	O2
Three	Faster	EE, O2, Vodafone	EE, O2, Vodafone

Source: Ofcom

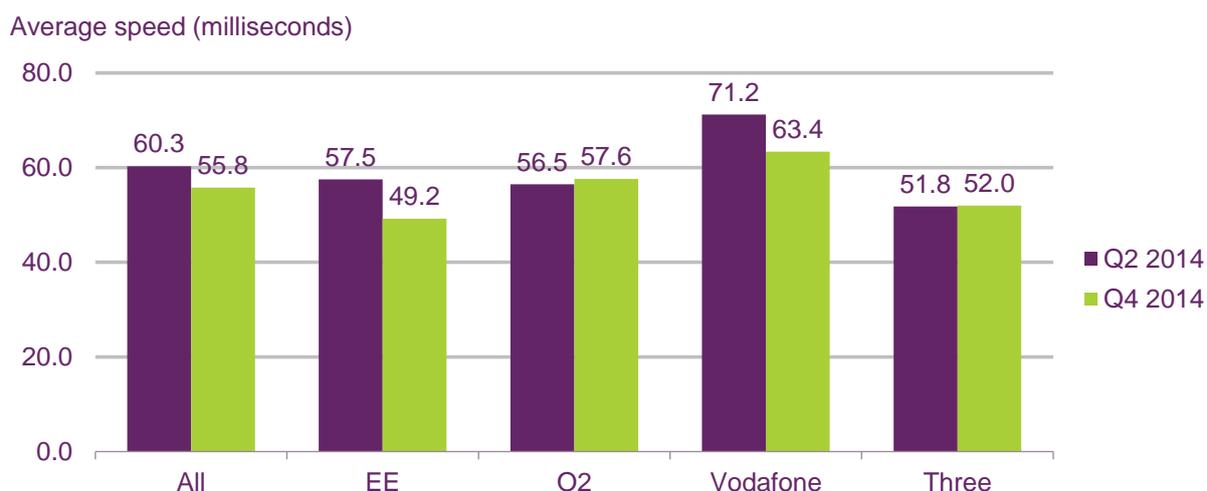
Note: Differences are significant to a 95% confidence level.

The total average 4G latency in Edinburgh was 7.5% lower than in Q2 2014

In Edinburgh, there was a 7.5% decrease in the 4G average latency between Q2 and Q4 2014, as shown in Figure 60, signalling an improvement in performance.

EE and Vodafone had significant improvements in their average latency over the same period, by 14.4% and 11.0% respectively. There were no statistically significant differences in the average 4G latency recorded for O2 and Three between Q2 and Q4 2014.

Figure 60 Average 4G latency, by provider, in Edinburgh (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 4G tests, by operator. All differences are significant to a 95% confidence level.

Figure 61 Average 4G latency, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	4G faster than:	
		Q2 2014	Q4 2014
EE	Faster	Vodafone	O2, Vodafone
O2	No significant difference	EE, Vodafone	Vodafone
Vodafone	Faster	-	-
Three	No significant difference	EE, O2, Vodafone	O2, Vodafone

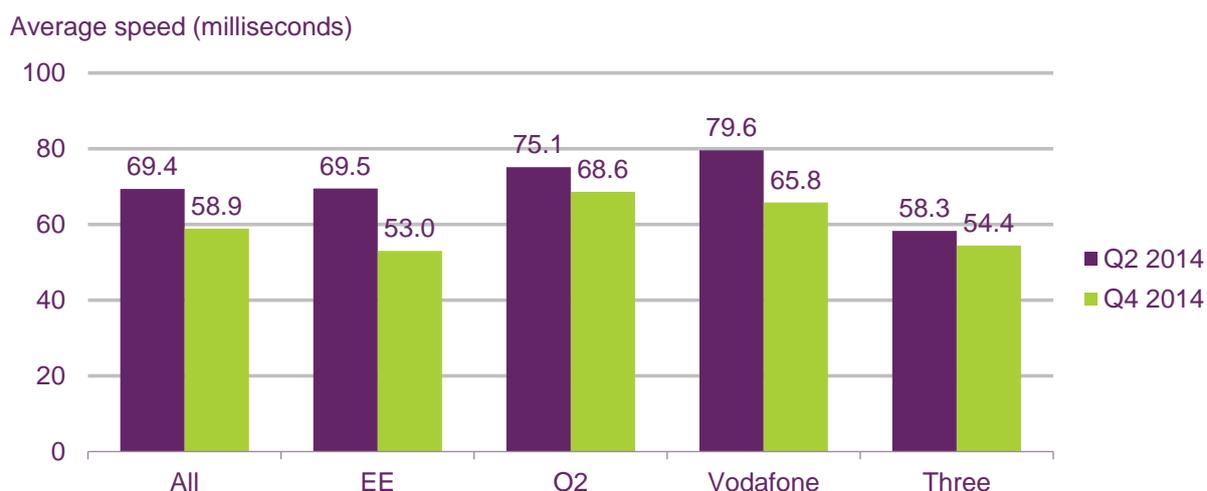
Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Total average 3G latency was 15.1% lower in Edinburgh in Q4 than in Q2 2014

There were significant performance improvements, both overall and for all four MNOs, in the average latency over 3G in Edinburgh between Q2 and Q4 2014 (Figure 62). The overall average 3G latency decreased by 15.1% to 58.9ms over this period; EE improved by 23.7%, O2 by 8.7%, Vodafone by 17.3% and Three by 6.7%.

Figure 62 Average 3G latency, by provider, in Edinburgh (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014 and October to December 2014

Note: Average (median) of all 3G tests, by operator. All differences are significant to a 95% confidence level.

