



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 services offered by 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.

The research outlined in this report was conducted between March and June 2014 in five UK cities where 4G services were available from all operators. Our methodology involved using smartphones to measure four key metrics that determine data connection performance: download speed, upload speed, web browsing speed and latency (measured through ping tests).

To provide context to the results, this report also includes 4G coverage information for each of the operators and highlights recent consumer research that Ofcom has undertaken in relation to consumers' use of smartphones and their attitudes towards, and use of, 4G services.

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

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Section 1

Executive summary

1.1 Introduction

The UK mobile market

The UK enjoys a dynamic and varied mobile telecommunications market. New services, devices and products continue to be released, benefiting consumers through greater choice and providing new and better ways to communicate.

A significant area of growth in recent years has been in mobile data services. The introduction of mobile devices such as smartphones and tablets, and the huge range of internet-based applications that they support, has created significant demand for mobile broadband. One way that mobile operators are meeting this demand from their customers is by rolling out new 4G network technology.

4G is the fourth and latest generation of mobile cellular communications technology. Each generation has offered enhanced capacity for voice or data services. The fourth generation has focused on boosting mobile broadband performance and is designed primarily to deliver significant increases in mobile broadband data capacity and performance.

The first national mobile network operator to commercially launch a 4G network was EE, in autumn 2012, followed by Vodafone and O2, which began offering 4G services at the end of summer 2013. Three launched publicly in March 2014. All national MNOs continue rapidly to deploy their 4G networks, and by June 2014 just under three-quarters of UK premises were in areas with outdoor 4G coverage from at least one MNO, and just under a third were in areas with similar coverage from all four MNOs.

UK consumers have been quick to take up the new 4G services. More than 9 million people can access a 4G service, and this figure is set to rise rapidly as the coverage of 4G increases and more 4G-capable devices are launched.

Providing consumers with the information required to make informed choices

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 performance of 3G and 4G data networks will help inform consumers, and encourage providers to improve their performance.

While this research may help some consumers in choosing a mobile provider for their specific need, we recognise that many other factors also affect consumer choice. In particular, factors such as price, handset, coverage, quality of customer service, and voice performance will all play a part in consumers' decisions. We also recognise that information on mobile broadband performance is also available from commercial companies.

1.2 Our methodology

Challenges and limitations of measuring mobile broadband

Our intention in this research was to help consumers understand the differences in performance between 4G and 3G mobile services. This kind of research is designed to support consumers in choosing a mobile service that best suits their needs. To meet this objective we chose a research methodology that closely matched the consumer experience of using mobile broadband, and introduced a detailed testing process that ensured that every MNO was tested on a fair and equal basis.

Our testing:

- used test applications running on unmodified and unbranded publicly available smartphones;
- took place in five cities between March and June 2014: London, Birmingham, Manchester, Edinburgh and Glasgow, to ensure we tested in areas where all four MNOs had 4G and 3G coverage;
- was carried out by experienced Ofcom engineers from our specialist spectrum engineering teams; and
- involved a total of 210,000 individual tests.

We measured four distinct metrics:

- HTTP download speed – the rate at which data can be transferred from the internet to a user's device (such as downloading apps, music or other files);
- HTTP upload speed – the rate at which data can be transferred from the user's device to the internet (such as uploading photos or other content to social media sites);
- web browsing speed – the time that it takes to load a standard web page; and
- latency – the responsiveness of the network, measured by recording the time it takes for a small piece of data to travel to one point and return a response to the user's device.

Our testing, as with any research, has limitations on its scope and use. In particular, the following points must be considered when viewing the results:

- Our work only measured the performance of mobile data networks.
- The highest number is not necessarily the best for a given application, as other factors can affect performance (for example, although a higher download speed will indicate that a network is capable of transferring data at a faster rate, a lower recorded time for web browsing will be better, as this will mean that a web page loads faster).
- Some statistically significant differences in performance that have been recorded may not have a perceivable impact on the consumer experience.

- Performance can vary between devices, and we have only tested using smartphones.
- Networks are in the process of being rolled out. The performance recorded in our testing between March and June 2014 may not reflect the future (or even current) performance of the mature networks.
- 4G subscribers are still in the minority and networks may therefore be lightly loaded; in the future increased network congestion (contention) may result in performance decreases.
- Our measurements do not assess coverage.¹
- We have not measured the performance of specific services or applications that are delivered over mobile broadband.

1.3 Key findings

4G networks currently perform much better than 3G networks

Our results show that, on average, UK 4G networks perform much better than 3G networks. These differences are consistent across all mobile operators, and we would expect consumers to notice material differences in the performance of mobile broadband when using any 4G network compared to a 3G network.

- 4G download speeds were more than twice as fast as 3G speeds. The overall average speed for 4G was 15.1Mbit/s, while for 3G it was 6.1Mbit/s.
- Upload speeds over 4G were more than seven times faster than those on 3G. The overall average upload speed for 4G was 12.4Mbit/s, while for 3G it was 1.6Mbit/s.
- Web browsing was faster on 4G than on 3G. The average time taken to completely load a standard web page on 4G was 0.78 seconds, while for 3G it was 1.06 seconds.
- 4G networks had a lower latency than 3G networks. Across all of our test sites, as an average of all of the networks we tested, latency on 4G was 55.0ms, and latency on 3G was 66.8ms.

EE recorded higher download and upload speeds on 4G, while Three performed best at web browsing and latency

EE performed better on download and upload speed than any other MNO.. In relation to web browsing and latency, Three was found to have the better performance.

- The average HTTP download speed for EE on 4G was 18.4Mbit/s. For O2 this was 15.6Mbit/s, for Vodafone 14.3Mbit/s and for Three 10.7Mbit/s.
- EE and Vodafone had the fastest average 3G download speeds, at 6.8 and 6.7Mbit/s respectively. For O2 this was 5.6Mbit/s and for Three 5.2Mbit/s.

¹ While not derived from our testing, we do include coverage information in section 3.4 of this report.

- EE had the highest average 4G upload speed in the areas that we tested. EE's 4G upload speed was 14.7Mbit/s, followed by O2 with 13.0Mbit/s, Vodafone with 11.4Mbit/s and Three with 11.1Mbit/s.
- Three had the fastest 3G upload speed (1.7Mbit/s). For O2 and EE this was 1.6Mbit/s and for Vodafone 1.5Mbit/s.
- Three had the fastest web browsing speed over both 4G and 3G. The time taken to load a standard web page on Three was 0.62 seconds over 4G and 0.93 seconds over 3G. For both 3G and 4G, EE had the second fastest web browsing speed.
- Three had the lowest latency on 3G and on 4G. Three's 4G latency was 47.6ms while the highest latency on 4G was for O2, at 62.7ms.

1.4 Next steps

Ofcom has an ongoing programme of work focussing on the quality of mobile networks, of which mobile broadband performance plays a part. We will be undertaking further testing of mobile broadband performance in Q4 2014 and intend to publish an update to this report in Q2 2015.

Section 2

Introduction

2.1 Introduction

The objective of this report is to ensure that consumers have clear information about 3G and 4G mobile broadband network performance. This is consistent with Ofcom's duties under the Communications Act to further the interests of citizens in relation to communication matters and to further the interests of consumers in relevant markets, and to have regard, among other things, to the interests of consumers in respect of price, quality of service and value for money.

Ofcom regularly publishes research into the performance of the UK's fixed-line residential broadband services, examining how speeds and other performance metrics vary by a number of factors including geographical location, time of day, access technology and internet service provider (ISP) package. The latest fixed broadband speeds report was published in October 2014.²

Our mobile broadband performance research was designed to gather performance data on the UK's four main mobile networks, operated by Everything Everywhere (EE), Telefonica UK (O2), Vodafone UK (Vodafone) and Hutchison 3G UK (Three).³ The research was designed to allow comparison of the performance of 3G and 4G networks, both on average and between mobile networks.

The results in this report were collected between March and June 2014. Ofcom engineers measured the performance of mobile networks across five urban areas in the UK, using consumer devices. 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 the mobile network operators we tested. Our testing was undertaken using unbranded Samsung Galaxy Note 3 smartphones.

Ofcom previously published research into mobile broadband in the UK in May 2011.⁴ The 2011 report found that there were significant differences in performance by the type of network connection (the 2011 report detailed the difference between 2G, 3G and HSPA network connections), and that there were differences in performance between the operators. The data presented in the 2011 report are not comparable to those included in this report, as different methodologies and statistical frameworks were used.

Structure of the report

The remainder of this section

- sets out our regulatory duties in relation to this research;

² Ofcom, *UK fixed-line broadband performance, May 2014: The performance of fixed-line broadband delivered to UK residential consumers*, 3 October 2014, http://stakeholders.ofcom.org.uk/binaries/research/broadband-research/may2014/Fixed_bb_speeds_May_2014.pdf

³ In the rest of this report, we will use the abbreviations in brackets.

⁴ Ofcom, *Measuring Mobile Broadband in the UK: performance delivered to PCs via dongles/datacards September to December 2010*, May 2011, http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/bbspeeds2010/Mobile_BB_performance.pdf

- details the objectives of this research, including what was in scope and what was out of scope of the research;
- indicates the limitations of this research; and
- summarises the methodology used in collecting and analysing the data.

The rest of this report is structured as follows:

- Section 3 sets out the context for 4G in the UK, including the availability and take-up of 4G.
- Section 4 provides information on how to understand and use our results, detailing what we have measured and how these measurements might relate to consumer applications of mobile broadband.
- Section 5 details the results from our testing, looking at average performance across all services included in the research, and then comparing MNO performance.
- The annexes to this report detail the testing methodology and the statistical frameworks used to analyse the data that we have collected.

Further to this report, we are doing on-going work looking into mobile quality of service, including consumers' experience of phone calls.⁵

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 speeds 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 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, and to consider, and to such extent that Ofcom thinks fit, take account of the results in carrying out our functions.

⁵ Ofcom, *Consumer experiences of mobile phone calls*, 12 August 2014, <http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/consumer-experiences-mobile-phone-calls/report.pdf>

Ofcom has a programme of research into the performance of fixed-line broadband. As the use of mobile broadband to access the internet continues to increase,⁶ we believe that similar research into mobile broadband is important. Similarly, as the availability of 4G services and the take-up of smartphones increases, we want consumers to be well-informed about 4G, and to understand the differences between 4G and 3G mobile services.

We note that data network performance is only one part of mobile quality of experience. Coverage, quality of voice calls and customer service, among other considerations, will also play a part. This report is part of a programme of work which includes consumers' experience of phone calls.

2.3 Objectives

The intention of this research report is to help consumers understand the performance differences between 4G and 3G mobile services. This kind of research is designed to support consumers in choosing a mobile service that best suits their needs.

The scope of this research

This research was designed to gather a dataset that would enable us to assess the performance of mobile broadband delivered to consumer smartphones, across 3G and 4G and across the four national mobile network operators (MNOs). The fieldwork for this project was conducted from March 2014 to June 2014. Data were collected in five cities in the UK, using consumer handsets to undertake static testing in indoor and outdoor (in-vehicle) locations.⁷

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 across these cities, 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.

We collected a range of performance data including download speed, upload speed, web browsing speed and latency. We collected the 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.

The SIM cards used for the testing were provided to Ofcom by the MNOs. These were test SIMs, which were designed to have the same profile as a consumer SIM, with the exception that the data limits imposed on consumer SIMs were removed.⁸ We undertook benchmarking testing using shop-purchased consumer SIMs to ensure that the test SIMs

⁶ Our research shows that in Q1 2014, 57% of adults in the UK were using the internet on their mobile phone, an increase of 18 percentage points on the same period in 2012.

⁷ 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.

⁸ 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.

were performing in the same way as standard consumer SIMs and had not been optimised for our testing..

Outside the scope of this research

This research concentrated on the network performance of 3G and 4G networks, as delivered to smartphones, in areas where the four network operators were providing 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 provide 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);
- the performance of mobile virtual network operators (MNVOs);
- mobile voice services, messaging services, 2G services;
- drive and other forms of in-motion testing; and.
- analysis of mobile broadband services provided by WiFi. (We note that WiFi services are included in some mobile broadband tariffs and can contribute to the overall mobile broadband quality of experience offered to a consumer).

2.4 Limitations of this research

This report focuses on the relative performance of 3G and 4G networks, in the areas in which we tested, between March and June 2014. Our research did not test coverage, call quality, text messaging or any other aspects of mobile quality of service. Ofcom has a programme of work related to mobile quality of service, which includes the consumer experience of mobile phone calls.⁹

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 and other performance measures such as upload speeds, web browsing speeds and latency. Other factors relevant to consumers when purchasing mobile services (such as price, traffic management policies, data allowances, customer service, billing etc.) are not discussed in this report.
- The performance of mobile broadband depends to a large extent on the network coverage available. Although this report includes some coverage information, the research does not assess levels of network coverage. Coverage is dependent on a

⁹ Ofcom, *Consumer experiences of mobile phone calls*, 12 August 2014, <http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/consumer-experiences-mobile-phone-calls/report.pdf>

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 using a mobile network in the same location can affect service performance, and this, combined with coverage fluctuation, means that the performance available to any individual consumer will vary both by time and by location.
- This research report presents information on the state of mobile broadband performance between March and June 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. We will be undertaking further testing of mobile broadband performance in Q4 2014 and intend to publish an update to this report in Q2 2015

2.5 Summary of our methodology

Our methodology has been designed to measure the consumer experience of using mobile broadband, and 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 MNOs network, on 3G and on 4G, on a fair and equivalent basis.

The high-level approach to our methodology is as follows, and is set out in detail in Annexes 1 and 2 of this report. All of our testing was carried out by experienced and qualified Ofcom engineers, drawn from our specialist spectrum engineering teams.

Device-based testing, using publicly available equipment that is available to the consumer

We selected the Samsung Galaxy Note 3 smartphone on which to carry out our testing. This device was chosen as it is a Cat4¹⁰ device, and was available for purchase from all of the MNOs.

We chose a Cat4 device because, based on current network deployments, this type of device would remove the possibility that the limiting factor in any testing is the device rather than the network. Cat4 devices will also provide us with longer-term consistency, should we decide to undertake further testing, as it will be longer before they become obsolete.

Software-based testing, using industry-standard measurement software that can be loaded on to consumer devices without modifying the devices

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

¹⁰ 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.

Testing in public places in cities, in areas where 4G has been launched

To be able to compare 3G performance with 4G performance we needed to test in places where 3G and 4G were both available from all the operators to be tested. This was so that we had a consistent location that could 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 the networks were tested on an equivalent basis.

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

Testing indoors and outdoors

We tested an equal number of indoor and outdoor locations. We used a 50:50 ratio of indoor and 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. We note that using an equal split of indoor and outdoor locations may differ from consumers' actual practice in using mobile broadband on handsets. However, without evidence to indicate an appropriate ratio, we consider that a 50:50 ratio does not favour one type of location over another, and ensures that the minimum of bias is introduced between the two location types.¹¹

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

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 have occurred 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.

¹¹ Looking at the difference between our testing in indoor and outdoor locations, we have found a significant difference in performance between indoor and outdoor locations for only one operator, EE. Its average HTTP download speed in outdoor locations was 20.5 Mbit/s. For indoor locations, it was 16.4Mbit/s. This is likely due to the different frequencies of spectrum currently deployed by the operators for their 4G services.

- 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.

Quality control

Following the completion of testing at each of our test sites, we checked that the data had been uploaded to the database, that restrictive capping as a result of breaching data allowances had not taken place on our SIMs, and that the correct number of tests had been performed.

Each sample site delivered 192 readings for each metric – 128 on 4G and 64 on 3G. There were twice as many results on 4G due to the need to run two cycles of 4G tests. This was because we set out to test EE's 4GEE (single-speed) and its 4GEE Extra (double-speed) tariffs. We were unable to test these tariffs consecutively, as we would have been unduly contending EE's network by running simultaneous tests.

Where restrictive capping had occurred, the test site became invalid and we discarded the results. The test site was then retested with a SIM on which the data allowance had not been breached. Other circumstances in which results were discarded were:

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

We also undertook due diligence on our test process and commissioned a specialist third party to audit the process. No significant issues arose as a result of the audit.

Data processing

We set a target of testing 50 test sites in each of five cities in the UK where 4G was available of EE, O2, Three and Vodafone. Each test site became one sample point, providing a framework of 250 sample points for each network on each technology and 250 sample points each for 4G and 3G.

We then averaged all of the sample points to create an overall 4G average and an overall 3G average. For each network, the average of its results from all of our sample points produced an overall average for each network in the areas in which we tested.

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

The purpose of this was to ensure that each test site and each urban area made an equal contribution to the results, without discarding any of the results from the areas in which we had over-sampled.

Detailed information about our data processing procedure is set out in Annex 2.

Section 3

4G in context

3.1 Introduction

This section of the report provides some context to the results from our research. It:

- explains what 4G is and how it compares to 2G and 3G;
- sets out the availability and coverage of 4G as of June and October 2014
- discusses take-up and use of 4G services; and
- explains the importance of smartphones for mobile broadband.

3.2 What is 4G?

What is 4G?

4G is the fourth generation of mobile cellular communications technology. Each generation has offered new services and enhanced capacity for voice or data services. The fourth generation focuses on boosting mobile broadband performance, and has been designed primarily to deliver significant increases in mobile data capacity and performance.

The first generation of mobile telephony services was based on analogue transmission technology and delivered basic voice services only.

Second generation (2G) replaced the analogue technology with digital, providing increased capacity to serve more voice calls in any given band of spectrum. It also introduced basic low-speed data services using 2G enhancements such as GPRS and EDGE.

Third generation (3G) services used new digital technologies to provide dedicated data services with significant increases over 2G in data speeds. It also provided increased capacity for both voice and data, with later enhancements such as HSPA offering further improvements to data services.

Fourth generation (4G) was designed from the outset to deliver a high-performance mobile broadband data service centred around an internet protocol (IP) packet core and offering the promise of much faster broadband than 3G could deliver, alongside increased capacity to deliver these improved speeds to more consumers.

This means that for consumers 4G services are ideally suited to delivering data-intensive applications such as video streaming, mapping and social networking.

The increase in download speeds since Ofcom measured mobile broadband network performance in 2010 demonstrates the evolution of mobile cellular communications technology, as well as indicating how 3G performance has also improved in this time period.¹² In September to December 2010, we found that the average speed delivered to a panel of consumers using mobile broadband dongles or data cards with laptops was 1.5 Mbit/s. In March to June 2014 we found that the average 3G speed delivered to

¹² However, it should be noted that the 2011 report is not wholly comparable to this report due to the different devices, methodology and statistical frameworks which were used.

smartphones was 6.1Mbit/s – a significant increase – and that the average 4G download speed was higher still, at 15.1Mbit/s.

Figure 1: Mobile broadband speeds in 2010 and 2014



Source: Ofcom, *Measuring Mobile Broadband in the UK: performance delivered to PCs via dongles/datacards September to December 2010 research report*, May 2011; *Ofcom mobile broadband measurement, fieldwork March to June 2014*

Note: Data are not wholly comparable and are presented as an illustrative example only.

Spectrum and 4G services

Radio spectrum is a major asset to the UK, serving as a critical input to a wide range of services including mobile communications, television and radio broadcasting services, emergency services' communications, air travel and many more. Spectrum is necessary for all wireless services, including 4G mobile broadband, and Ofcom is responsible for managing spectrum use in a way that maximises its benefits to citizens and consumers.

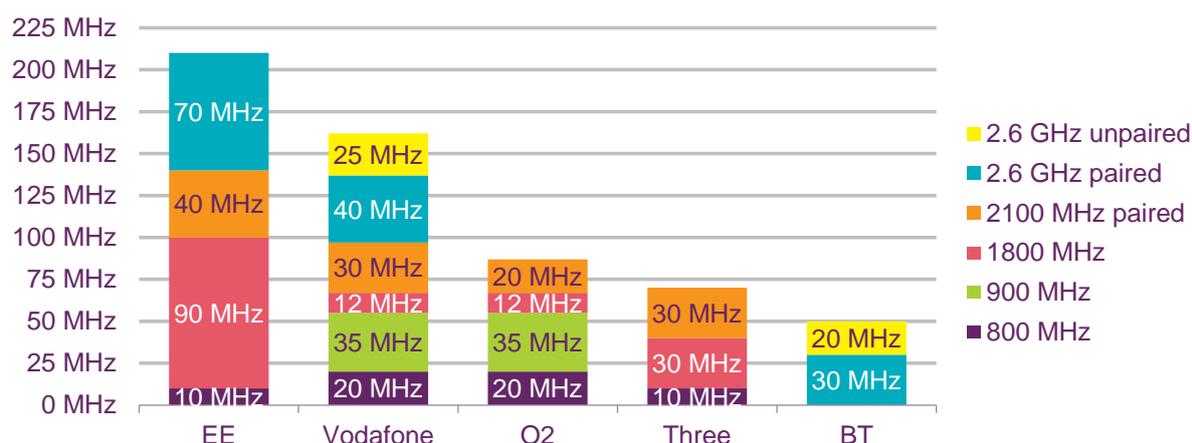
The spectrum used for mobile communications needs to be at frequencies that are capable of providing a combination of good coverage and sufficient capacity to ensure that high quality services can be delivered to many people at the same time.

In February 2013, the 4G spectrum auction concluded and the winners were announced. The spectrum awarded in the 4G auction comprised spectrum at 800MHz (which is particularly good for coverage) and at 2.6GHz (which has lots of capacity). However, this is not the only spectrum that can be used for 4G. We have also liberalised¹³ the spectrum bands that mobile operators already hold (and currently use, for 2G and 3G services), so that they can also be used for 4G services as and when suitable equipment becomes available. This change enabled EE to launch 4G services using its existing 1800MHz spectrum, ahead of the 4G auction.

A summary of the spectrum holdings of all MNOs is shown in Figure 2.

¹³ Liberalisation is the removal and/or reduction of restrictions on spectrum use.

Figure 2: UK mobile network operators' spectrum holdings



Source: Ofcom

Note: BT is included as a mobile network operator on the chart as it was awarded the spectrum indicated in the chart in the 2013 4G award process. BT is currently not yet using this spectrum to offer mobile services to consumers.

As the use of mobile broadband continues to grow, network capacity is likely to need boosting to avoid the risk of congestion and slowing download speeds. While operators will continue to improve their networks, extra spectrum may also be required. We will auction additional spectrum in the 2.3GHz and 3.4GHz bands in [2015/16]¹⁴, and have proposed that the 700MHz band could be made available from 2022¹⁵. We are also considering a number of other longer-term spectrum options¹⁶, and are working to ensure that the necessary international agreements are in place to enable their use.

3.3 Availability of 4G services

The UK's four national mobile network operators (MNOs) are currently building 4G mobile networks across the UK.

The first national mobile network operator to launch a commercial 4G service was EE, in October 2012, following liberalisation of its 1800MHz licence. EE initially launched in 11 cities.

Following the auction for UK 4G spectrum, O2 and Vodafone both launched 4G in August 2013, using the 800MHz spectrum they were awarded. Three trialed its 4G service to a limited base of users in London, Birmingham and Manchester in December 2013, enabling the service for all customers in coverage areas where 4G had been deployed in March 2014.

Figure 3 lists the MNOs, when they launched 4G, and the cities in which they launched and plan to launch, based on their own public announcements.

¹⁴ <http://stakeholders.ofcom.org.uk/binaries/consultations/pssr-2014/summary/pssr.pdf>

¹⁵ <http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/summary/main.pdf>

¹⁶ See Ofcom: *Mobile Data Strategy* <http://stakeholders.ofcom.org.uk/consultations/mobile-data-strategy/>

Figure 3: UK mobile network operators' 4G launch dates

Operator	Cities	Date of Launch
EE	London, Manchester, Bristol, Birmingham, Cardiff, Edinburgh, Leeds, Liverpool, Sheffield, Glasgow, Southampton	October 2012
EE	Derby, Newcastle, Nottingham	6 December 2012
EE	Belfast, Hull, Maidenhead, Slough	25 December 2012
EE	Bradford, Chelmsford, Coventry, Doncaster, Dudley, Leicester, Luton, Newport, Reading, Rotherham, St Albans, Sunderland, Sutton Coldfield, Walsall, Watford, West Bromwich and Wolverhampton	January – March 2013
EE	Altrincham, Bedford, Camberley, Crawley, Farnborough, Farnham, Maidstone, Rochdale, Tonbridge, Welwyn Garden City	24 July 2013
O2	London, Leeds, Bradford	29 August 2013
Vodafone	London	29 August 2013
Vodafone	Birmingham, Coventry, Leicester, Nottingham, Sheffield	26 September 2013
Vodafone	Glasgow, Edinburgh	24 October 2013
Vodafone	Manchester	30 October 2013
O2	Birmingham, Coventry, Edinburgh, Glasgow, Leeds, Leicester, Liverpool, Manchester, Newcastle, Nottingham and Sheffield.	19 November 2013
O2	Edinburgh, Newcastle, Huddersfield and Rotherham	21 November 2013
Vodafone	Newcastle	21 November 2013
Vodafone	Bradford, Leeds	28 November 2013
Three	London, Birmingham, Reading and Manchester	10 December 2013
Three	Aberdeen, Birmingham, Blackpool, Bolton, Bournemouth, Bradford, Brighton, Bristol, Cambridge, Cardiff, Coventry, Derby, Dundee, Edinburgh, Exeter, Glasgow, Gloucester, Huddersfield, Ipswich, Kingston Upon Hull, Leeds, Leicester, Liverpool, London, Luton, Manchester, Milton Keynes, Newcastle Upon Tyne, Northampton, Norwich, Nottingham, Oxford, Peterborough, Plymouth, Portsmouth, Preston, Sheffield, Slough, Southampton, Southend On Sea, Stoke On Trent, Stockport, Swindon, Watford and York.	Before end of 2014
Vodafone	Northern Ireland	12 June 2014

Source: Public statements and press releases from the MNOs

Ofcom's testing focused on five cities; Figure 4 sets out the cities in which Ofcom has tested and the date when 4G was launched by each MNO in those cities.

Figure 4: Ofcom's test cities and the mobile operators' 4G launch dates

Cities tested by Ofcom	Operator	Date of Launch
London	EE	October 2012
	Vodafone	August 2013
	O2	August 2013
	Three	December 2013
Manchester	EE	October 2012
	Vodafone	October 2013
	O2	October 2013
	Three	December 2013
Birmingham	EE	October 2012
	Vodafone	September 2013
	O2	November 2013
	Three	December 2013
Glasgow	EE	October 2012
	Vodafone	October 2013
	O2	November 2013
	Three	2014
Edinburgh	EE	October 2012
	Vodafone	October 2013
	O2	November 2013
	Three	2014

Source: Public statements and press releases from the MNOs

In addition to the four national MNOs, some MVNOs have started offering 4G services.

Coverage of 4G networks

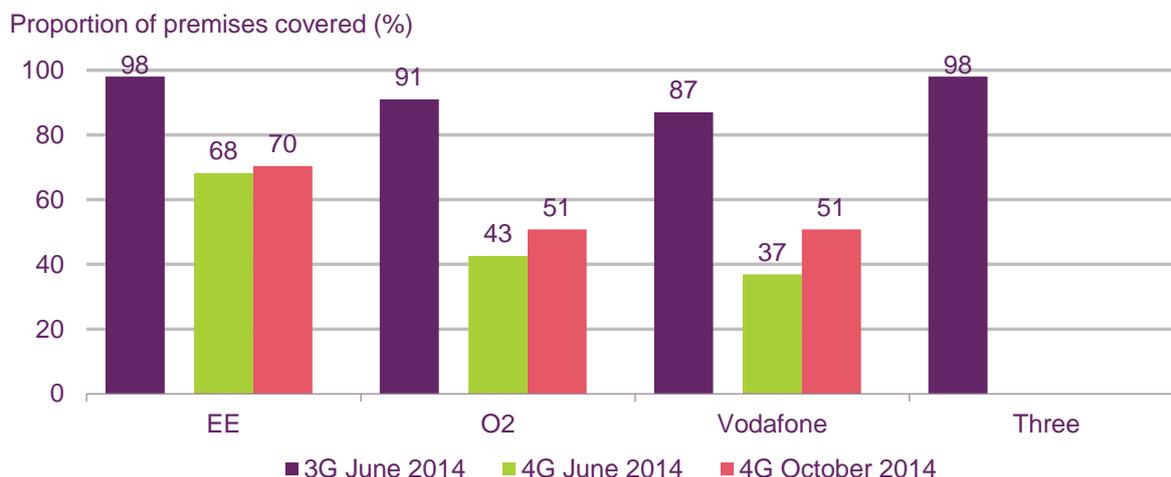
As shown in Figure 5, during the fieldwork period for our testing, EE's 4G services were available at 68% of UK premises, giving it the largest UK 4G network. At the time of our testing, O2 covered 43% of premises, Vodafone 37% .

Between June and October, all of the operators have increased the proportion of premises served by their 4G networks.. O2 and Vodafone now cover the same proportion of premises with their 4G services (51%). EE has increased coverage to 70%.

For all of the operators, 4G coverage is not as wide as their 3G coverage.

These coverage figures represent outdoor coverage and are based on detailed coverage maps provided to Ofcom by the operators. Further information on how these figures are produced, and maps of 3G and 4G coverage, can be found in Annex 3 of this report.

Figure 5: Estimated 3G and 4G premises coverage by national MNO: June and October 2014



Source: Ofcom based on predicted coverage data supplied by operators

Ofcom's methodology estimates premises with coverage, based on operator signal strength predictions. 3G and 4G data for EE, O2 and Vodafone, and 3G data for Three, are based on the operators' submissions, checked against Ofcom's own field measurements. In the time available it was not possible to resolve differences between Three's data and Ofcom's field measurements on 4G coverage, leading to its omission from this report. However, while not reporting estimates, Ofcom notes recent data, collected and published by OpenSignal¹⁷, shows Three has the lowest 4G coverage of the four national operators.

¹⁷ OpenSignal produce independent maps of mobile coverage using crowdsourced data from an App downloaded on Android and iOS. OpenSignal measure coverage based on how often a user running one of their apps can connect to a 3G or 4G network. By checking this automatically every 15mins they can build up a geographical picture of where 3G and 4G services are available and calculate the average time that users of a given mobile network can access 3G and 4G services. A higher number suggests that operator has better coverage. Note that these numbers are not a percentage of geographical area covered by mobile networks.

The report is available here: <http://opensignal.com/reports/2014/10/uk-networks-report/>

3.4 Take-up and use of 4G

4G is now offered by all four national mobile network operators (MNOs). Ofcom research estimated that there were over 6 million 4G mobile subscriptions in the UK at the end of March 2014 when we started our fieldwork.¹⁸ This was equivalent to approximately 8% of all active mobile subscriptions.

This represents a significant increase compared to March 2013, when EE, the only UK 4G provider at that time, announced that it had 318,000 4G subscriptions (end of March 2013),¹⁹ accounting for less than 0.5% of all UK mobile subscriptions.

Take-up of 4G has increased further since March 2014, and as of Q2 2014 there were an estimated 9.2 million 4G mobile subscriptions across the four national MNOs. EE had 4.2 million 4G subscriptions, O2 2.1 million, Three 2 million and Vodafone 0.9 million.²⁰

As Three is offering its 4G services to all of its subscribers with a 4G-enabled handset in areas where it has 4G coverage, at no additional cost, all Three subscriptions are theoretically 4G-capable. However, not all of Three's subscribers are using 4G-ready devices and some of these will be in areas where Three's 4G services are not yet available.

The four national MNOs have suggested that consumers with 4G subscriptions tend to use more data than 3G users. In its financial results for January to March 2014, Telefonica (O2) said that on average, its UK 4G subscriptions consumed twice as much data as its 3G subscriptions.²¹ Higher data use might be partly due to the faster download speeds available on 4G, or possibly because higher data users are the first to move to 4G.

The capability of 4G services to provide faster download speeds is reflected in the higher levels of use of mobile networks by 4G users to access video content (Figure 6). In April 2014, 59% of smartphone owners who use 4G said that they had downloaded or streamed video content over a mobile network at least once; this compares to 41% of non-4G users. However, there were no statistically significant differences in levels of use of email, mobile apps, accessing music content or making VoIP calls between 4G and non-4G users. This is likely to be because these services all require relatively little data bandwidth and can be performed efficiently on a 3G network.

¹⁸ Ofcom, *The Communications Market Report 2014*, 7 August 2014

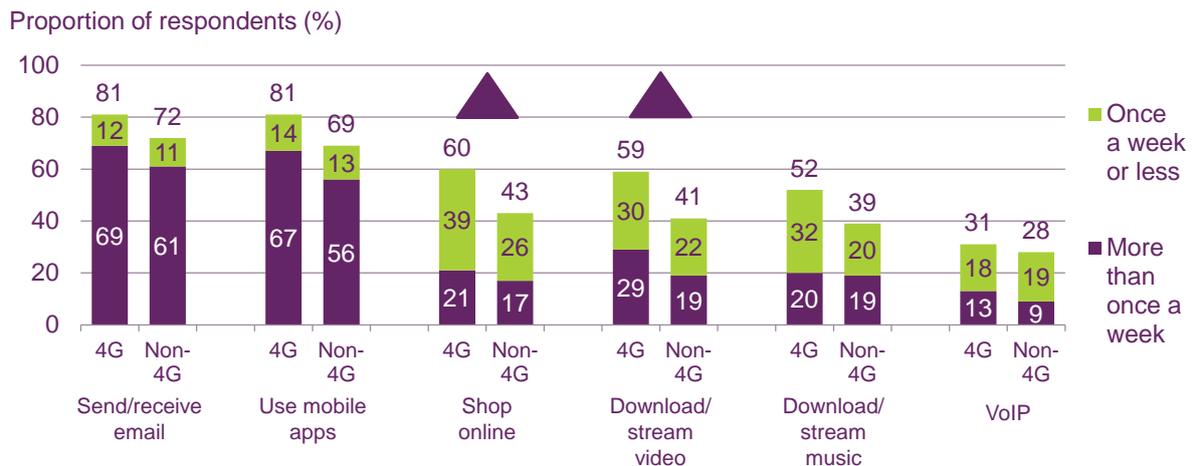
¹⁹ EE, *EE results for the first quarter to 31 March 2013*, 23 April 2013 [<https://explore.ee.co.uk/our-company/newsroom/ee-results-for-the-first-quarter-to-31-march-2013>]

²⁰ Williams, C, 'Vodafone market share hit by high 4G prices', *The Telegraph*, 13 August 2014; citing data from operators' investors reports and announcements.