Figure 63 Average 3G latency, by provider, in Edinburgh: significant differences

	Q4 compared to Q2 2014	3G faster than:	
		Q2 2014	Q4 2014
EE	Faster	O2, Vodafone	O2, Vodafone
O2	Faster	-	-
Vodafone	Faster	-	O2
Three	Faster	EE, O2, Vodafone	O2, Vodafone

Source: Ofcom

Note: Differences are significant to a 95% confidence level.

Annex 1

Understanding and using our results

1.1 Introduction

This section is intended to explain how the results should be understood and interpreted. It sets out:

- what we have measured;
- how these measurements were made;
- how these measurements relate to the consumer experience of mobile broadband; and
- important points to note when reviewing the results.

1.2 General rules for using these results

When reviewing our results it is important to note the following points:

- Our work measured mobile broadband performance only.
- Indication of better performance: the highest number is not necessarily the best for a given application, as other factors can affect performance.
- Relative difference: even a statistically significant difference may have no perceivable impact on the consumer's quality of experience.
- Performance can vary between devices; we have tested only on smartphones.
- Networks are still in the process of being rolled out. The measured performance may not reflect the current or future performance of mature networks.
- The number of 4G subscribers is increasing, which may lead to higher network load and a reduction in performance. Conversely, as 4G networks are further optimised, performance may improve.
- Our measurements do not assess coverage.
- We have not measured the performance of specific services or applications that are delivered over mobile broadband.

1.3 What we measured

We measured four distinct metrics:

- HTTP download speed;
- web browsing speed;
- HTTP upload speed; and

- latency.

These metrics capture important aspects of mobile broadband network performance. We note that other metrics can be used to characterise 4G and 3G network performance. We also acknowledge that other metrics, relating to different aspects of mobile services such as voice calls, would be required to give a complete picture of mobile performance for the consumer.

Our results are intended to be used as part of the information a consumer may find useful when considering which mobile provider to select.

The following sub-sections explain each of the four metrics in more detail.

HTTP download speed

HTTP (hypertext transfer protocol) is the method commonly used to transfer information over the World Wide Web; for example, in delivering web pages or a video stream. Download speed indicates the rate at which a connection is able to transfer data from the internet to the consumer. A connection with a higher download speed would take less time to transfer the same data than a connection with a lower download speed. For example, at a constant speed of 20Mbit/s (20 million bits per second), the theoretical time taken to download a 10MB (83,886,080 bits of data) file would be just over four seconds, while on a constant speed of 10Mbit/s, it would be just over eight seconds.¹⁹

The rate of HTTP download can vary according to the location and time of day, even during a short session of use, for a multitude of reasons. Some of these effects may be related to the mobile network that is providing the connection to the internet (such as contention on the cell, or the use of traffic management). However, it can also be limited by factors outside the control of the mobile network operator. For example, if multiple users are attempting to access content from the same server at the same time, and that server lacks the capability to serve them all at the same time, the download rate could be limited.

HTTP is used to deliver many types of content, including web pages, audio, video, and images, as well as for downloading applications. While HTTP is used for delivering various types of content, this content may be treated in different ways by the content providers and by the networks that transmit the information. The size and quality of a video file may be determined by the content provider, depending on the device or the network over which the content is being delivered. The network may choose to re-encode this content before providing it to the end-user, in order to provide the video more quickly, and by minimising the volume of data transferred, minimising use of its network capacity. Web pages may also be compressed from their original sizes, and smaller-sized or lower-quality images may be served to the user.

Web browsing speed

Web browsing speed indicates the amount of time it takes to completely load a standard HTML reference web page. The page used in our testing is an ETSI (European Telecommunications Standards Institute) standard reference page, designed for

¹⁹ Bits and bytes are terms for units of digital information. A bit is a single numeric value, either one or zero, that represents a single unit of digital information. A byte is a sequence of bits, and is most commonly formed of eight bits.

smartphones to represent a typical HTML web page.²⁰ As stated on the ETSI website the goal of service testing is to get a quantitatively correct impression of the service usage experience from a typical user's point of view. We tested one single website (specially designed web content) on a specially assigned and well-controlled web server to facilitate the necessary control of environmental conditions.

Using a standardised web page hosted on a dedicated server means that the conditions for downloading this page remain the same for each test. Using a live web page for testing would mean that contention from other users on the server hosting the content could affect the performance, and there would also be the potential for the content to be optimised by mobile operators during our testing, which might have different effects on our testing at different times of day.

However, we note that due to the potentially different routes taken to other websites to those used in our tests and the potential use of different server and handset software, it is possible that tests involving other websites might yield different results.

HTTP upload speed

Like download speed, upload speed indicates the rate at which a connection is able to transfer data from one source to another, although with upload speed this represents the rate at which data can be transferred from the device to the internet.

Latency

Latency indicates the delay between a request for information and the response. A connection with low latency will feel more responsive for simple tasks like web browsing, and certain applications perform far better with lower latency.

Latency was measured by sending a series of ICMP (internet control message protocol) ping tests. Latency refers to the responsiveness of a network and is measured as the time between sending a signal and receiving a response. Its effect can be demonstrated through live satellite television news broadcasts, where a delay is sometimes seen between a presenter asking questions in a studio in the UK and the response from the reporter in a distant location.

Low latency is important for applications that require information to be delivered with as little delay as possible. In particular, low latency is most important when using video calling or VoIP (voice over internet protocol).