²¹ Telefonica, *Results: January to March 2014*,

http://www.telefonica.com/en/shareholders_investors/pdf/rdos14t1-eng.pdf

Figure 6: 4G and non-4G mobile use of mobile services (April 2014)



Source: Ofcom mobile coverage questionnaire

Base: All respondents with a smartphone and aware of services they receive with 4G, n=125

Question: Q20 How often, if at all, do you use your main mobile phone to...?

Note: Statistically significant differences in overall use of mobile services between 4G and non-4G respondents are indicated by triangles.

For a significant minority, data caps may restrict the amount of data that is used

Most of the tariffs offered by the national mobile network operators in the UK include a data cap. This is an allowance of data use which is included within the cost of the contract. Any data used by the customer outside this allowance in the monthly billing period may be subject to additional costs. Ofcom research indicates that 28% of those who use 3G and/or 4G connections claim to limit their use of data to avoid paying additional costs outside the standard cost of their contract (Figure 7). There was no significant difference in agreement with this statement between those on 3G contracts and those on 4G contracts.

Figure 7: Proportion of people who claim to limit their data use to stay within their contracted data allowance



Source: Ofcom research into use of and attitudes toward cellular and WiFi data use

Base: All who use 3G/4G (N=766) Question: Which of the following statements apply to you?

The data caps in place on 4G tariffs vary by operator, as Figure 8 shows. All of the operators offer tariffs with a range of data caps, with 500MB being the lowest offered (by all but Vodafone) and 50GB being the highest of those that are capped, offered only by EE. Three is the only operator to offer a tariff with unlimited 4G data. All of the other tariffs include a restriction on the volume of data included within the monthly allowance. In October 2014, a SIM-only 12-month contract with unlimited data from Three was priced at £15. The closest priced tariff from EE (£15.99) includes just 2GB of data. The closest priced tariff from O2, at £16, offers 1GB of data, as does the closest price tariff from Vodafone, at £16.50.

Figure 8: Data allowances on 4G tariffs offered by EE, O2, Vodafone and Three

	EE	O2	Vodafone	Three
Unlimited				✓
50GB	✓			
20GB	✓	✓	✓	
10GB	✓		✓	
8GB		✓		
7GB			✓	
5GB	✓	✓		
4GB			✓	✓
2GB	✓	✓		✓
1GB	✓	✓	✓	✓
500MB	✓	✓		✓

Source: Pure Pricing

3.5 The use of smartphones in the UK

Smartphones are becoming one of the most-used media and communications devices in the UK. As of Q1 2014, 61% of UK adults owned a smartphone and 57% of adults used data services on a mobile phone²²

Recent consumer research undertaken by Ofcom explored the services and applications that people access over the internet using their smartphones. A selection of the findings of this research is highlighted here to provide context to the mobile broadband performance results in Section 5 of this report.

The remainder of this section of the report investigates how smartphones are being used by consumers regardless of the network used to connect, and it therefore captures use across 2G, 3G, 4G and WiFi.

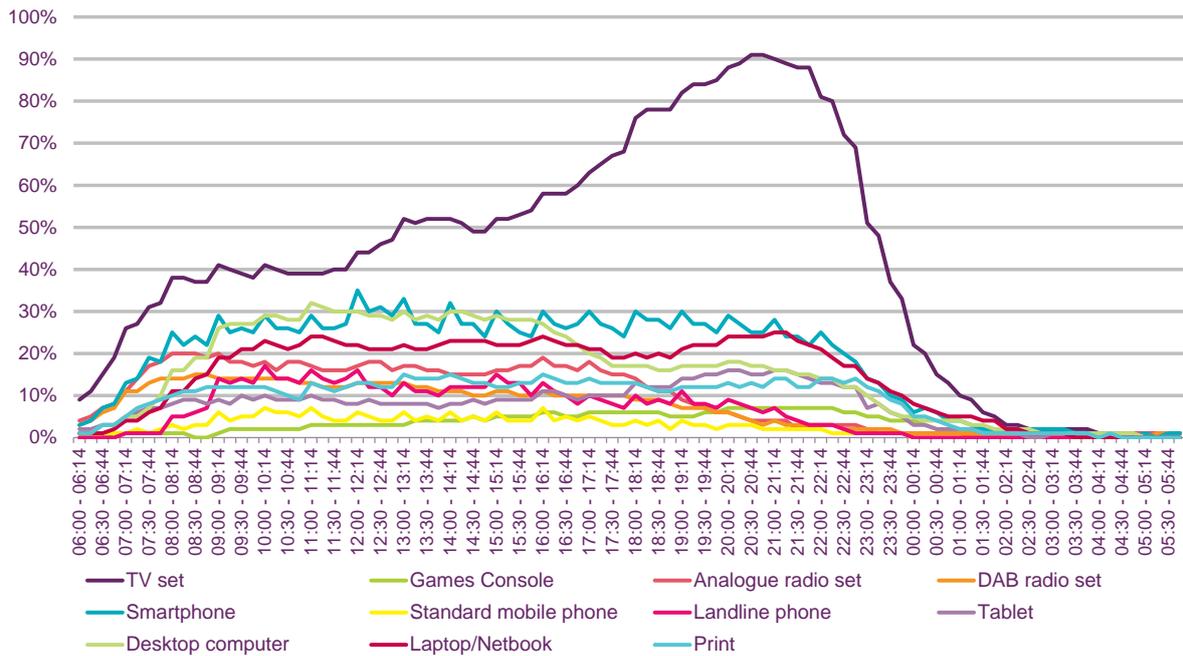
In Q1 2014, Ofcom undertook in-depth diary-based consumer research to understand how UK adults and children used media and communications services throughout the day. This research explored both personal and business use, and in- and out-of-home use, over a seven-day period.

This research found that smartphones maintain a steady reach²³ of approximately 25% to 30% of UK adults throughout the day from 8am to 10pm, and from 4pm to 10pm they are the second most-used device, after TV sets (Figure 9).

²² Ofcom, *The Communications Market Report 2014*, August 2014, pp.365-6

²³ 'Reach' is a calculation of the proportion of users who have reported using a device for at least one minute.

Figure 9: Weekly reach of devices, across the day

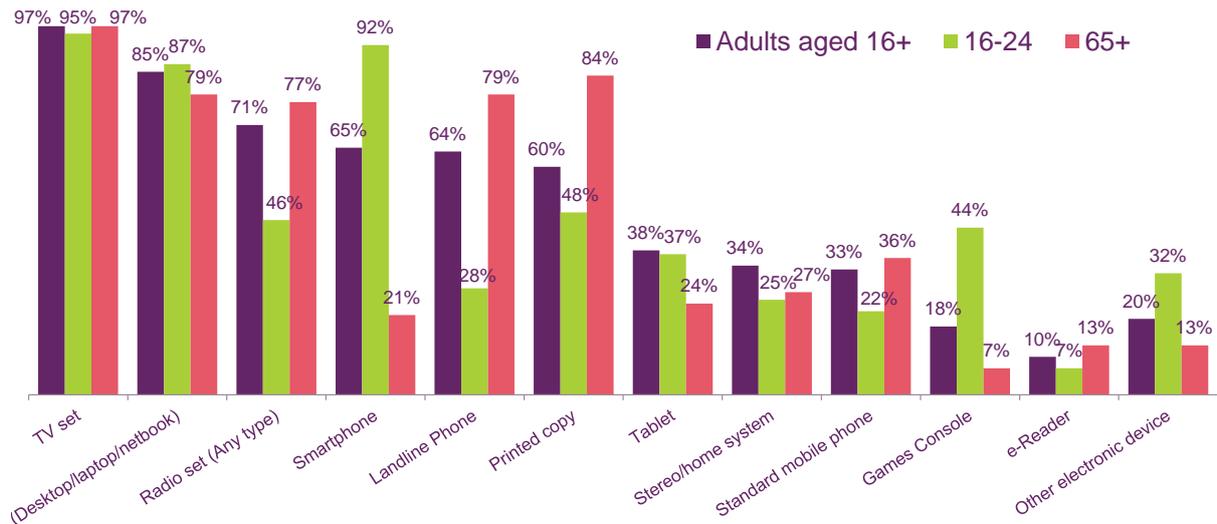


Source: Digital Day 7-day diary
 Base: All adults 16+ (1644) - data aggregated to 15-min slots

Two-thirds (65%) of adults use a smartphone each week

In the UK 65% adults had used a smartphone during the diary week, rising to 92% of those aged 16-24. UK adults are spending an average of 1 hour 22 minutes on their smartphones each day; this includes simultaneous activity, such as using the smartphone while watching TV, or doing another media or communication activity.

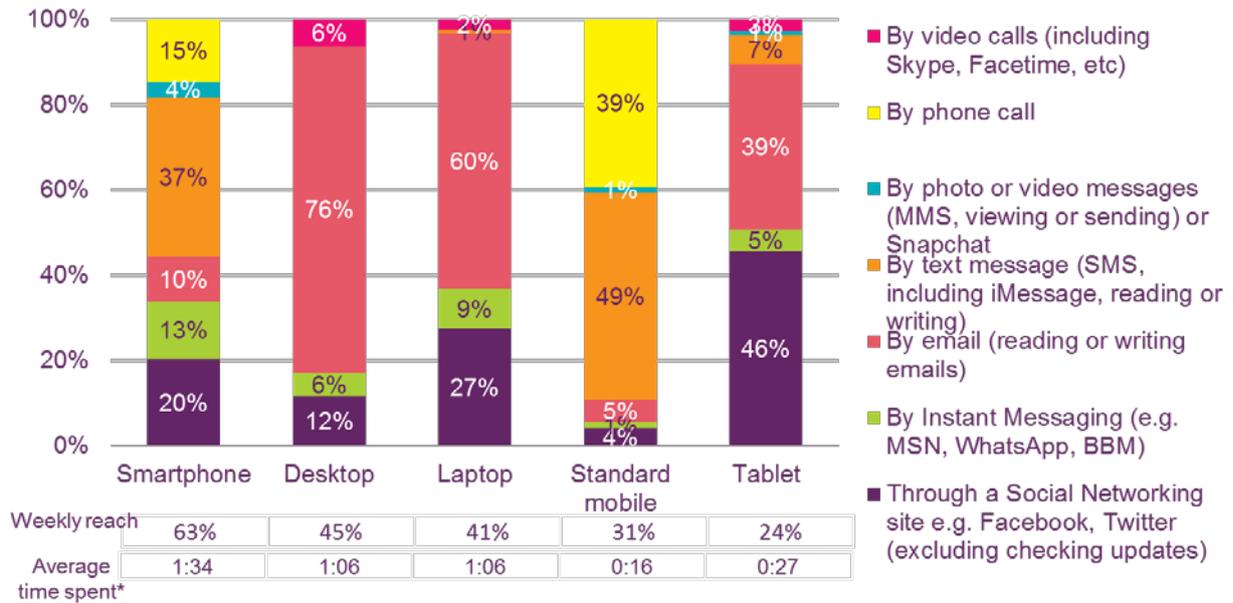
Figure 10: Weekly reach of devices, by age: 16-24 and 65+



Source: Digital Day 7-day diary
 Base: All adults aged 16+ (1644), 16-24 (101), 65+ (259)
 Ranked by % reach of all adults

Just over half (52%) of smartphone communication activities are accounted for by calls and texts. Figure 11 shows that almost two-fifths (37%) of communication activities on a smartphone are taken up by text messaging, while phone calls account for 15%. Emails account for 10%, instant messaging for 13% and communication through social networking accounts for 20%.

Figure 11: Proportion of communication activities, by device



Source: Digital Day 7-day diary

Base: All communication activity records for adults 16+ (37827)

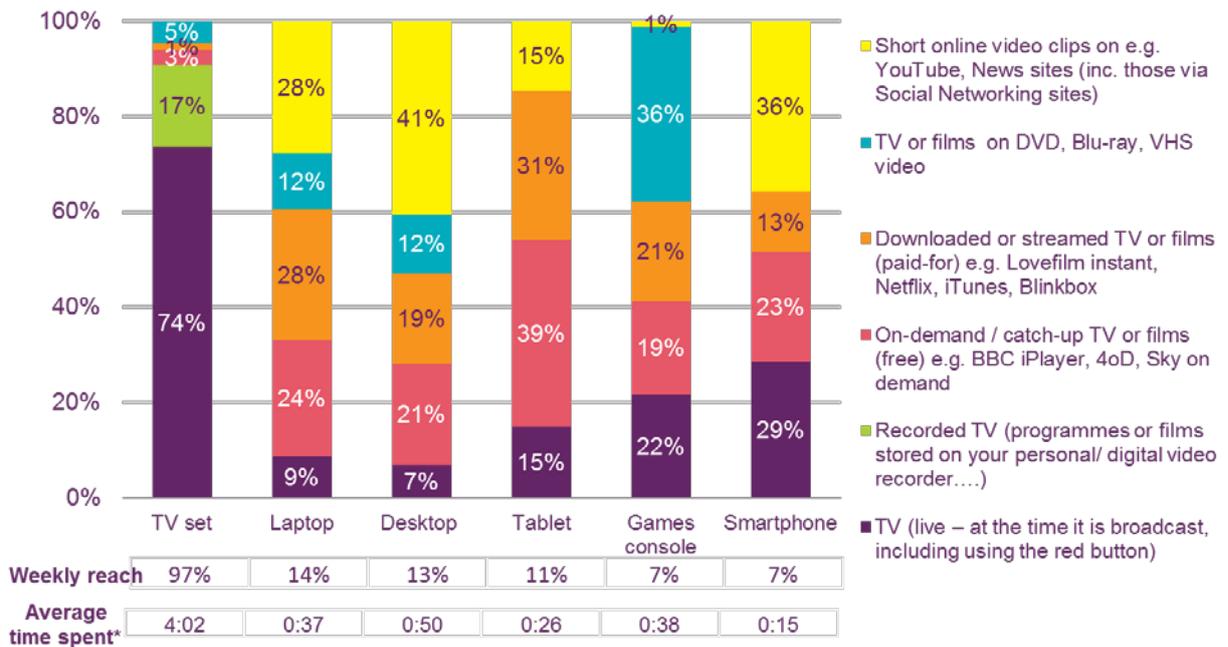
*Average time spent is the average time spent on each device per day for communicating, among those who did it all over the week

Weekly reach is for communication activities. Only devices with weekly reach for communication above 3% shown

Less than one in ten respondents used their smartphone to watch audio-visual content

While smartphones are used for a range of communications activities, Figure 12 shows that they are also used for watching activities, including video clips. However, less than one in ten (7%) of our respondents had used a smartphone to watch content, and those that did spent an average of 15 minutes per day doing so. The most likely content to be watched on a smartphone was short online clips, from providers such as YouTube. One third of all time spent watching audio-visual content on a smartphone was spent watching short video clips online.

Figure 12: Proportion of watching activities, by device



Source: Digital Day 7-day diary

Base: All watching activity records for adults 16+ (25272)

*Average time spent is the average time spent on each device per day for watching, among those who did it all over the week

Weekly reach is for watching activities. Only devices with weekly reach for watching above 3% shown

Section 4

Understanding and using our results

4.1 Introduction

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

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

4.2 What we measured

We measured four distinct metrics:

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

These metrics capture important aspects of mobile broadband network performance. We note that other metrics can be used to characterise 4G or 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.

As a result 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 10 Mbit/s, this would be just over eight seconds.²⁴

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, images as well as 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 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 the content is being delivered over. 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.

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.

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 smartphones to represent a typical HTML web page.²⁵

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.

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.

²⁴ 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.

²⁵ 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

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).

4.3 How these metrics are measured.

All our measurements have been undertaken using Spirent's Datum software testing application. The descriptions below explain what Datum does to measure each metric.

HTTP download speed – higher number is faster

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 calculated by dividing the amount of data received by the 30-second period, to produce a metric of megabits per second (Mbit/s). This indicates the speed at which a network has downloaded data using HTTP.

HTTP upload speed – higher number is faster

Measured by initiating the upload of 100 MB 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 the 15-second period. As with download speed, this produces a metric of megabits per second (Mbit/s).

Web browsing speed – lower number is faster

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).

Latency – lower number is faster

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).

4.4 Comparing our metrics to real services and applications

Our tests measure network performance. These types of metric 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 their customers. This includes re-encoding video to reduce the bit rate, cacheing 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 so 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.

4.5 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 experience.
- Performance can vary between devices; we have just tested on smartphones.
- Networks are in the process of being rolled out. The measured performance may not reflect the current or future performance of the mature networks
- 4G subscribers are still in the minority and therefore networks may be lightly loaded. In future higher loading may lead to a reduction in performance. Similarly, as the 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.

Section 5

Our results: mobile broadband network performance

5.1 Introduction

This section of the report sets out the results from our testing, as below:

- HTTP download speed as an aggregated average across all networks, on 4G and 3G
- HTTP download speed as an aggregated average across all networks, on 4G and 3G, split by the areas in which we tested
- HTTP download speed on each network, on 4G and 3G
- HTTP upload speed as an aggregated average across all networks, on 4G and 3G
- HTTP upload speed as an aggregated average across all networks, on 4G and 3G, split by the areas in which we tested
- HTTP upload speed on each network, on 4G and 3G
- Web browsing speed as an aggregated average across all networks, on 4G and 3G
- Web browsing speed as an aggregated average across all networks, on 4G and 3G, split by the areas in which we tested
- Web browsing speed on each network, on 4G and 3G
- Latency as an aggregated average across all networks, on 4G and 3G
- Latency as an aggregated average across all networks, on 4G and 3G, split by the areas in which we tested
- Latency on each network, on 4G and 3G

These results represent the network performance at the times that we tested in the areas where we took our measurements. Figure 13 shows the dates and locations of our fieldwork.