1.4 How these metrics are measured

We collected our data using a proprietary software testing application, Datum, supplied by telecommunications testing company Spirent, which provides systems and services for measuring and analysing the user experience of mobile devices and services. The Datum application ran directly on the consumer handsets we used for testing. All of our testing was carried out using Samsung Galaxy Note 3 handsets. These were generic, unbranded handsets, unlocked to all networks and without the modifications which may be made by network operators in the MNO-branded devices that are sold in their retail outlets.

²⁰ More information on the development of the mKepler reference web pages used in testing can be found on the ETSI website:

http://www.etsi.org/deliver/etsi_tr/102500_102599/102505/01.03.01_60/tr_102505v010301p.pdf

The descriptions below explain what Datum does to measure each metric.

HTTP download speed (a higher number indicates better performance)

Measured by initiating the download of a 2GB file and downloading for 30 seconds. After 30 seconds, the connection times out and the download speed metric is then calculated by dividing the amount of data received by 30, to produce a metric of megabits per second (Mbit/s). This indicates the speed at which a network has downloaded data using HTTP.

Web browsing speed (a lower number indicates better performance)

Measured by loading an ETSI-standard reference page and recording the amount of time that this page takes to load. This produces a time in seconds (s). The test times-out when the web page fails to download within 15 seconds.

HTTP upload speed (a higher number indicates better performance)

Measured by initiating the upload of 100MB of data and uploading for 15 seconds. After 15 seconds the connection times out and the upload speed metric is calculated by dividing the amount of data sent by 15. As with download speed, this produces a metric of megabits per second (Mbit/s).

Latency (a lower number indicates better performance)

Measured using ICMP ping. Five packets are sent to a dedicated ICMP server and returned, and the average time that these packets take to complete this round trip is recorded. This produces a metric in milliseconds (ms).

1.5 Comparing our metrics to real services and applications

Our tests measure network performance. These types of metrics are often described as quality of service parameters (QoS). Consumers use different applications on their mobile devices, and their perception of the experience of using their applications and services is what matters most to them. How a consumer rates their experience of a mobile service is referred to as quality of experience (QoE)

To make some of the metrics easier to understand we would ideally like to translate our QoS metrics into QoE metrics. A simple demonstration of this might be:

QoS: “this service has a latency of 32ms on average”,

QoE: “this service is good for VoIP on average”.

In reality, it is not always possible to produce this type of simple translation. This is because many factors can affect the performance of a particular application: e.g.:

- **Device capability:** demanding applications such as gaming or HD video may be limited by the device.
- **Mobile network optimisation:** Mobile operators often optimise content and types of data delivered to their customers to manage capacity demands and deliver a better service to more customers. The level of optimisation may change for different circumstances or users.

- **Application servers:** The servers running a specific application may lack the capacity to deal with high demand, resulting in reduced performance.

We have not attempted to translate our results into an explicit indication of how our metrics might represent consumer quality of experience, for these reasons. The ways in which online services and content are provided over networks differ by provider, and the way the traffic is handled differs by network, so to create a consistent approach to modelling our results, which is fair to all providers, is not feasible.

An example of these differences is in streaming video. This is a service area that attracts significant investment by MNOs, to deliver the best possible service to as many consumers as possible. Video streaming demands high bandwidth (i.e. fast data rates) and MNOs undertake a variety of activities to improve the service they offer to their customers. This includes re-encoding video to reduce the bit rate, caching popular videos at the edge of the network to deliver faster response times, and optimising content for device screen size and resolution.

This all means that it is not possible to assess video performance by simply looking at the maximum download rate achievable on a network.

In general terms, a higher download rate should deliver a better video streaming experience. For most mobile video applications a data rate beyond 2 to 3Mbit/s should be enough to ensure a high quality viewing experience, and increases in speed beyond this will generally have limited impact on viewing experience. As videos are viewed for a period of time it is not just the speed that is important, but the ability of that rate to be sustained over the duration of the video, and potentially while the user is on the move.

Another example would be translating latency into VoIP performance. It is generally accepted that as long as latency does not exceed, for example, levels of between 100 and 200ms, the voice call will be of adequate quality. Therefore if, for example, latency on one network is 30ms, but 50ms on another network, both are likely to deliver high-quality VoIP services. An additional complication to consider is that mobile operators often prioritise VoIP traffic to reduce latency. Our testing would not capture this effect, as we measure only the generic latency. For this reason, drawing conclusions from our latency measurements in respect of VoIP performance should be undertaken with caution.

Annex 2

Testing methodology

2.1 The principles of our methodology

Our methodology has been designed to measure metrics relevant to the consumer experience of using mobile broadband. It has also been designed to produce a statistically robust dataset that treats each MNO on a fair and equivalent basis. This is to allow us to compare 4G and 3G networks as a whole, and to be able to compare the performance of each MNO's network on 3G and the performance of each MNO's network on 4G on a fair and equivalent basis.

The measurement of mobile broadband performance is still evolving, with a range of different metrics used for testing. As part of our next steps we are going to review all metrics we currently measure.

2.2 Device-based testing

For our first report we selected the Samsung Galaxy Note 3 smartphone to carry out our testing. This device was chosen as it is a Cat4 device²¹ that was available for purchase from all of the MNOs. In our second research we continued using the same device type to be able to compare some of the results.

We chose a Cat4 device because, based on the network deployments at that time, this should have removed the possibility that the limiting factor, in any testing that we did, was the device rather than the network.

Although there were other Cat4 devices, at the time of starting our first testing the Samsung Galaxy Note 3 was the only Cat4 smartphone that was available to purchase from all of the MNOs. MNOs undertake testing of handsets on their networks before including them in their product range, and so it was important to use a device that would be compatible with all of the networks.