Figure 13: Areas and dates of our fieldwork

City	Dates of testing	Additional testing
Birmingham	28 April to 30 May 2014	26 June 2014
Edinburgh	28 April to 30 May 2014	-
Glasgow	24 March to 25 April 2014	-
London	24 March to 24 April 2014	11-12 & 24-25 June 2014
Manchester	18 March to 23 April 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.

5.2 HTTP download speed on 4G and 3G as an overall average

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.

These results show the average rate at which data could be downloaded 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 to produce an average for each technology. The second set of results (for download speed) look at the average speed of each of the networks in the areas tested and the distribution of speeds by sample point for each network across 4G and 3G.

Information on how we have processed the raw data from our tests is included in Annex 2 of this report.

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

Across all of the networks in the areas where we tested, the overall average 4G download speed was around 2.5 times faster than the average 3G download speed. The average 4G download speed was 15.1Mbit/s and the average 3G download speed was 6.1Mbit/s.

Figure 14: Average overall 4G and 3G HTTP download speeds



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

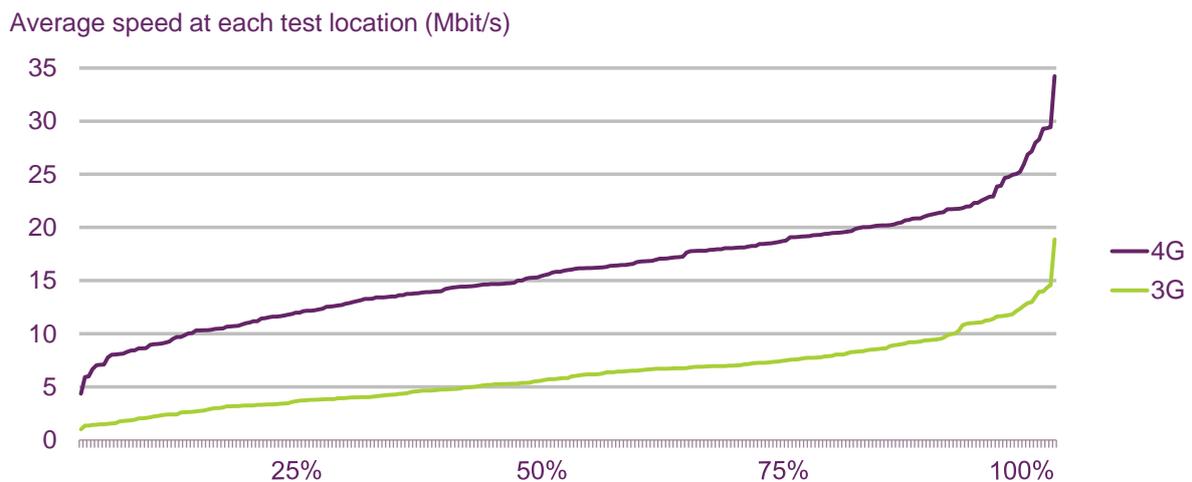
Note: Average of all 4G tests and all 3G tests

Half of 4G download speeds are above 16.0Mbit/s

Across all of the networks in the areas in which we tested, we found that half of our test locations resulted in an average 4G download speed of 16.0Mbit/s or above. As an average of all networks, the highest speed for 4G was 34.2Mbit/s. This was significantly faster than the highest speed for 3G, which, as an average across all networks, was 18.9Mbit/s.

The speed advantage of 4G is demonstrated in Figure 15, which shows that 25% of test locations resulted in an average HTTP download speed for 4G that was faster than the maximum average speed recorded for 3G.

Figure 15: Distribution of 4G and 3G HTTP download speeds



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

Note: Average speed at 4G and at 3G at each test location.

The lowest average speed for 4G was faster than 33% of average 3G speeds

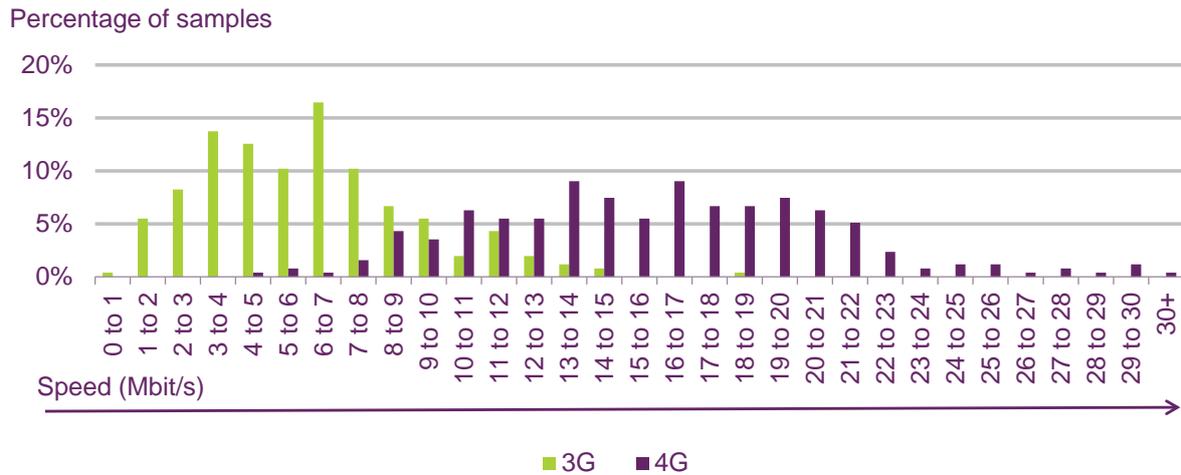
The distribution of download speeds shows that currently 4G provides a significant speed advantage over 3G. Ten per cent of our test locations resulted in an average 3G speed that was higher than 10Mbit/s, while 89% of our test locations resulted in an average 4G speed higher than 10Mbit/s. The lowest average speed recorded for 4G across all networks was 4.4Mbit/s – this was higher than 33% of the average 3G speeds.

Taken as an average across all of the networks and all of the areas in which we tested, 3G download speeds were between 1.0Mbit/s and 18.9Mbit/s. For 4G, the absolute range of results was wider, spanning from 4.4Mbit/s to 34.2Mbit/s.

Between the first and third quartile for these results (the middle 50% of tests), download speeds on 3G ranged between 3.8Mbit/s and 7.7Mbit/s. For 4G, again this was wider, ranging between 12.4Mbit/s and 19.2Mbit/s.

It should be noted that 4G networks are still lightly loaded, as subscriber numbers are still low, and therefore the impact of network contention (as more people use 4G services) could reduce the speed difference between 3G and 4G over time. Equally, networks are still being rolled out and optimised by MNOs, and this could improve the speed performance of 4G over 3G.

Figure 16: Distribution of 4G and 3G HTTP download speeds



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

In the cities where we did our testing, the highest average download speed for 4G was in Edinburgh

Averaging the results for all of the networks in each of the cities where we tested shows that the highest average speeds for 4G and for 3G were in Edinburgh. The average 4G speed for Edinburgh was 16.8Mbit/s and the average 3G speed was 7.8Mbit/s.

Speeds were also higher than average, for both 4G and 3G, in Glasgow and Manchester, with no significant differences between the average 4G speeds of 16.4Mbit/s and 16.1Mbit/s in these two cities.

The lowest average speeds for 4G were in London, which had an average 4G download speed of 13.1Mbit/s and the lowest 3G download speed (4.1Mbit/s).

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

Figure 17: Average 4G and 3G HTTP download speeds, by test location



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average of all 4G tests and all 3G tests, by test location.

Figure 18: Average 4G and 3G download speeds, by test location: significant differences

	4G faster than:	3G faster than:
Birmingham	London	London
Edinburgh	Glasgow, Manchester, Birmingham, London	Glasgow, Manchester, Birmingham, London
Glasgow	Birmingham, London	Birmingham, London
London	-	-
Manchester	Birmingham, London	Birmingham, London

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

Our methodology was designed to treat each network equally. We tested each network at the same time and in the same 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 where all operators had 4G coverage, this was not always possible. Three was at an early stage of its 4G roll-out when we tested and there were some locations where we were unable to obtain a 4G signal. We have examined the data to ensure that no bias has been introduced into the results from this. The process of this is explained in detail in Annex 2. The coverage of the four networks as of June and October 2014 is set out in section 3.4 of this report.

As EE offers two 4G services, with a clear differentiation on speed²⁶ between the two tariffs, we set out to test two tariffs for EE, and take measurements for its 4GEE and 4GEE Extra tariffs. As set out in our methodology, we have used test SIMs provided by the operators to do our testing. These test SIMs had the volumetric data caps removed. This meant that we were able to use significant amounts of data without the necessity of managing large numbers of SIMs to ensure we did not breach the data limits included on most consumer tariffs. Breaching the data caps of consumer tariffs may have potentially led to traffic management policies affecting our testing. As EE does not test its network using SIMs that are profiled to its 4GEE (single-speed) tariff, it was unable to provide test SIMs for this service.

To be able to test the 4GEE service, we procured consumer SIMs on the 4GEE tariff. However, the SIMs that we procured, while not being 4GEE Extra, were provisioned to be 'double speed'. We were therefore unable to test the single speed tariff from EE and found no significant difference between the performance of our consumer SIMs and the EE test SIMs. We note that in its recent tariff refresh, EE offers double speed on its 4GEE tariff where the data allowance is 2GB or above.²⁷

We have decided that as the results for EE's two tariff families were the same, that there was no benefit in publishing the results separately. The charts and analysis that follow include the findings for those tests undertaken on the test SIMs provided by EE and therefore include only one series for EE.

²⁶ We note that speed is not the only differentiation between the tariffs, and the 4GEE Extra tariff also includes other features to distinguish it from the 4GEE tariff.

²⁷ EE, *Price plan guide: SIM only; Available from 17 September 2014*, September 2014, http://ee.co.uk/content/dam/ee-help/Help-PDFs/EE_PAYM%20SIMO%20post%20170914.pdf

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

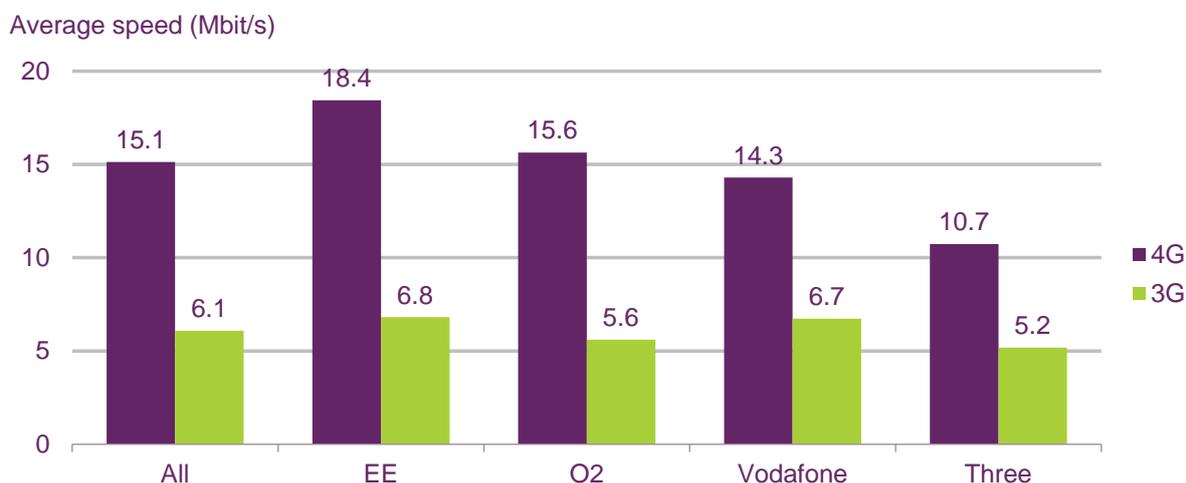
The fastest average speeds, taken across all of the sample sites in our testing, were for EE at 18.4Mbit/s.

The lowest average 4G speed across all of the cities where we tested was for Three at 10.7Mbit/s. For O2, the average 4G download speed was 15.6Mbit/s and for Vodafone it was 14.3Mbit/s. For all of the operators, the average 4G speed in the areas where we tested was at least twice as fast as the average 3G speed.

For 3G HTTP download speeds, EE and Vodafone had the fastest average speeds, with no significant difference between the average 3G speed on these networks. The average speed on 3G for O2, at 5.6Mbit/s, was faster than Three at 5.2Mbit/s.

However, we note that download speed alone does not provide a complete indication of network performance, and measures of web browsing speed and latency should also play a part in a full consideration of performance.

Figure 19: Average 4G and 3G HTTP download speeds, by provider



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

Note: Average of all 4G tests and all 3G tests, by operator. The sample size for Three on 4G is smaller than for the other MNOs (159 vs 254) due to its having a smaller coverage area at the time of testing.

Figure 20: Average 4G and 3G HTTP download speeds, by provider: significant differences

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

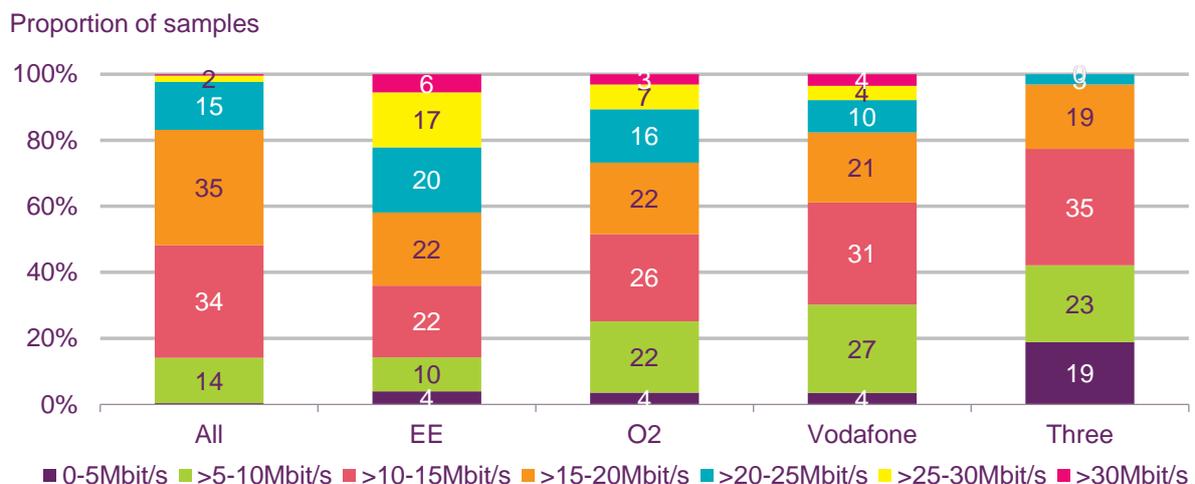
Note: Differences are significant to a 95% confidence interval

Almost 60% of Vodafone and Three’s 4G HTTP download speeds were between 5Mbit/s and 15Mbit/s

The distribution of 4G HTTP download speeds by network is set out in Figure 21. For all networks, the majority of download speeds recorded in our testing were above 10Mbit/s. For EE, over 40% of our sample points produced an average download speed of 20Mbit/s or above. For O2, 27% of sample points were above this speed, for Vodafone 18% and for Three 3%.

While Three also had the highest proportion of download speeds up to 5Mbit/s (19%), over one-third of sample points produced a speed between 10 and 15Mbit/s for Three, and 19% of sample points produced a speed between 15 and 20Mbit/s.

Figure 21: Distribution of 4G HTTP download speeds, by network



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

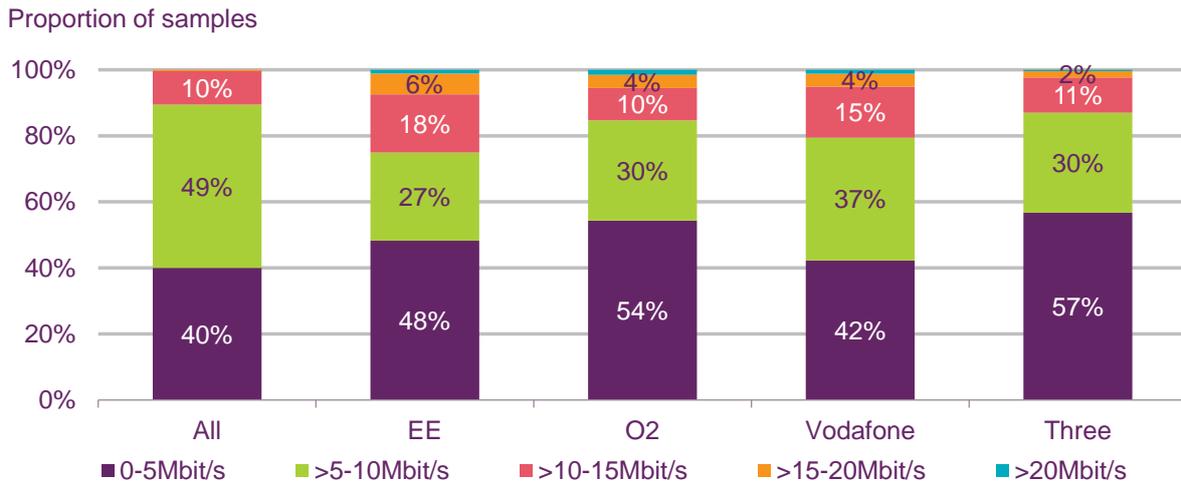
Note: Average speed at 4G and at 3G at each test location.