The devices that we used were not MNO-branded devices; i.e. they were not purchased from the MNOs. MNO-branded devices generally have firmware pre-installed which is tailored to their network. There is also the possibility of minor customisations to hardware specifications.

To allow us to achieve comparable measurements, and to test every network under the same conditions, we did not want to use MNO-branded devices as this would mean that each handset could have been modified in a different way, and would therefore perform in a slightly different way. Using MNO-branded devices would also have precluded us from rotating SIMs across the handsets. This SIM rotation is important for removing differences between handsets due to manufacturing tolerances. We recognise that there may be small differences in network performance between a branded and unbranded handset, but we consider that the benefits of handset rotation and treating each network equally, outweigh any benefits of using branded handsets.

²¹ A Cat4 device, short for Category 4, is the latest evolution of mobile technology running on 4G networks. A Cat4 device has a maximum data speed of 150Mbit/s. A Cat3 device has a maximum speed of 100Mbit/s.

We did not set out in this work to measure the relative performance of different makes or types of device. We wanted to test network performance, therefore as many elements as possible, including the devices used, were set as constants across the testing to maintain comparability across networks.

2.3 Software-based testing

We used the ‘Datum’ product from Spirent to perform testing. Spirent is a provider which specialises in services and systems for measuring the user experience of mobile devices and services. The Datum product allows customised test sets, close to the consumer experience of mobile broadband use, to be determined and then tested through an app loaded on to the test device. The test app itself requires no modification of the handsets and can be downloaded by anyone from the standard app stores.

2.4 Testing in public places

To be able to compare 3G performance with 4G performance we needed to test in places where 3G and 4G were both available. This was so that we had a consistent location that would provide readings for both technologies.

To be able to compare performance on each network, we needed to test in places where 4G was available from all operators. Again, this was to ensure that as many as possible of the potential variables remained constant, and to ensure that all networks were tested on an equivalent basis.

At the time of testing, 4G services were primarily available in urban areas. For this reason, the locations that we chose to test in were in cities across the UK. In each city, our testing area was a 4km radius from the mainline train station, which for London was Charing Cross. A 4km radius was used as we considered that this allowed a large enough testing area to avoid any undue clustering of results.

Figure 64 Test cities and centre point of our 4km radius test area

City	Centre point
Edinburgh	Edinburgh Waverley
Leeds	Leeds New Street
London	Charing Cross
Newcastle	Newcastle Central Station
Poole/Bournemouth	Dual centres based on Poole and Bournemouth stations (4km around each)

Source: Ofcom

Test locations themselves were identified by using a variant of stratified random sampling. Each test area was divided into four quadrants, and 50 locations were selected at random, with even distribution across the four quadrants. Test locations were then confirmed as being within the 4G coverage areas of the MNOs, using online coverage checkers. Where locations were not within 4G coverage areas, they were moved to the nearest coverage area.

Three was the exception to this rule. As Three had launched its 4G service later, its roll-out at the time of testing was still more limited than that of the other MNOs. It was therefore not possible to restrict our test locations to those areas where Three had coverage, without

undue clustering of locations. The way in which we have dealt with the smaller sample size for Three is explained in Annex 3 of this report.

2.5 Testing in indoor and outdoor locations

We tested an equal number of indoor and outdoor locations. We used a 50:50 ratio of indoor to outdoor locations as we do not have sufficient evidence to suggest that consumers use mobile broadband services more in one type of location than in another. Using an equal split ensures that we do not introduce any bias between the two location types.

In our indoor locations, handsets were placed on a flat surface with an appropriate distance between each device. Our outdoor locations were taken while stationed in a static vehicle, with handsets mounted in cradles attached to inside of the windows.

2.6 Testing in a fair and unbiased way

Our test processes were designed to ensure that each network was tested on an equal basis.

- Each network was tested concurrently to ensure that environmental conditions were the same for each operator.
- Identical handsets were used for each network.
- SIMs were rotated between devices to eliminate any bias that might occur from variations in individual handset performance.
- All of our testing took place while stationary, to ensure repeatability.
- 16 measurements for each metric were taken for each network at each test location. Handsets were rotated after four cycles to ensure that each handset spent the same amount of time at each point.
- Undue contention was avoided by testing networks in parallel and ensuring that no concurrent tests were run on the same network.
- All testing took place between 7am and 7pm, Monday to Friday.

2.7 Our test process

Each cycle of tests includes 16 iterations of our test set, and rotation of the position of the handsets. Each iteration of the test set followed the following process:

- START
- Wait six seconds
- HTTP download 2GB file, enforced time-out at 30 seconds
- 5x ping tests, enforced time-out at one second
- Wait six seconds
- HTTP upload 100Mb of random data, enforced time-out at 15 seconds

- Wait six seconds
- HTTP 'get' mKepler reference web page, enforced time-out at 15 seconds
- END

This process was repeated four times. After four iterations, the positions of the handsets were rotated. This was repeated until each device had run tests in each position.

Each location produced 32 individual results for each metric for each network, 16 each for 4G and 3G. Multiple tests were run at each location so that the impact of any short-term environmental factors would be minimised. Each cycle of tests was required to produce a minimum of ten valid results for each metric for the location to be considered valid. The sampling framework, and how these data were processed, is set out in detail in Annex 3 of this report.

2.8 SIMs

Each MNO provided SIMs to Ofcom to use for the testing period. Due to the amount of data to be used during these tests, the SIMs provided were standard consumer SIMs with the volumetric data caps removed.²² The performance of the MNO-supplied SIMs was compared to the performance of consumer SIMs to ensure that the test SIMs were performing in the same way as standard consumer SIMs and had not been optimised for our testing. The consumer SIMs were purchased from each MNO's online store, to ensure that they were representative of available consumer tariffs.

²² The process of testing uses significant amounts of data in a short space of time. Using SIMs with the data limits removed means that the burden of SIM management is vastly reduced.

Annex 3

Data processing

3.1 Quality control

Following the completion of testing at each of our test sites, we checked that the data had been uploaded to the database.

We performed two main checks on the data at this stage:

- that restrictive capping as a result of breaching data allowances had not taken place on our SIMs – confirmed through visual observation²³; and
- that the correct number of tests had been performed²⁴

If restrictive capping had occurred, the test site would have become invalid and it would have been re-tested with a SIM on which the data allowance had not been breached. Further instances where results would have been discarded were:

- If there had been additional results (most commonly as a result of aborted runs or unintentional starts), the additional results would have been identified and rejected.
- Where a network had dropped from 4G to 3G during the test, these results would be excluded.
- We set a minimum of ten valid tests for each MNO for each technology, so if this minimum criteria were met, the test site would be valid. If there were fewer than ten valid samples after we removed samples for any of these reasons, we re-tested the location.

Figure 65 below sets out the number of results for each metric that we set out to achieve at each test site:

²³ Although in practice, this was frequently detected by the engineers in the field, who would flag this while observing the tests. This would often manifest as a failure to upload the test results to the database. Where it was not detected by the engineers, it was clear that consistently low speeds across all iterations of the test observed during the quality control process would be the result of data capping.

²⁴ Ideally 128 at each sample site, consisting of 64 on 4G and 64 on 3G but a test site was deemed valid as long as there was a minimum of ten valid tests for each MNO for each technology.

Figure 65 Intended number of samples for each metric at each test site

	EE	O2	Three	Vodafone	Total
RUN1 – 4G	16	16	16	16	64
RUN2 – 3G	16	16	16	16	64
Total 4G	16	16	16	16	64
Total 3G	16	16	16	16	64

Source: Ofcom

3.2 Processing the data

Our framework was designed to provide 50 test sites in each of our five cities, with readings taken at each site for each network and technology to provide a total of 250 test locations per technology, per network. We did this by setting a target of 50 test sites in each of five cities in the UK where 4G was available on EE, O2, Vodafone and Three.

For download and upload speed, each test site became one sample point.²⁵ We could then average all of the sample points to create an overall 4G average and an overall 3G average. For each network, an average of its results from all of our sample points produced an overall average for each network in the areas in which we tested.

The framework is designed to deliver the sample set in Figure 66.

Figure 66 Targeted sample set, by city and mobile network operator

	Edinburgh		Leeds		London		Newcastle		Poole/ Bournemouth		Total	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
EE	50	50	50	50	50	50	50	50	50	50	250	250
O2	50	50	50	50	50	50	50	50	50	50	250	250
Vodafone	50	50	50	50	50	50	50	50	50	50	250	250
Three	50	50	50	50	50	50	50	50	50	50	250	250

Source: Ofcom

Note: Each valid sample is comprised of a minimum of ten valid samples across each technology at each of our sample locations for each MNO.

As Three's roll-out of its 4G service was not as advanced as those of the other MNOs during our testing, its coverage in the cities other than London was less comprehensive than that of the other MNOs. This meant that we were unable to achieve as many valid samples for Three's 4G network as for the other operators. Our achieved sample set, by city and network for HTTP download, is set out in Figure 67.

²⁵ As outlined in Annex 2, a sample set of 50 contains a sample of up to 800 readings, with 16 readings taken at each location.

Figure 67 Achieved valid sample set, for HTTP download, by city and mobile network operator

	Edinburgh		Leeds		London		Newcastle		Poole/Bournemouth		Total	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
EE	50	50	53	53	50	50	52	52	54	54	259	259
O2	50	50	53	52	50	50	52	52	54	54	259	258
Vodafone	50	50	53	53	50	50	52	52	54	54	259	259
Three	34	50	48	53	50	50	40	52	28	54	200	259

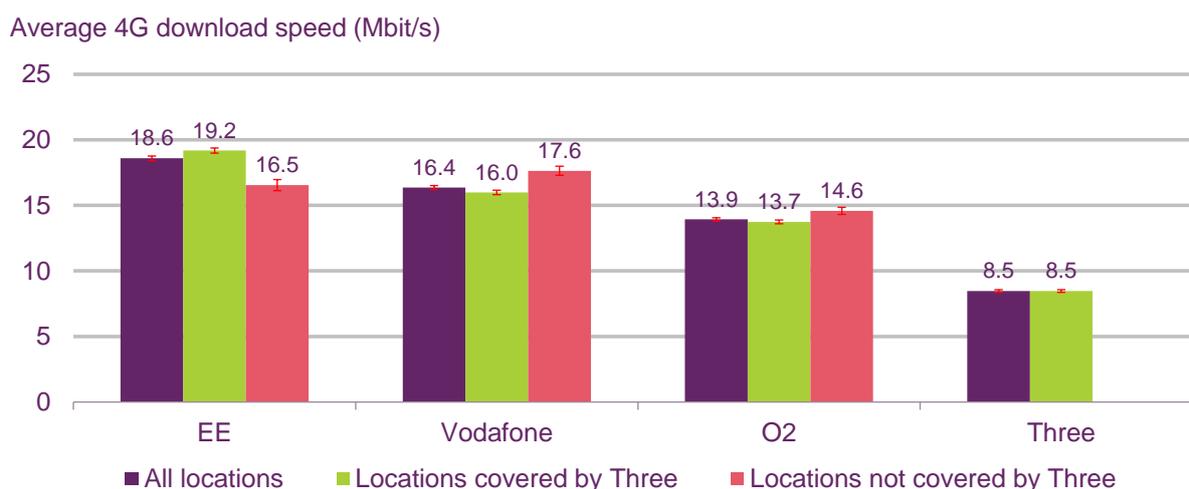
Source: Ofcom

Note: Each valid sample is comprised of a minimum of ten valid samples across each technology at each of our sample locations for each MNO.