One in four (25%) of 3G speeds for EE were above 10Mbit/s

More than half of 3G HTTP download speeds for O2 and Three were 5Mbit/s or below. Vodafone had the greatest proportion of 3G download speeds higher than 5Mbit/s (58%), followed by EE (52%). Over one third of Vodafone’s 3G download speeds were between 5 and 10Mbit/s – for the other three MNOs, 30% of 3G download speeds, or less, were between this range.

EE had the largest proportion of 3G download speeds above 10Mbit/s, with 25% of locations resulting in average speeds above this. For Vodafone, 21% of average 3G speeds were above 10Mbit/s. For O2, the figure was 16%, and for Three it was 13%.

Figure 22: Distribution of 3G HTTP download speeds, by network



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average 3G speed at each test location.

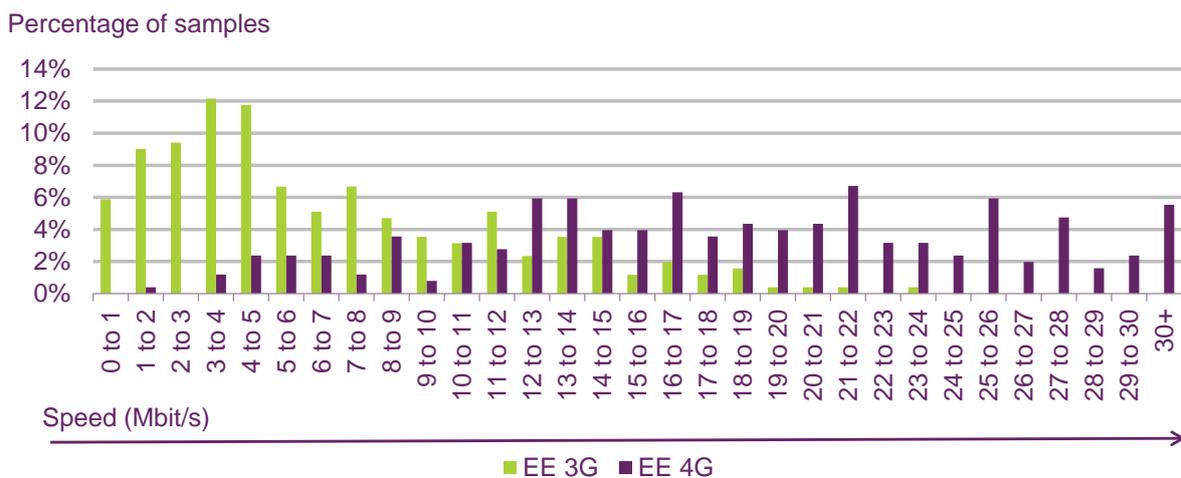
For EE, average 4G download speeds higher than 30Mbit/s were recorded at 6% of test locations

The fastest average 4G download speeds in our testing were recorded for EE. Over 4G, the highest average download speed was 49.6Mbit/s.

The average 4G download speed for EE was 18.4Mbit/s. Between the first and third quartile for these results (the middle 50%), download speeds for EE on 4G were between 12.9Mbit/s and 23.9Mbit/s. For 3G, it was between 3.0Mbit/s and 10.0Mbit/s.

Just less than half (48%) of 3G download speeds on EE were below 5Mbit/s – for 4G, fewer than 5% of results were below 5Mbit/s.

Figure 23: Distribution of 4G and 3G HTTP download speeds: EE



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

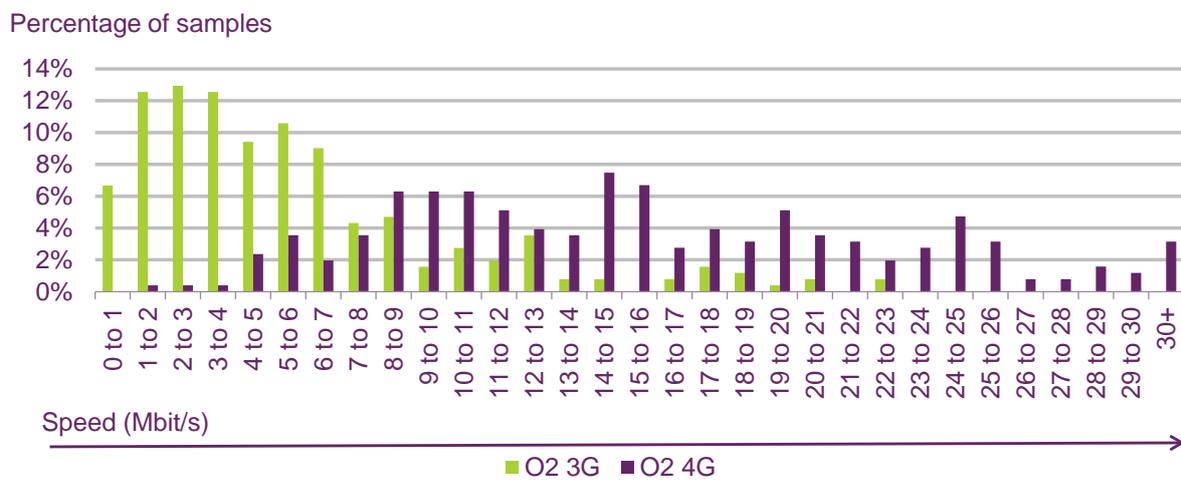
O2's average 4G download speed was 15.6Mbit/s

Across the areas in which we tested, O2's 4G download speeds were between 1.2Mbit/s and 44.4Mbit/s. As Figure 24 shows, the majority of our sample sites resulted in 4G download speeds above 5Mbit/s for O2.

Between the first and third quartile for these results (the middle 50%), download speeds for O2 on 4G were between 9.8Mbit/s and 20.5Mbit/s. The range of results for 3G was narrower, ranging from 2.5Mbit/s at the first quartile to 7.3Mbit/s at the third quartile.

While there is a clear concentration of 3G download speeds for O2 between 1Mbit/s and 7Mbit/s, as shown on Figure 24, only a minority of test locations have resulted in 3G download speeds far higher than this. Five per cent of our test locations resulted in a 3G download speed between 15Mbit/s and 23Mbit/s.

Figure 24: Distribution of 4G and 3G HTTP download speeds: O2



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

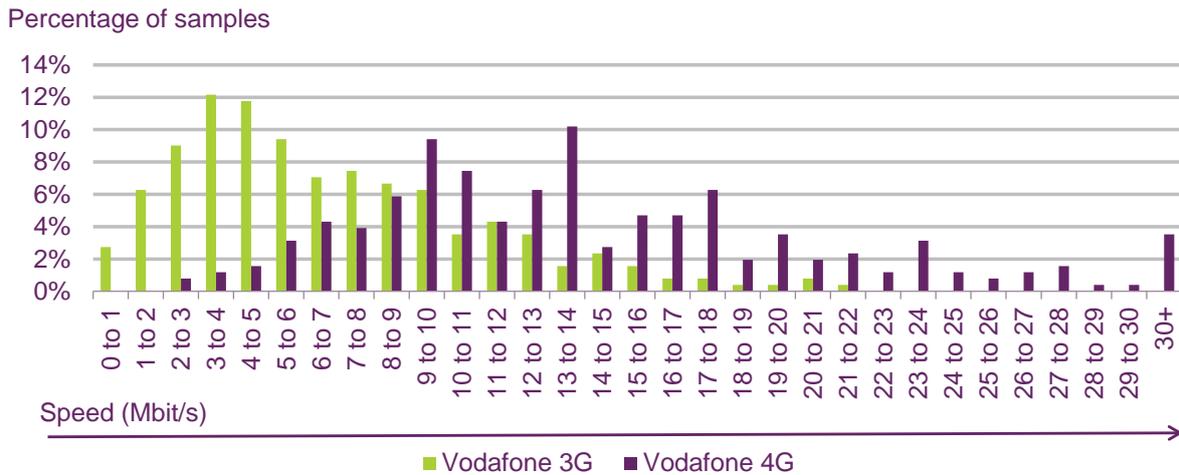
Note: Average speed at 4G and at 3G at each test location.

Vodafone's average 4G download speed was 14.3Mbit/s

Across the areas in which we tested, Vodafone's 4G download speeds were between 2.1Mbit/s and 36.5Mbit/s. As Figure 25 shows, almost all of our sample sites resulted in average 4G download speeds above 5Mbit/s for Vodafone.

Between the first and third quartile for these results (the middle 50%), download speeds for Vodafone on 4G were between 9.5Mbit/s and 17.5Mbit/s. This range for 3G was narrower, ranging from 3.6Mbit/s at the first quartile to 9.4Mbit/s at the third quartile.

Figure 25: Distribution of 4G and 3G HTTP download speeds: Vodafone



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

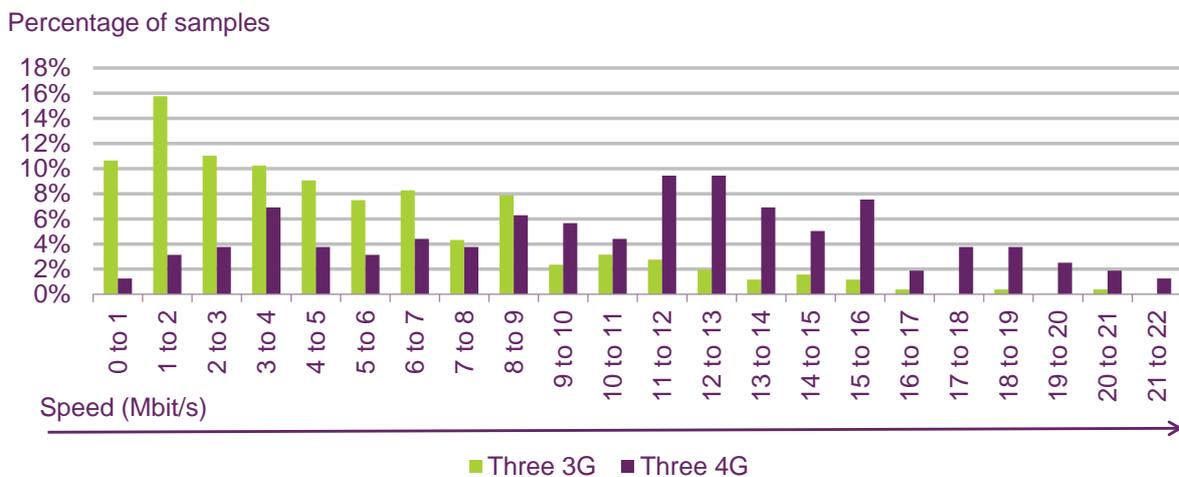
Three’s 4G download speeds ranged between 0.8Mbit/s and 21.5Mbit/s.

Three was the only network where our testing did not record an average download speed on 4G at any of our sample points in excess of 22Mbit/s. 4G download speeds on Three ranged between 0.8Mbit/s and 21.5Mbit/s.

Between the first and third quartile for these results (the middle 50%), download speeds on 4G were between 6.7Mbit/s and 14.4Mbit/s. This range for 3G was narrower, ranging from 2.0Mbit/s to 7.8Mbit/s.

Three was the last operator to launch commercial 4G services in the UK. Our testing took place during March and June 2014. At this time, Three had recently started the process of introducing 4G services to its customers. Three’s 4G product is different to that offered by the other MNOs, in that it is offered without a price premium to new and existing customers who have a 4G-enabled handset and are in an area where coverage is available.

Figure 26: Distribution of 4G and 3G HTTP download speeds: Three



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

5.4 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 to do so, producing a metric of megabits per second (Mbit/s).

A higher HTTP upload speed would mean that uploading data, such as photographs or videos, should take less time, as data will be transferred from the user at a faster rate. At a constant speed of 20Mbit/s, it would be expected to upload a 10MB file in 4 seconds, while on a constant speed of 10Mbit/s this would be expected to take 8 seconds.

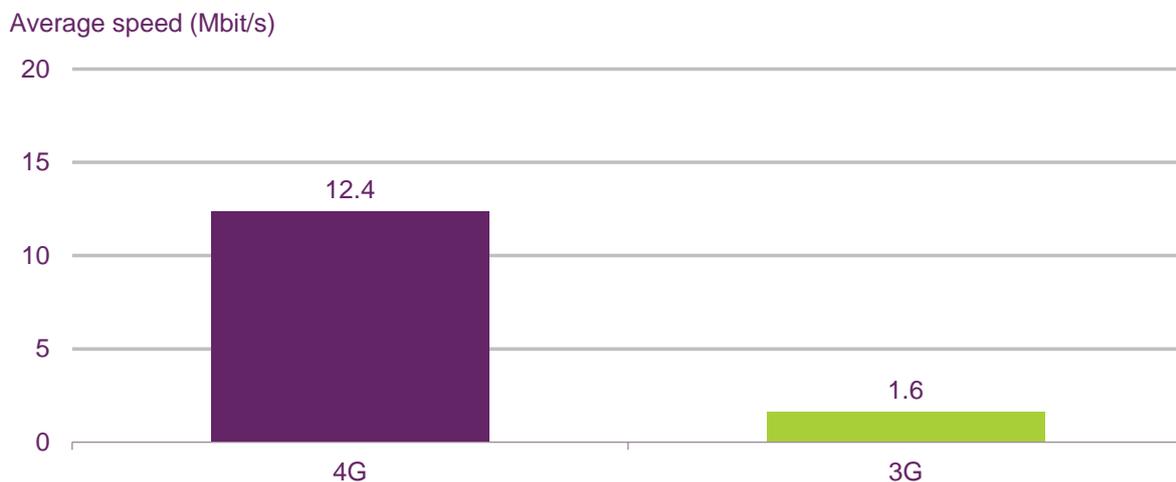
These results show the average rate at which data could be uploaded across all of our tests. The first results take an aggregate of all of our valid 4G and 3G results across all of the networks to produce an average for each technology. The second set of results for upload speed look at the average speed of each of the networks in the areas in which we tested, and the distribution of speeds by sample point for each network across 4G and 3G. Information on how we have processed the raw data from our tests is included in Annex 2 of this report.

Upload speeds on 4G are more than seven times faster than 3G

Across all of the networks in the areas where we tested, the overall average 4G upload speed was significantly faster than the average 3G upload speed. The average 4G upload speed was 12.4Mbit/s and the average 3G upload speed was 1.6Mbit/s.

We would expect that uploading content such as photographs or videos to the internet using a 4G connection would take far less time than doing so over a 3G connection.

Figure 27: Average 4G and 3G HTTP upload speeds overall



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

Note: Average of all 4G tests and all 3G tests

In the areas where we did our testing the highest average 4G upload speed was in Manchester

Averaging the results for all of the networks in each of the cities where we tested shows that the highest average upload speed for 4G was in Manchester. Our test locations in Glasgow

and London had the lowest average 4G upload speeds. London also had the lowest average 3G upload speed, followed by Birmingham.

Edinburgh and Glasgow had the fastest average 3G upload speeds, although the difference between Glasgow and Manchester was not significant.

We note that we tested 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.

Figure 28: Average 4G and 3G HTTP upload speeds, by test location



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average of all 4G tests and all 3G tests, by test location.

Figure 29: Average 4G and 3G HTTP upload speeds, by test location: significant differences

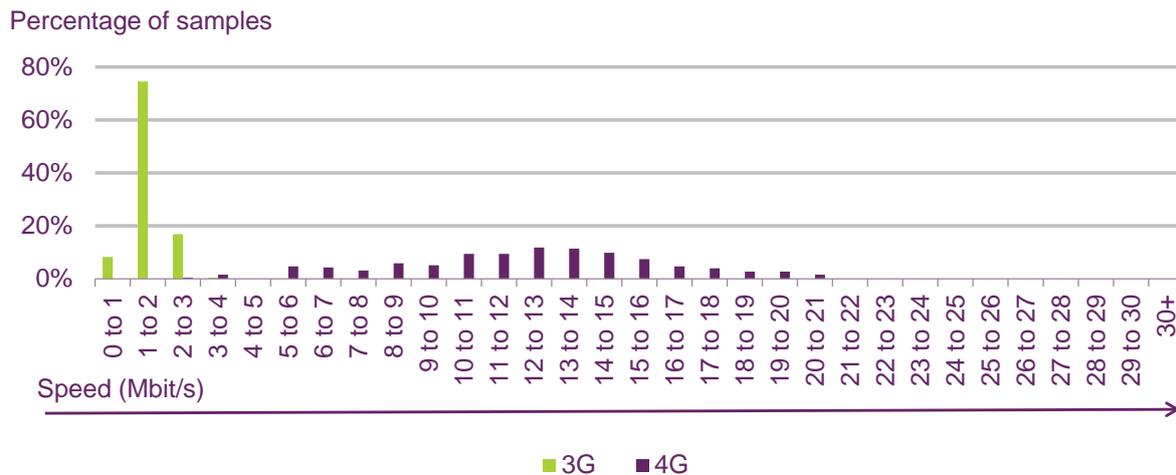
	4G faster than:	3G faster than:
Birmingham	Glasgow, London	London
Edinburgh	Glasgow, London	Birmingham, London, Manchester
Glasgow	-	Birmingham, London
London	-	-
Manchester	Birmingham, Edinburgh, Glasgow, London	Birmingham, London

Three-quarters of 3G upload speed test results were between 1Mbit/s and 2Mbit/s

On average, across all of the networks and all of the areas in which we tested, more than 99% of 3G upload speed test results were less than 3Mbit/s.