To maintain as large a sample size as possible, for each of the networks, we needed to determine whether including results for the sites where we were unable to test 4G for Three would result in any bias against the other networks. This might be the case, for example, if areas where Three had not introduced 4G were hard to reach, or otherwise difficult to serve, and would result in poorer results for the other network operators. If this were the case, comparing networks across all locations would be unfair and would favour Three.

To test that hypothesis, we have compared the average 4G download performance across locations not covered by Three with the average performance across locations where Three had coverage. This is shown in Figure 68, which indicates that although the average download speed varies for the other networks when the locations covered/not covered by Three are compared, no advantage is gained by Three due to their limited coverage because of their much lower average speed.

Figure 68 Average 4G download speed across all locations, and across locations covered/ not covered by Three



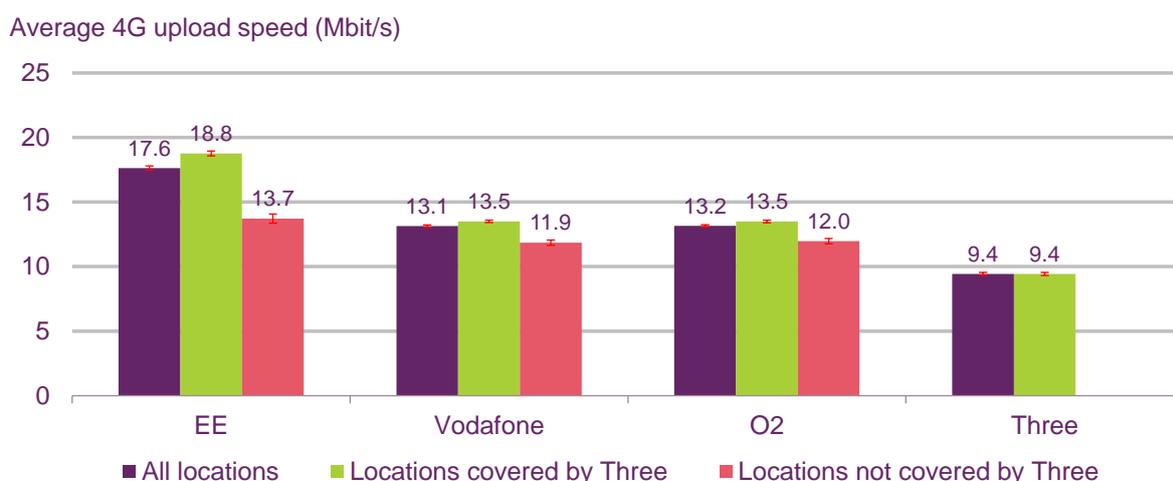
Source: Ofcom mobile broadband measurement, fieldwork October to December 2014

Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

For the same reasons, Three does not get an advantage in our results for Edinburgh (Figure 15) as its speeds are already significantly slower than the average speeds of the other MNOs.

For our HTTP upload tests, we compared the average performance across locations not covered by Three with the average performance across locations where Three had coverage. This is shown in Figure 69. It shows that there is a bias in favour of Three's performance levels in this metric, since each MNO experiences a drop in average upload speed when we look only at those locations not covered by Three. However, the discussion is fairly academic, since all of the other MNOs have significantly faster average upload speeds than Three over 4G, when locations covered by Three are analysed.

Figure 69 Average 4G upload speed across all locations and across locations covered/not covered by Three



Source: Ofcom mobile broadband measurement, fieldwork October to December 2014
 Note: As we tested across some different cities in Q2 and Q4 2014, these results are not comparable with the equivalent figures published in our first report on mobile broadband performance.

Neither does Three gain an advantage in our upload speed results for Edinburgh (Figure 45), because of the existing significant difference in upload speed between it and the other three MNOs.

The achieved valid sample set for HTTP upload speed is set out in Figure 70. There were slightly fewer 3G samples for Vodafone upload speeds than for its download speeds, but the slight bias in Vodafone's favour from this is negligible, due to the low number of locations concerned.

Figure 70 Achieved valid sample set for HTTP upload, by city and mobile network operator

	Edinburgh		Leeds		London		Newcastle		Poole/Bournemouth		Total	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
EE	50	50	53	53	50	50	52	52	54	54	259	259
O2	50	50	53	53	50	50	52	52	54	54	259	259
Vodafone	50	50	53	46	50	50	52	50	54	54	259	250
Three	34	50	48	53	50	50	40	52	28	54	200	259

Source: Ofcom

Note: Each valid sample is comprised of a minimum of ten valid samples across each technology at each of our sample locations for each MNO.

For download and upload speed, we were able to use the average (mean) of our results to calculate our overall averages, and averages for each MNO, and calculate significant differences to a 95% confidence level.

For web browsing speed and for ping, the distribution of results did not correspond to a standard statistical distribution. A non-standard distribution means there is no logical basis for excluding outliers, as deviant readings are only able to be identified relative to a standard distribution. Using the mean to calculate averages based on a non-standard distribution can lead to a small number of large or small readings, unduly affecting the overall average.

For these reasons we have used the median to calculate the averages for web browsing speed and for ping.

Calculating the significance of differences between medians is not as straightforward as calculating the difference between means. To do this, we looked at the percentages of readings for each network that were at or below the overall median. For those networks where the medians were the same, we would expect to get a similar proportion of results at or below the median. However, as shown in Figure 71, while EE and Vodafone had similar median results (0.768 seconds compared to 0.762), they had a significantly different proportion of results that were at or below their overall median (41.4% compared to 34.6%). As such, it was necessary to calculate the median for EE and Vodafone individually, which confirmed that there was no statistically significant difference between web browsing over 4G for EE and for Vodafone.

Figure 71 Web browsing speed: calculating significant differences

	Overall	EE	O2	Three	Vodafone
Median result	0.724	0.768	0.706	0.626	0.762
% of results at or below overall median	50%	41.4%	57.9%	70.8%	34.6%
95% confidence interval		1.5%	1.5%	1.6%	1.4%

Source: Ofcom

We also examined our results for web browsing speed and for ping to determine whether any advantage was afforded to Three as a result of the smaller sample size. Although there was a slight bias in Three's favour for web browsing speeds overall, and latency when compared to EE, it does not impact on the conclusions of this report, since the difference in medians between the locations covered by Three, and those not, is small compared to the lead Three has over the other networks.

Looking at the Edinburgh results for web browsing and latency, testing confirms that the significant differences between Three and the other MNOs would not unfairly benefit Three due to its smaller sample size, such are the differences that exist between each network in Q2 and Q4 2014.

Weighting the results

To ensure that each valid sample, and each city, makes an equal contribution to the results, we have applied simple weighting to the results.

As the number of valid readings at each test site varies, we have applied weighting so that the number of readings after weighting is the same for each location within a city, and for each city overall. In locations where we have 16 valid readings, each will get a weight of 1.000. In a location where we have 13 valid readings, these would be weighted to 16, so each would get a weight of 1.231 ($13 \times 1.231 = 16$).

For those cities where we have in excess of 50 samples, we have weighted down the locations. For example, we have 53 locations in Leeds, but want the results for Leeds to represent 20% of the total across the five cities. For this reason, we have weighted each location down by $50/53$, which means each test site is equivalent to 15.09 readings. A test site with 16 readings, in Leeds, will therefore receive a weight of 0.9434. A test site with 14 valid readings would get a weight of 1.078.²⁶

The purpose of this is to ensure that each test site and each urban area makes an equal contribution to the results, without discarding any of the results from the areas where we have over-sampled.

This means that we are effectively calculating an average for each location, then calculating an average for each city, then calculating an overall average from the cities. We are not compensating for locations where no 4G readings were possible; for example, by increasing the weighting of the locations where Three had coverage in Poole/Bournemouth, as we consider that including only real results means that the analysis profile more closely reflects the places and networks where a 4G signal can be obtained. It also provides more robust results from a statistical point of view, as heavy weighting for a small number of locations would increase the variances.

Figure 72 shows the effective sample size, which summarises the extent of our weighting on each network. This represents the equivalent sample we would require for the same accuracy if we didn't need to weight.

²⁶ To get to this weighting, we divide the target sample by the achieved sample. In the case of Leeds this is $50 / 53$, which equals 0.9434. A test site with 16 valid readings is then multiplied by this figure (16×0.9434) which equals 15.09. To carry the same weight, a test site with fewer than 16 valid readings must therefore have the equivalent of 15.09 readings. A site with 14 valid readings would carry a weight of 1.078, because $14 \times 1.078 = 15.09$.

Figure 72 Effective sample size

	All		EE		O2		Vodafone		Three	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
Original planned sample	15,099	16,000	4,000	4,000	4,000	4,000	4,000	4,000	3,099	4,000
Actual sample of readings	15,595	16,381	4,103	4,116	4,133	4,119	4,134	4,016	3,225	4,130
Effective weighted sample	15,508	16,336	4,093	4,107	4,127	4,109	4,128	3,999	3,161	4,124

Source: Ofcom

Note: The planned sample for Three allows for the fact that some locations couldn't be covered.

Annex 4

3G and 4G coverage

The coverage figures in this report are based on detailed coverage data provided to us by the MNOs. The operators produce these data using computer models to estimate the signal strength at different locations. The models take into account multiple factors, including the distance from the local mast, the terrain and the the nature of obstacles in the area.

When estimating premises coverage we apply a signal strength threshold to the operators' predictions to determine whether or not their signal is sufficiently strong at each location in the UK where there are premises. We use a dataset provided by the Ordnance Survey to determine the location of premises.

To allow comparison to be made between operators, we had to adopt a common methodology for this report. We have applied a signal strength threshold of -100 dBm RSCP of the common pilot channel for 3G and for 4G we have applied a signal threshold of -113 dBm RSRP. This is consistent with the thresholds we used in the first mobile broadband performance report, published in November 2014.