Upload speeds on 4G were significantly faster, ranging from 2.6Mbit/s to 20.9Mbit/s. The mid-range (between the first and third quartiles) was from 10.0Mbit/s to 14.8Mbit/s.

Figure 30: Distribution of 4G and 3G HTTP upload speeds



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

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

Our methodology was designed to treat each network equally. We tested each network at the same time and in the same location. The smartphones used were all generic, unbranded and unmodified, were of identical specification and build, and were running the same operating system.

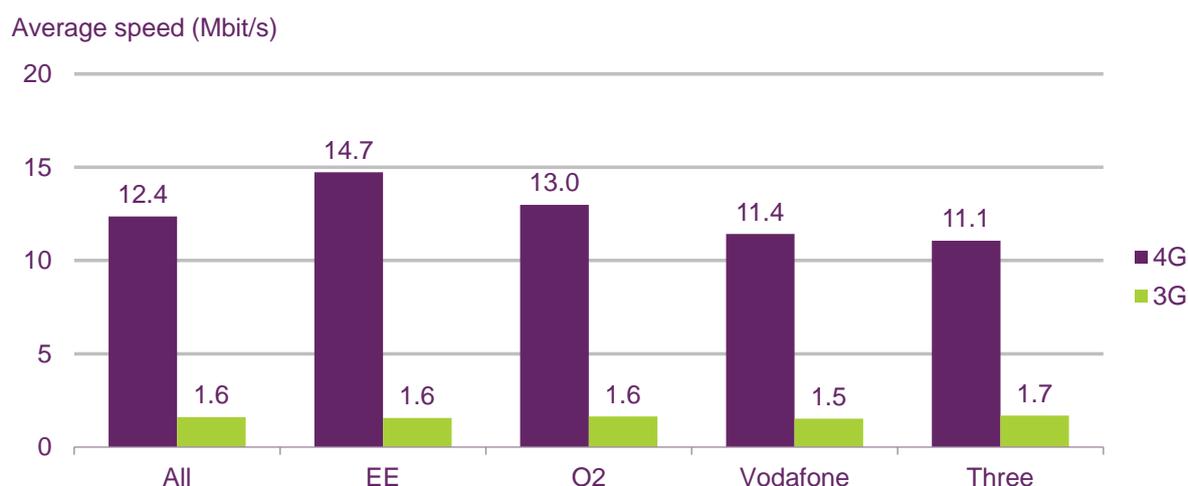
While we intended to test in areas where all operators had 4G coverage, this was not always possible. Three was at an early stage of its 4G roll-out when we tested and there were some locations where we were unable to obtain a 4G signal. We have examined the data to ensure that no bias has been introduced into the results from this. The process of this is explained in detail in Annex 2. The coverage of the four networks as of June and October 2014 is set out in section 3.4 of this report.

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

EE and O2 had 4G upload speeds that were above average, with EE’s 4G upload speeds the highest at 14.7Mbit/s. Vodafone and Three were both below the average 4G upload speed, but Three had the fastest 3G upload speeds at 1.7Mbit/s.

There was less variance between the operators for the average 3G upload speeds than there was for 4G upload speeds.

Figure 31: Average 4G and 3G HTTP upload speeds, by provider



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

Note: Average of all 4G tests and all 3G tests, by operator, only in locations where Three has coverage

Figure 32: Average 4G and 3G upload speeds, by provider: significant differences

	4G faster than:	3G faster than:
EE	O2, Vodafone, Three	-
O2	Vodafone, Three	EE, Vodafone
Vodafone	Three (see note)	-
Three	-	EE, O2, Vodafone

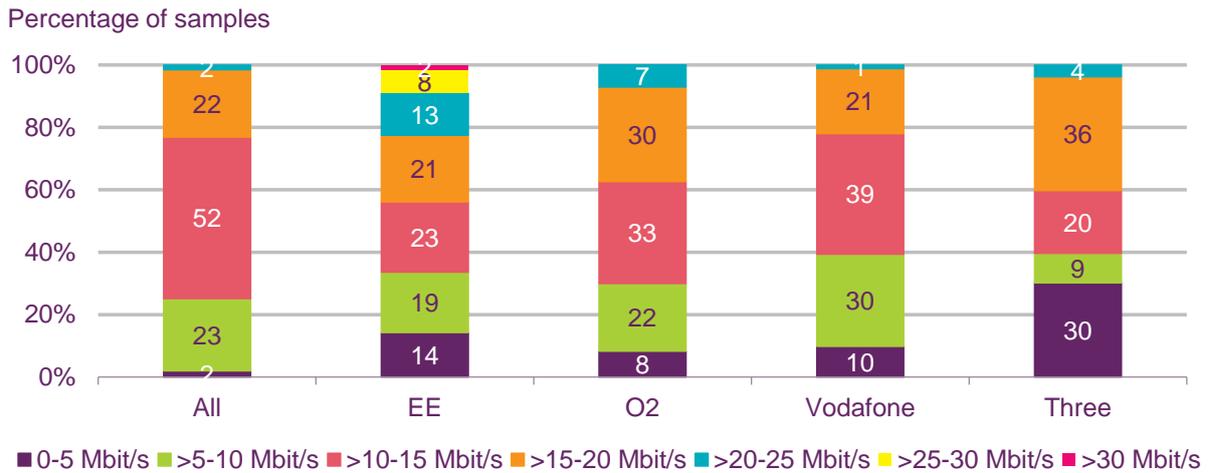
Note: At the time of testing, 4G coverage from Three was not available in all of our test locations. We have analysed our data to see if any unfair advantage is afforded to Three from this. For example, if there is a difference in performance between all of the test locations and only those which Three has coverage. Restricting the analysis to the locations covered by Three, Vodafone has a small, but statistically significant, difference in performance between it and Three. Among the full dataset, there is no statistically significant difference between Vodafone and Three. All differences are calculated to a 95% confidence interval.

Four in ten of Three's upload speeds were above 15Mbit/s

While Three had the largest proportion of test sites that resulted in 4G upload speeds higher than 15Mbit/s, it also had the highest proportion of upload speeds below 5Mbit/s. Thirty per cent of Three's 4G upload speeds were 5Mbit/s or below, and 36% were between 15 and 20Mbit/s.

EE had the highest proportion of upload speeds in excess of 20Mbit/s out of all the operators. At our test sites, no other operator recorded a 4G upload speed higher than 25Mbit/s.

Figure 33: Distribution of 4G HTTP upload speeds, by network



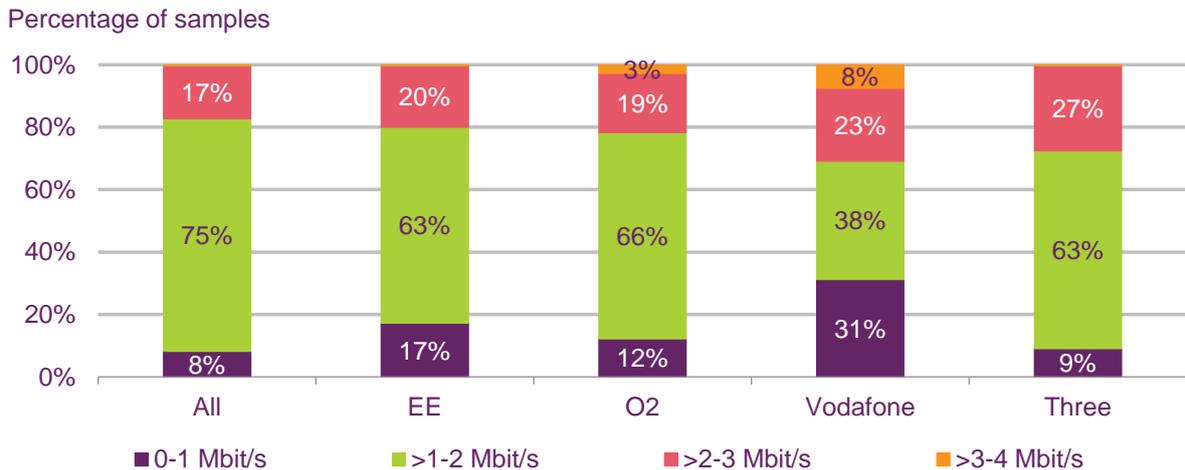
Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location where each operator had 4G coverage.

The average upload speeds on 3G ranged between 0.6Mbit/s and 3.1Mbit/s

Upload speeds on 3G were significantly lower than on 4G. During our testing, none of our sample sites resulted in a 3G upload speed in excess of 4Mbit/s for any of the operators. Three had the lowest proportion of 3G upload speeds that were less than 1Mbit/s, and a majority of sample sites resulted in speeds between 1 and 2Mbit/s for EE, O2 and Three.

Vodafone had the largest proportion of 3G upload speeds between 3 and 4Mbit/s (8%), but it also had the largest proportion of upload speeds up to 1Mbit/s (31%).

Figure 34: Distribution of 3G HTTP upload speeds, by network



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location where each operator had 4G coverage.

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

The results for web browsing speed indicate the time that it took 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.

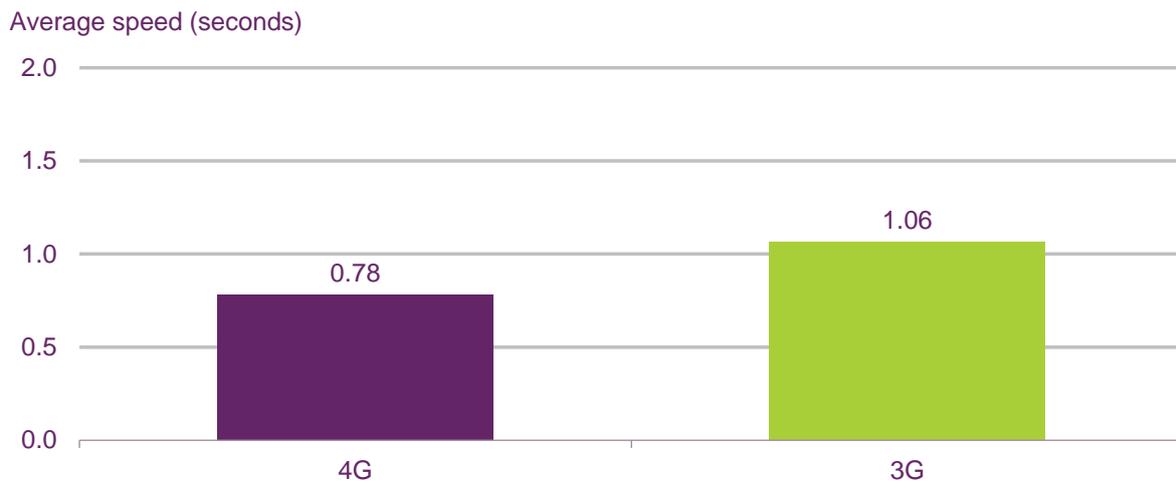
These results show the average rate at which a web page could be completely loaded across all of our tests. The first results take an aggregate of all of our valid 4G and 3G results across all of the networks to produce an average for each technology. The second set of results for web browsing speed look at the average speed of each of the networks in the areas in which we tested, for each network across 4G and 3G.

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 2 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 0.78 seconds. For 3G it was 1.06 seconds.

Figure 35: Average time taken to load a web page on 4G and 3G (lower is better)



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

Note: Average (median) speed at 4G and at 3G at each test location.

London had the fastest 4G web browsing speed and the slowest 3G web browsing speed

Across all of the networks and the cities that we tested in, our results show that London had the fastest 4G web browsing speed, taking an average of 0.72 seconds to load a standard web page. The slowest average 3G web browsing speed was also recorded in London, where it took 1.2 seconds to load a standard web page.

The fastest average 3G web browsing speed was in Manchester. With the exception of London, which was significantly slower, the small differences in 3G web browsing speed were not significant.

The slowest average 4G web browsing speed was in Glasgow, where it took an average of 0.82 seconds to load a web page. The differences between Birmingham, Edinburgh and Manchester were not statistically significant.

Figure 36: Average time taken to load a web page on 4G and 3G, by test location (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average (median) speed at 4G and at 3G at each test location.

Figure 37: Average time taken to load a web page on 4G and 3G, by test location: significant differences

	4G faster than:	3G faster than:
Birmingham	Glasgow	London
Edinburgh	Glasgow	London
Glasgow	-	London
London	Birmingham, Edinburgh, Glasgow, Manchester	-
Manchester	Glasgow	Birmingham, Edinburgh, Glasgow, London

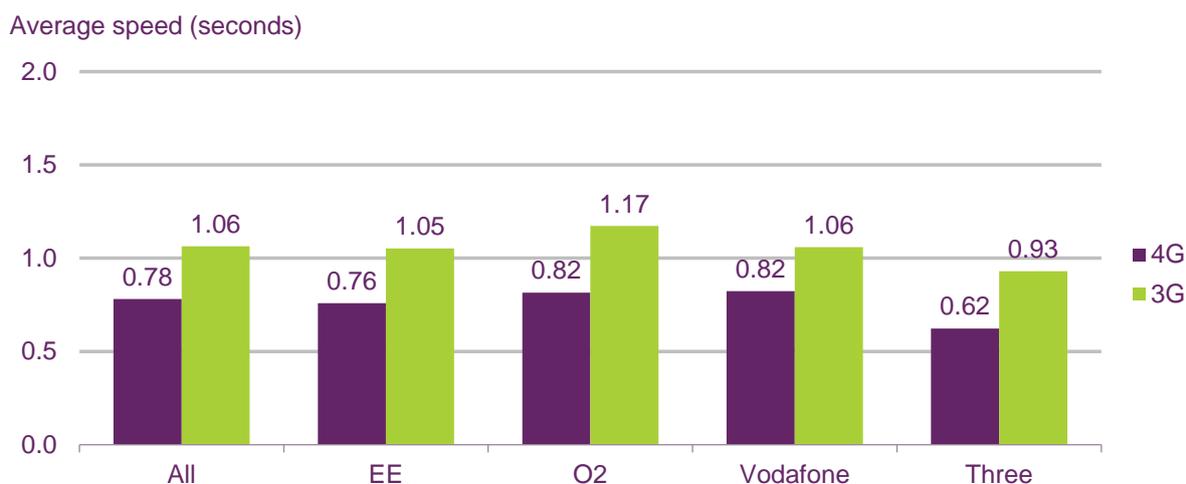
5.7 Web browsing speed on 4G and 3G, by network

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

The time taken to load a standard web page on 4G for Three was 0.62 seconds, the fastest of all the networks we tested. EE had the second fastest 4G web browsing speed. The average time taken to load a web page on O2 and Vodafone was the same on each network, at 0.82 seconds.

Three's 3G web browsing speed, at 0.93 seconds, was also the fastest that we tested and the only average time under one second for all of the networks. This was followed by EE and Vodafone, with no significant difference between the average web browsing speed on these two networks. The average time taken to load a standard web page on O2 was 1.17 seconds.

Figure 38: Average time taken to load a web page on 4G and 3G, by provider (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average (median) speed at 4G and at 3G at each test location.

Figure 39: Average time taken to load a web page on 4G and 3G, by provider (lower is better)

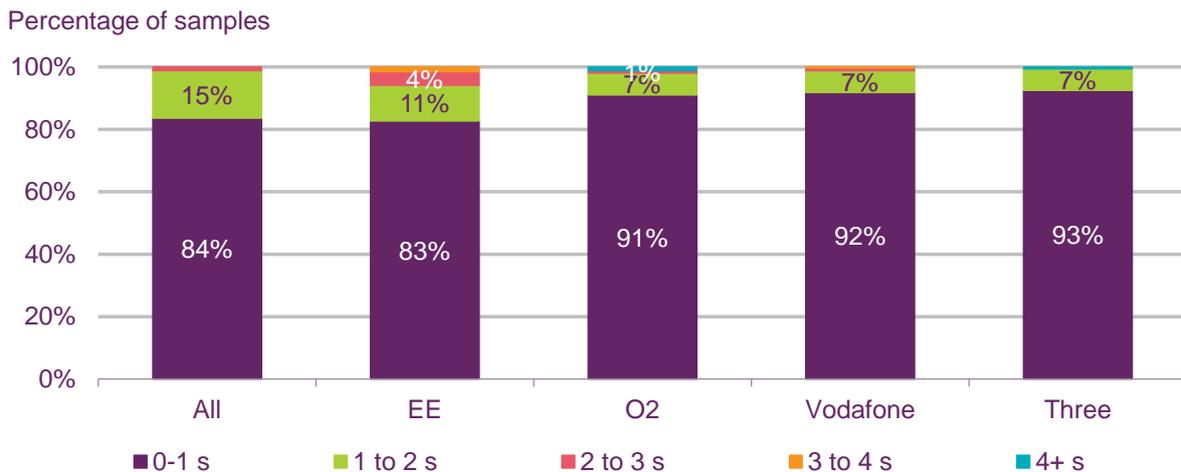
	4G faster than:	3G faster than:
EE	O2, Vodafone	O2
O2	-	-
Vodafone	-	O2
Three	EE, O2, Vodafone	EE, O2, Vodafone

At the majority of our test sites, web pages loaded in less than one second over 4G

Across all networks on 4G, the majority of test sites resulted in a web browsing speed of less than one second. For Three, Vodafone and O2, more than 90% of our samples resulted in a 4G web browsing speed of less than one second. This was slightly lower for EE, which had a higher proportion of samples resulting in web browsing speeds in excess of one second.