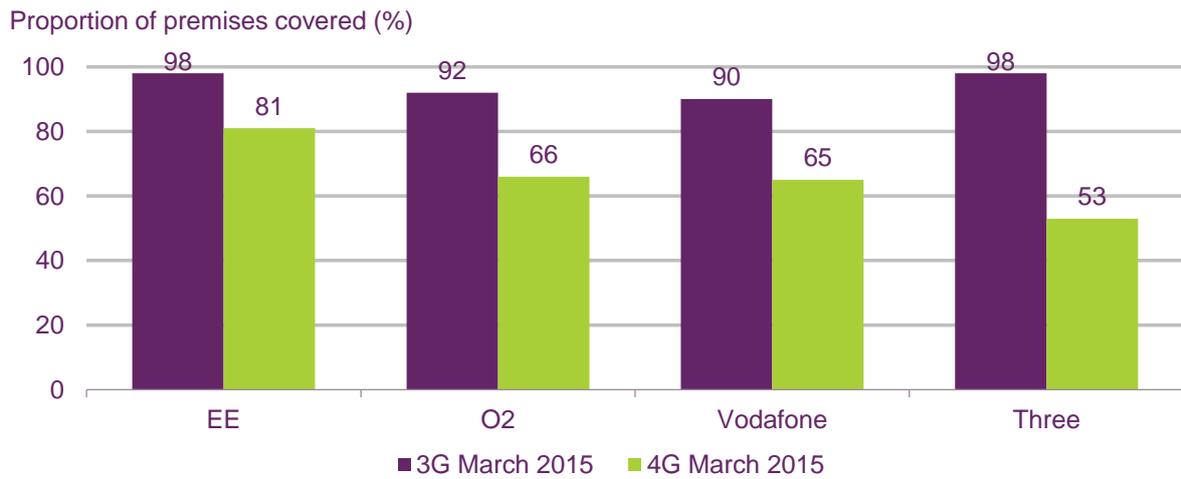
When the MNOs publicly state their own coverage, it is possible that they may base their figures on slightly different methodologies to that used in this report. For example, they might apply different signal thresholds, or use different underlying databases of premises or population. These differing methodologies can result in different, and often higher, estimates of coverage to those published in this report. For example, one MNO has informed us that the 4G coverage experienced by its customers is greater than the figures we have published in this report.

We also note that the thresholds that we have applied in this report to estimate coverage are more conservative (i.e. they result in lower estimates of coverage) than those the MNOs have agreed to achieve in relation to their commitment to Government to provide coverage to 90% of the land area of the UK by the end of 2017.

We are undertaking further technical research to review, among other things, the signal thresholds we apply when reporting coverage. This is to ensure that the figures we report fully reflect the consumer experience of use mobile services.

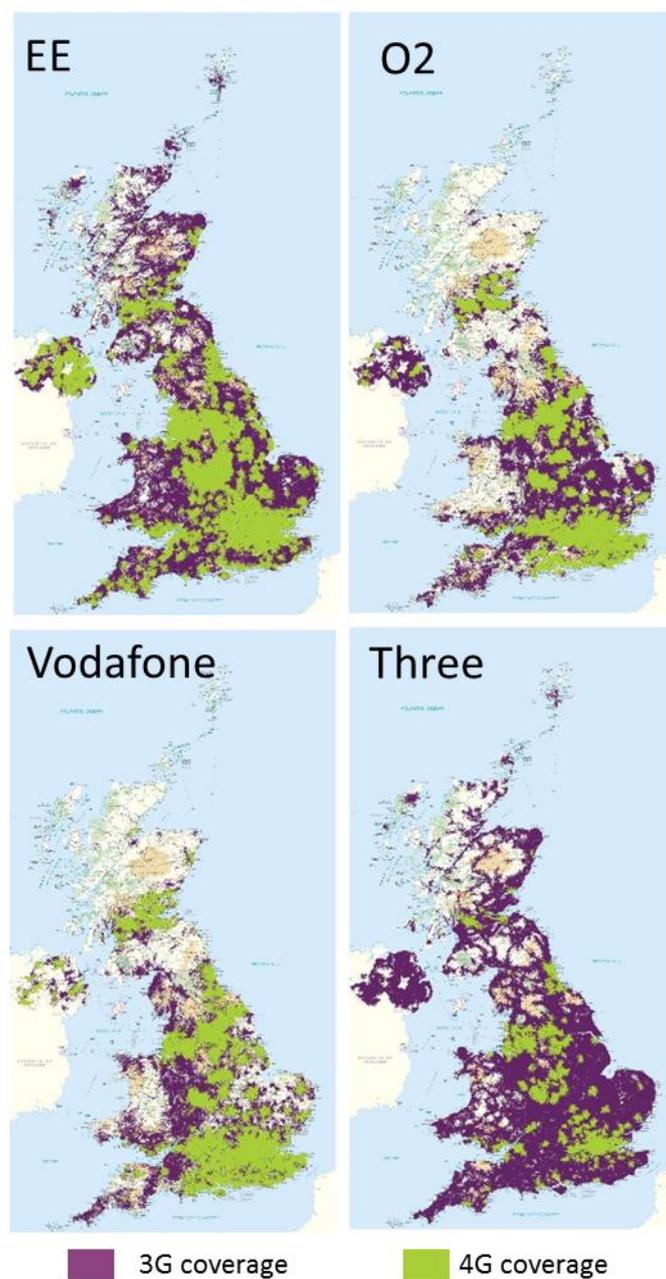
Figure 73 shows our estimates of 3G and 4G premises coverage, based on MNO signal strength predictions, in March 2015, and the signal thresholds detailed above. Figure 74 shows how this coverage is distributed across the UK.

Figure 73 Estimated 3G and 4G premises coverage, by MNO



Source: Ofcom estimate based on data supplied by operators

Figure 74 3G and 4G coverage for the four national MNOs: March 2015



Source: Ofcom/operators

Note: Ofcom's methodology estimates premises with coverage, based on operator signal strength predictions. 3G and 4G data for EE, O2, Vodafone, and Three, are based on the operators' submissions.