Although Three had the lowest 4G HTTP download speed in the areas where we tested, it had the fastest 4G web browsing speed. This is likely to be due to the different ways in which each of the operators optimise traffic on their networks.

Figure 40: Distribution of 4G web browsing speeds, by network (lower is better)



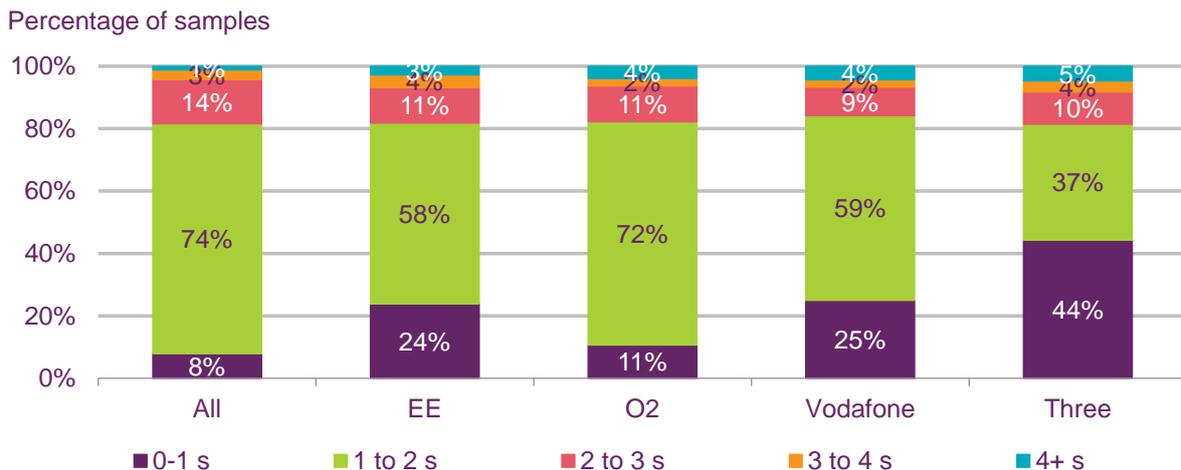
Source: Ofcom mobile broadband measurement, fieldwork March to June 2014

Three’s web browsing speed on 3G was less than one second at 44% of our test sites

Across all networks on 3G, 74% of our test sites resulted in an overall web browsing speed between one and two seconds. With the exception of Three, the majority of 3G web browsing speeds for each networks was between one and two seconds. Three had the largest proportion of 3G web browsing speeds at less than one second, with 44% of our test sites producing this result.

EE and Vodafone had the largest proportion of sample sites where the average time taken to load a web page over a 3G connection was longer than two seconds – 24% for EE and 25% for Vodafone.

Figure 41: Distribution of 3G web browsing speeds, by network (lower is better)



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

5.8 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.

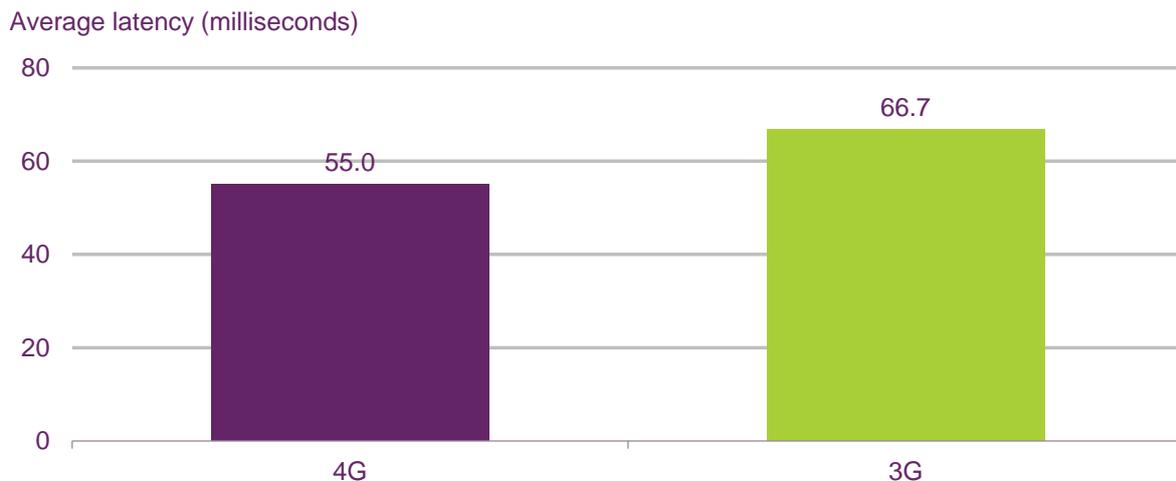
These results show the average round trip time²⁸ of the data sent in our ICMP ping tests across all of our tests. The first results take an aggregate of all of our valid 4G and 3G results across all of the networks to produce an average for each technology. The second set of results for latency looks at the average result for each of the networks in the areas where we tested, for each network across 4G and 3G.

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 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 2 of this report.

4G networks have a lower latency than 3G networks

Across all of our test sites, as an average of all the networks we tested, latency on 4G was 55.0 milliseconds (ms), and latency on 3G was 66.7ms.

Figure 42: Average 4G and 3G latency overall (lower is better)



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

Note: Average of 4G and at 3G at each test location

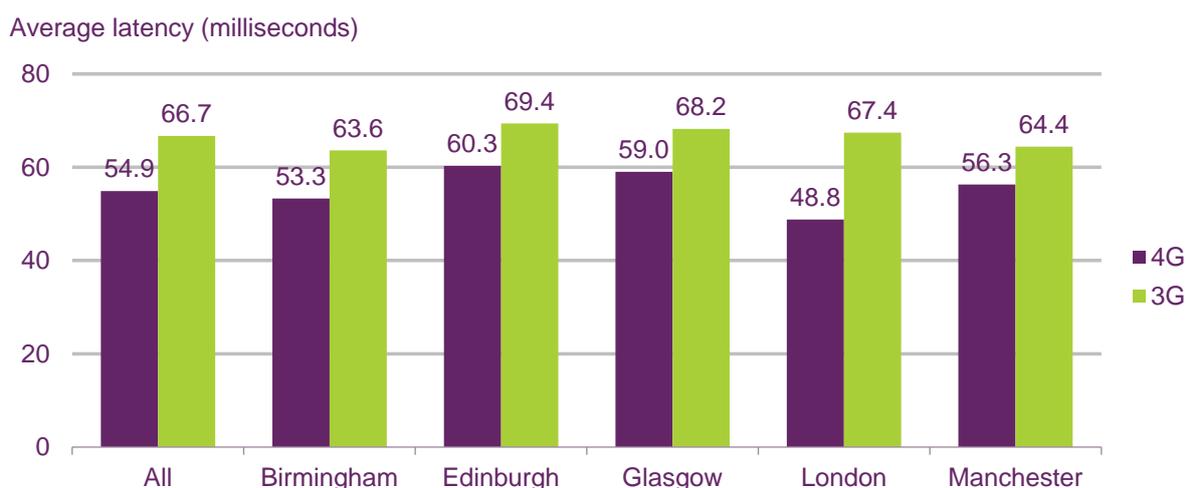
The lowest average 4G latency was in London

The lowest average latency on 4G was 48.8ms, in London. This was followed by Birmingham at 53.3ms, then Manchester at 56.3ms. Latency was highest over 4G in Edinburgh, where the average was 60.3ms.

On 3G, the lowest average latency was in Birmingham, at 63.6ms. Edinburgh had the highest on 3G, as it did on 4G, with an average reading of 69.4ms.

²⁸ The round trip time is the time between sending a packet data to a server and receiving a response

Figure 43: Average 4G and 3G latency, by test location (lower is better)



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

Note: Average of 4G and at 3G at each test location

Figure 44: Average 4G and 3G latency, by test location: significant differences

	4G faster than:	3G faster than:
Birmingham	Edinburgh, Glasgow, Manchester	Edinburgh, Glasgow, London, Manchester
Edinburgh	-	-
Glasgow	Edinburgh	Edinburgh
London	Birmingham, Edinburgh, Glasgow, Manchester	Glasgow, Edinburgh
Manchester	Glasgow, Edinburgh	London, Glasgow, Edinburgh

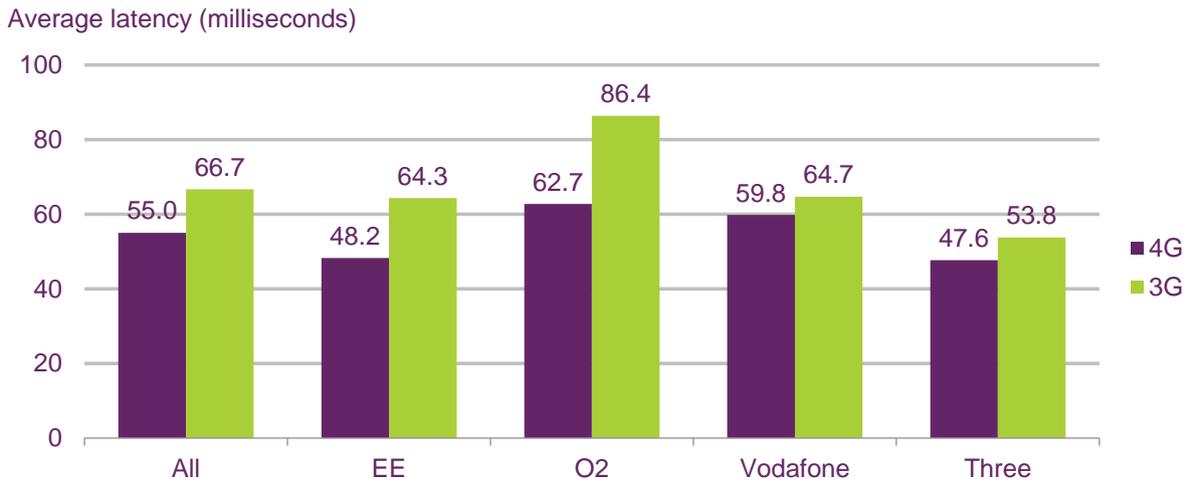
5.9 Latency on 4G and 3G, by network

Three had the lowest latency on 3G and on 4G

At 47.6ms, Three's average 4G latency was lower than on any other network. Three's 3G latency, at 53.9ms, was lower than 4G latency on O2 (62.7ms) and on Vodafone (59.8ms).

Across all networks, latency was lower on 4G than on 3G, although the scale of the difference between technologies varied by network. O2 had the highest latency on 3G (86.1ms) and on 4G (62.7ms), as well as the largest difference between the two technologies. The difference between 3G and 4G was smallest for Vodafone, with an average 3G latency of 64.7ms and an average 4G latency of 59.8ms.

Figure 45: Average 4G and 3G latency, by provider (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

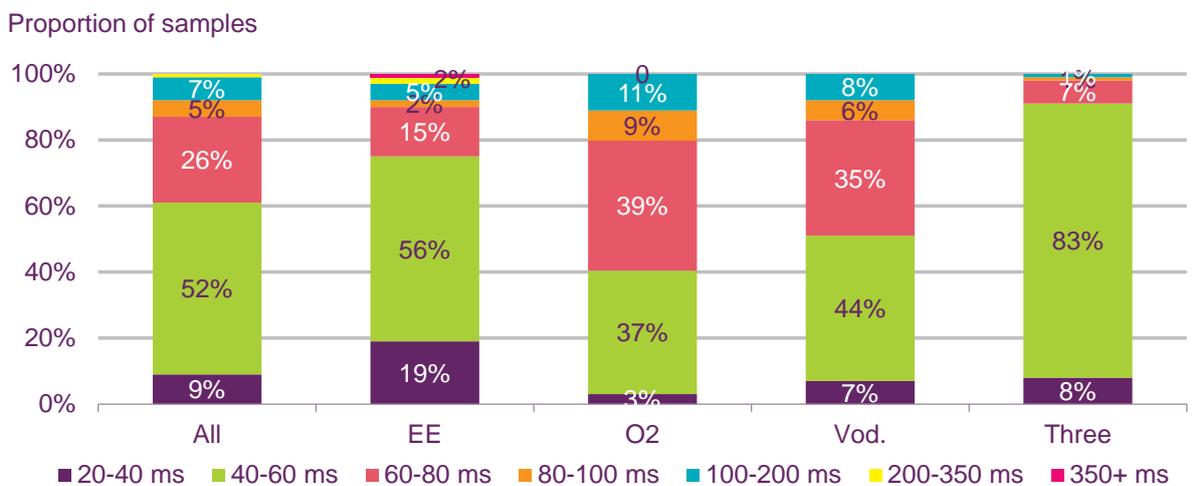
Figure 46: Average 4G and 3G latency, by provider: significant differences

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

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

Across all networks on 4G, 61% of test sites resulted in an average latency of 60ms or less. EE had the highest proportion of test sites with a latency of 20 to 40ms, with 19% of test sites producing this result for EE. Three’s latency was the most consistent of all the networks, with 83% of test sites resulting in a latency between 40 and 60ms.

Figure 47: Distribution of 4G latency, by network (lower is better)



Source: Ofcom mobile broadband measurement, fieldwork March to June 2014
 Note: Average speed at 4G and at 3G at each test location.

Almost half (47%) of 3G latency results for Three were less than 60ms

As an average across all networks on 3G, 50% of test sites resulted in latency higher than 80ms, with 32% being between 80 and 100ms, and 18% higher than 18ms.

Three had the highest proportion of results less than 80ms (78%), and 47% of test sites resulted in an average 3G latency of less than 60ms for Three. O2 had the highest proportion of results that were higher than 100ms (35%), followed by EE and Vodafone, which each had just under one-fifth of test sites resulting in 100ms or more.

Figure 48: Distribution of 3G latency by network (lower is better)



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

Note: Average speed at 4G and at 3G at each test location.

Annex 1

Methodology in detail

1.1 The principles of our methodology

Our methodology has been designed to measure 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 high-level approach to our methodology is as follows:

- Device-based testing – using publicly-available equipment (available to the consumer).
- Software-based testing – using industry-standard measurement software that can be loaded onto consumer devices without modifying the devices.
- Testing in public places in cities in areas where 4G has been launched.
- Testing indoors and outdoors.
- Taking sufficient samples to produce statistically significant results.
- Testing in a fair and unbiased way.
- Using experienced and qualified Ofcom engineers to carry out the testing.

Using actual devices, rather than network probes, in public places was a key consideration in capturing the consumer experience as closely as possible.

1.2 Device-based testing

We selected the Samsung Galaxy Note 3 smartphone to carry out our testing. This device was chosen as it is a Cat4 device²⁹ that was available for purchase from all of the MNOs.

We chose a Cat4 device because, based on current network deployments, this should remove the possibility that the limiting factor, in any testing that we do, is the device rather than the network. Cat4 devices also provide us with longer-term consistency should we decide to undertake further testing, as it will be longer before they become obsolete.

Although there are other Cat4 devices, at the time of starting our 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.

²⁹ 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.

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 sometimes 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.

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.

1.3 Software-based testing

We used the ‘Datum’ product from Spirent to do our 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.

The test set that we used produced the following metrics:

Figure 49: Metrics and Datum test cases

Metric	Test case
HTTP download speed	HTTP transfer of 2GB file for 30 seconds
HTTP upload speed	HTTP transfer of 100MB data for 15 seconds
Web browsing speed	Retrieval of ETSI mKepler standards based web page
Latency	5 x ICMP ping test

These tests were chosen to be able to inform certain elements of the consumer experience. Download speed provides an indication of how long it may take to download files, such as music or apps, to the consumer device. Upload speed provides an indication of how long it may take to post media, such as sharing pictures or video through social networking sites, to the internet. The web browsing speed indicates how long a standard web page would take to load completely, and latency gives an indication of how responsive the network is, which may be a particular interest for consumers using VoIP or video calling services. More information on our metrics and results can be found in Section 4 of this report.

1.4 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 50: Test cities and centre point of our 4km radius test area

City	Centre point
Birmingham	Birmingham New Street Station
Edinburgh	Edinburgh Waverley
Glasgow	Glasgow Central
London	Charing Cross
Manchester	Manchester Piccadilly

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 only recently publicly launched its 4G service, its roll-out at the time of testing was 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.

1.5 Testing in indoor and outdoor locations

We tested an equal number of indoor and outdoor locations. We used a 50:50 ratio of indoor and 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 the windows.

1.6 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.

1.7 Testing two tariffs from EE

EE's 4G network, in contrast to the other MNOs, is offering two services (4GEE and 4GEE Extra) that are differentiated, at least partly, by speed. Although there are other differences between the two tariffs, the 4GEE Extra service is branded as 'double speed 4G'.

As EE provides two 4G services, differentiated partly by speed, we considered it appropriate to test both the 'single speed' and the 'double speed' services from EE. The 4G product ranges from the other MNOs were not explicitly differentiated by speed or expected performance, so we tested one service on 4G from O2, Three and Vodafone.

We incorporated this into our testing process by running three cycles of testing at each of our locations. Each cycle was undertaken with four handsets testing each network simultaneously: a 3G cycle, a 4G cycle with EE's single-speed service, and a 4G cycle with EE's double-speed service. To avoid undue contention with ourselves, we did not test the two EE 4G services simultaneously.

As we have noted in section 5.3 of this report, To be able to test the 4GEE service, we procured consumer SIMs on the 4GEE tariff. However, the SIMs that we procured, while not being 4GEE Extra, were provisioned to be 'double speed'. We were therefore unable to test the single speed tariff from EE and found no significant difference between the performance of our consumer SIMs and the EE test SIMs.

1.8 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 48 individual results for each metric for each network: 32 4G results and 16 3G results. 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.

1.9 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. The performance of the MNO-supplied SIMs was compared to the performance of consumer SIMs, purchased from each MNO's online store, to ensure that they were representative of available consumer tariffs.

For EE, however, test SIMs representative of its 4GEE (single-speed) tariff were not available, as EE does not test its network using consumer SIMs. For this reason, Ofcom procured a number of 4GEE SIMs from EE's online store, so that both EE tariffs could be tested.

Annex 2

Data processing

2.1 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 observation³⁰; and
- that the correct number of tests had been performed (each sample site delivers 192 tests – 128 on 4G and 64 on 3G).

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 were 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 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.

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

Figure 51: Intended number of samples for each metric at each test site

	EE (4GEE)	EE (4GEE Extra)	O2	Three	Vodafone	Total
RUN1 – 4G		16	16	16	16	64
RUN2 – 3G		16	16	16	16	64
RUN3 – 4G	16		16	16	16	64
Total 4G	16	16	32	32	32	128
Total 3G		16	16	16	16	64

³⁰ 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.

2.2 Processing the data

Our framework has been designed to produce 250 sample points for each network on each technology, and 250 sample points each for 4G and 3G. 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.

Each test site became one sample point. 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 52.

Figure 52: Targeted sample set, by city and mobile network operator

	Birmingham		Edinburgh		Glasgow		London		Manchester		Total	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
4GEE	50	50	50	50	50	50	50	50	50	50	250	250
4GEE Extra	50		50		50		50		50		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

Three was the last MNO to launch its 4G service, and initially introduced it in Birmingham, London and Manchester. As Three was in the process of rolling out its 4G service while we were testing, its coverage in Glasgow and in Edinburgh 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, most notably in Glasgow. Our achieved sample set, by city and network for HTTP download, is set out in Figure 53.

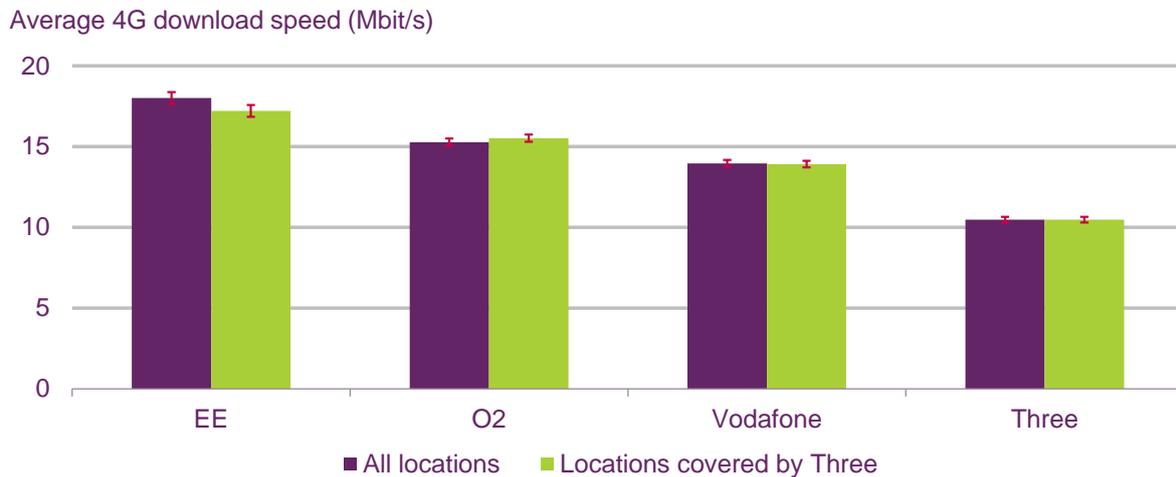
Figure 53: Achieved valid sample set, for HTTP download, by city and mobile network operator

	Birmingham		Edinburgh		Glasgow		London		Manchester		Total	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
EE	50	50	54	54	53	53	50	50	47	48	254	255
O2	50	50	53	54	53	53	50	50	48	48	254	255
Vodafone	50	50	54	54	53	53	50	50	48	48	255	255
Three	42	50	29	54	4	53	49	50	35	48	159	255

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 we can include results where we do not have results for Three we have compared the average 4G download performance across all locations with the average performance across locations where Three has coverage. This is shown in Figure 54, which indicates that the differences between the two averages are not significant and therefore no undue advantage is being given to Three as a result of the smaller sample size.

Figure 54: Average 4G download speed across all locations and across locations covered by Three



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

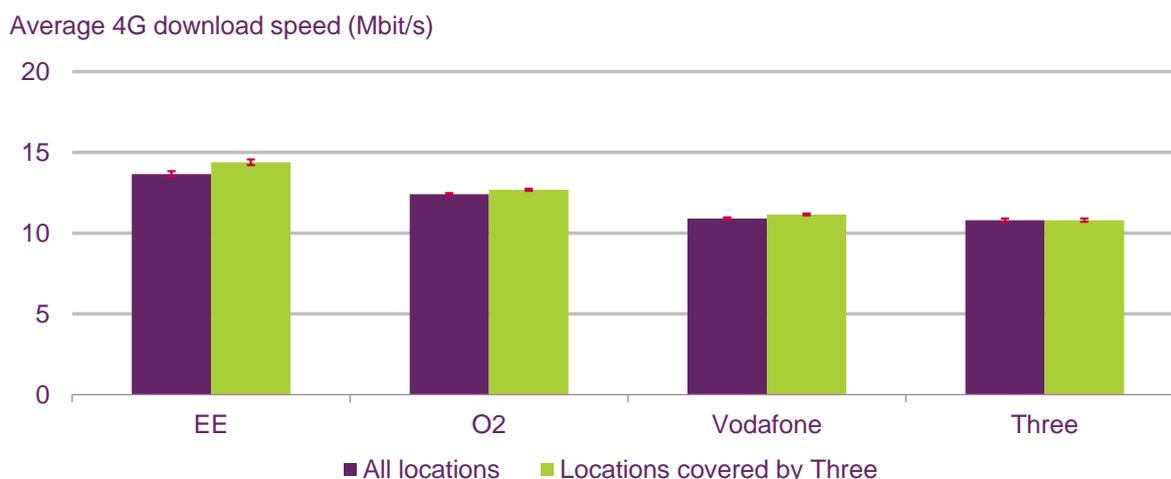
For our HTTP upload tests, we also compared the average performance across all locations with the average performance across locations where Three had coverage. This is shown in Figure 55. Although in the case of HTTP download speed there was no significant difference between performance in areas where Three had coverage and areas where it did not, for upload speed there was a difference.

In the locations covered by Three, we can see that performance on Vodafone and O2 is 2% better when restricted to the slightly smaller sample size, and 4GEE and 4GEE Extra perform 6% better.

It is therefore necessary to determine whether any differences in Three's performance are being unduly favoured by this potential advantage. To do this, we have recalculated the differences between the other networks based only on the locations that Three covers. The only relationship between the networks that is affected is the one between Three and Vodafone.

Across all locations, there is no significant difference between Three and Vodafone. Within only those locations that Three covers, a small (but statistically significant) difference is seen between these two networks, with Vodafone now being marginally faster than Three.

Figure 55: Average 4G upload speed across all locations and across locations covered by Three



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

The achieved valid sample size for HTTP upload speed is set out in Figure 56. Slightly more results were removed due to 4G falling to 3G than for download speed. Where this has affected the number of valid samples, in comparison to those used for download speed, it is indicated in bold on the table.

Figure 56: Achieved valid sample set for HTTP upload. by city and mobile network operator

	Birmingham		Edinburgh		Glasgow		London		Manchester		Total	
	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G	4G	3G
EE	50	50	54	54	53	53	50	50	46	48	254	255
O2	50	50	53	54	53	53	50	50	48	48	254	255
Vodafone	50	50	53	54	53	53	50	50	48	48	255	255
Three	42	50	29	54	4	53	49	50	35	48	159	255

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 interval.

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 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 which were at or below the overall median. For those networks where the medians are the same, we would expect to get a similar proportion of results at or

below the median. This is demonstrated in Figure 57, which shows that where the median result is relatively similar for O2 (0.815) and Vodafone (0.823), there are also a relatively similar proportion of results for these networks which are at or below the overall median (39.5% for O2 and 35.8% for Vodafone).

We can then apply a 95% confidence interval to test whether these differences are significant. In the case of O2 and Vodafone, we were able to determine that the fairly small difference between these two networks is significant.

Figure 57: Web browsing speed: calculating significant differences

	Overall	EE	O2	Three	Vodafone
Median result	0.781	0.759	0.815	0.623	0.823
% of results at or below overall median	50%	56.7%	39.5%	80.5%	35.8%
95% confidence interval		1.5%	1.1%	1.1%	1.1%

We also examined our results for web browsing speed and for ping to determine whether there is any advantage afforded to Three as a result of the smaller sample size, and we have found that this is not the case.

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 need to 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 Glasgow, but want the results for Glasgow 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 Glasgow, will therefore receive a weight of 0.9434. A test site with 14 valid readings would get a weight of 1.078.³¹

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

³¹ To get to this weighting, we divide the target sample by the achieved sample. In the case of Glasgow 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 $14 \times 1.078 = 15.09$.

compensating for locations where no 4G readings were possible; for example, by increasing the weighting of the locations where Three had coverage in Glasgow, 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.

Annex 3

3G and 4G coverage

3.1 The coverage figures used in this document

The coverage figures in this report are based on detailed coverage maps provided to us by the MNOs. The Operators produce these maps 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, terrain and 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. For 3G we apply a signal strength threshold of -100 dBm RSCP of the common pilot channel. For 4G we apply a signal threshold of -113 dBm RSRP.

Predicting the way radio waves will travel from the mast to the mobile user is highly complex and subject to a margin of error. To assess the accuracy of the operators' predictions we have compared their predictions to real world measurements we have made.

For 4G, we found that in over 90% of locations where Vodafone, EE and O2 predicted they would have a signal above our threshold this was the case. For 3G the figure was slightly lower for all four national MNOs, at between 80% and 90%. We consider these predictions to be sufficiently accurate to be used to estimate coverage levels. In addition, as these operators are achieving similar levels of accuracy in their predictions, we are able to compare the relative coverage of the networks using the data they have provided us.

For Three, we found a greater disparity between the 4G signal measurements we made and Three's predictions than was the case for the other operators. In the time available it was not possible to resolve differences between Three's data and Ofcom's field measurements on 4G coverage, leading to its omission from this report.

Measuring 3G coverage

The nature of 3G technology is that network coverage and mobile broadband speeds can reduce when more handsets are active on the network. As such, any estimate of coverage has associated with it assumptions on network loading i.e. how busy the network is and the speeds that it is able to deliver to end users.

Under the terms of their spectrum licences, the operators are required to provide outdoor 3G coverage to 90% of the population at a speed of 768Kbps when the network is lightly loaded i.e. there is only a single user on the cell. Compliance with the obligation is assessed through a computer model that estimates the strength and quality of the 3G signal across the populated areas of UK. All the operators have met their 3G licence obligations.

When estimating coverage for this report we have applied a signal strength threshold which we consider to be more challenging than the equivalent terms of the spectrum licences. This is to reflect the increased take-up and use of 3G devices and consumers' expectations of speed and coverage i.e. networks are busier than is assumed in the 3G licence terms and consumers expect higher speeds.

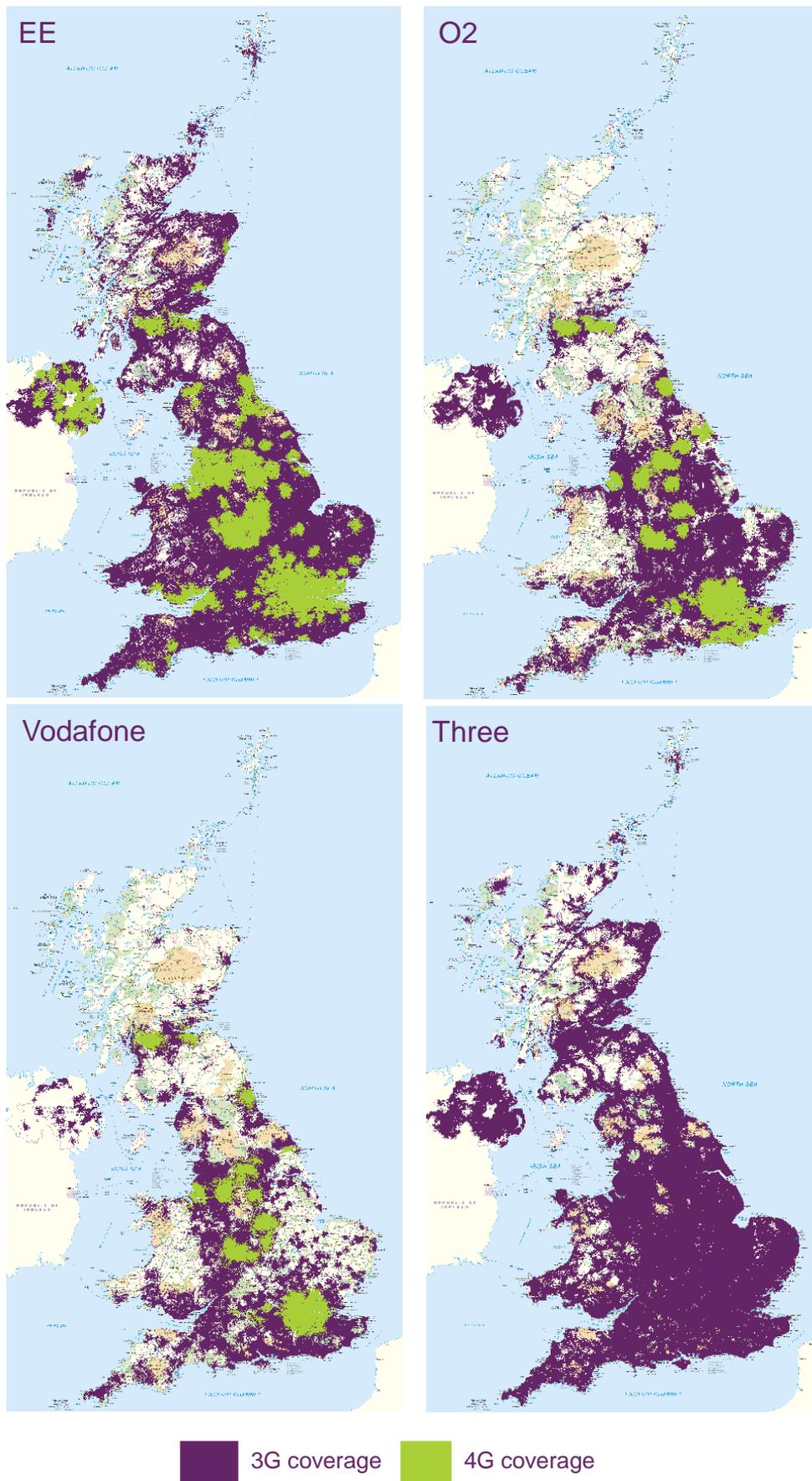
Under the more challenging conditions we have applied in this report estimated coverage levels may be lower than those required to meet spectrum licence terms. For example, in the case of Vodafone the methodology used in this report results in a coverage estimate of 87%

premises. This is not an unexpected result and shows that any estimate of 3G coverage has assumptions on network loading and performance associated with it.

In addition to differences in the way we measure signals, the coverage figures in this report refer to premises coverage and we have used data from the Ordnance Survey that lists the location of individual postal delivery addresses. This is a different approach to that used in the 3G licence coverage obligations which is set in terms of population coverage. The two methodologies will produce slightly different results, as the population figures will take variation in the number of people per premises into account (based on census data compiled by the Office of National Statistics).

When the MNOs publically state their own coverage, it is likely that they will base their figures on a slightly different methodology to the one used in this report. For example, they may apply different signal thresholds or use different underlying databases of premises or population. To allow comparisons to be made between operators we have had to adopt a common methodology for this report. We will continue to review and improve on this methodology in future publications.

Figure 58: 3G and 4G coverage for the four national MNOs, June 2014



Source: Ofcom/operators

Note: Ofcom's methodology estimates premises with coverage, based on operator signal strength predictions. 3G and 4G data for EE, O2 and Vodafone, and 3G data for Three, are based on the operators' submissions, checked against Ofcom's own field measurements. In the time available it was not possible to resolve differences between Three's data and Ofcom's field measurements on 4G coverage, leading to its omission from this report.