Measuring Mobile Broadband in the UK:
performance delivered to PCs via dongles/datacards

September to December 2010

Research Report

May 2011

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Purpose of this report

In order to understand the performance of UK mobile broadband connections using dongles and datacards, we commissioned research to identify the average actual download throughput speeds that they deliver, along with a number of other metrics which determine the consumer experience of using mobile broadband services. This is the first report on mobile broadband performance and follows the publication of four reports on fixed broadband speeds.

The results provide extremely useful insights into the factors that affect and determine mobile broadband performance, but with the following limitations:

- The research is into the performance of mobile broadband delivered via dongles and datacards (usually to laptop PCs). The findings may not be representative of the performance delivered to smartphones or other mobile devices.

- The research is into the performance of cellular mobile broadband only; mobile broadband services sometimes also include free WiFi access in WiFi hotspots, but these were out of scope for the research.

- The information presented in this report relates to mobile broadband download speeds and other performance measures such as upload speeds, latency, jitter, etc. Other factors relevant to consumers purchasing mobile broadband – such as price, traffic management policies, data allowances, customer service, etc. – are not discussed in this report.

- The performance of mobile broadband depends to a large extent on the network coverage available (i.e. the ability to gain access to the mobile network and the type of bearer used when accessing the mobile internet e.g. whether it is a 2G or 3G connection). This research does not assess levels of network coverage, and coverage is dependent on a number of factors including distance from the base station, whether you are inside a building or outdoors, the number of people using a mobile network in the same location and whether you are stationary or in-motion. Reporting of average performance information in this report therefore does not necessarily reveal the performance available to any individual consumer.

- This research report presents information on the state of mobile broadband performance in the UK between September and December 2010. However, the mobile broadband market continues to evolve rapidly, and the speeds and general performance results set out in this report are therefore liable to change. For example, since the merger of T-Mobile UK and Orange UK in July 2010, the two networks are becoming increasingly integrated.

- Despite these limitations we hope that this report can also serve as a useful reference source for consumers and our other stakeholders.

- We welcome feedback on all of Ofcom's reports. Please email comments to Ofcom's Market Intelligence team at market.intelligence@ofcom.org.uk.

Key statistical concepts used in this report

This report presents the findings from research which has involved the collection and interpretation of 4.2 million data points. It has been a complex process, both technically and statistically, and as a consequence the analysis may not be as easy to understand as that in many of our research publications.

The Glossary in Annex 1 provides a detailed definition of the technical terms we use throughout the report. However, knowledge of the following is important in order to understand how we have analysed the performance data.

- We present data in the report only in cases where there are sufficient data points to deliver a statistically sound result. This means that we report performance only when statistical analysis indicates that our findings are accurate enough to be useful. Accuracy is determined by the number of measurement tests undertaken, the size of the sample (number of fixed probes and panelists) and also by the variation (spread or range of results) between the fixed probes and panelists.

- In order to acknowledge the limited accuracy of the estimates and to ensure that we highlight only those differences that are statistically significant, for many charts we do not show a value but instead show a range around the mean value which indicates the statistical confidence we have in our results. The range we use is called a 95% confidence interval, which is a statistically-derived range calculated from the standard error (which is itself calculated from the sample size and the variation within the sample). A 95% confidence interval means that if we repeated the research again with a different sample assembled in the same way there would be a 95% probability that the mean value would be in the range shown. Where we have large samples and/or little variation within the sample, the confidence interval is much narrower than where we have smaller samples and/or large variation within the sample. Differences are reported as significant if they are significantly different as judged by a two-tailed 5% test of statistical significance.

A detailed explanation of our statistical methodology is provided in Annex 3.

Section 1

Executive Summary

Background

1.1 Ofcom's primary duty under the Communications Act 2003 (the "Act") is to further the interests of UK citizens and consumers in carrying out our functions[1]. In addition to securing the availability of a wide range of electronic communications services including broadband services, encouraging investment and innovation in relevant markets and the availability and use of high-speed data services, we must have regard to the interests of consumers in respect of price, quality of service and value for money. Our duties include the requirement to carry out research into consumers' experiences of the way services are provided and to publish and take account of the results of such research[2].

1.2 Ofcom has an ongoing programme of research into the performance of fixed-line broadband. We believe that similar research into mobile broadband is useful as take-up of mobile broadband increases and an increasing number of households use mobile broadband as their only internet connection. Our research finds that there were around 4.8 million active mobile broadband subscribers using datacards or dongles at the end of 2010 compared to 2.6 million at the end of 2008[3]; 7% of UK households have it as their only means of internet access, compared to just 3% in Q1 2009.[4]

About this research

1.3 Ofcom partnered with broadband test and measurement specialists Epitiro to measure the network performance delivered by the UK's five mobile networks ('3', O2, Orange, T-Mobile, Vodafone), and to understand the consumer experience of users accessing data services via USB modems or datacards.

1.4 Measurements were made on key performance indicators which affect the consumer experience of mobile broadband applications such as web browsing, downloading files, on-line gaming and streaming video. Measurements included upload and download speeds, web page download times, latency, DNS resolution times, packet loss and jitter.[5].

1.5 Over 4.2 million tests were run from September to December 2010 using three data collection methodologies.

- Static test probes installed in 97 locations across the UK, each with connections to all five operators and testing hourly. The objective here was to research the performance of 3G/HSPA networks, so locations were chosen where all networks

[1] Communications Act 2003, Part1, Section 3 (1)
[2] Communications Act 2003, Part 1m Section 14 (1)
[3] Based on information supplied to Ofcom by mobile operators and MVNOs
[4] Ofcom Communications Market Report, August 2010, pp291-294, http://stakeholders.ofcom.org.uk/binaries/research/cmr/753567/CMR_2010_FINAL.pdf; Q1 2011 data available at: http://stakeholders.ofcom.org.uk/binaries/research/statistics/tech-tracker-q1-2010.pdf .
[5] Further details on how these metrics are used to inform understanding of mobile broadband performance can be found on page 13 of this report.

had good 3G coverage and any data collected from 2G connections was discarded.

- Drive testing in dense urban city, urban sprawl, provincial town, rural and semi-rural county locations (performing tests while stationary). The objective here was to explore how performance varied both within and between areas with different demographic characteristics.

- A consumer panel of over 1,000 mobile broadband USB modem and datacard users with an installed test application that tested up to 4 times per day. The objective here was to research the performance actually delivered to mobile broadband users.

Network capability results (static probe testing)

1.6 From our deployment of static probes we analysed only the faster 3G and HSPA data (2G connections were excluded) to understand network capability. From the locations tested we determined the following:

- The average download speed was 2.1Mbit/s. This means, for example, that a 5MB music track would download in about 20 seconds and a 250MB video file (for example a standard definition 30min TV programme) would download in about 17minutes.

- The average time for each test probe to download web pages from popular UK web sites was 2.2 seconds. Over half of all pages (59%) were downloaded in less than 2 seconds, but 12% of requests took longer than 4 seconds.

- Latency, a measure of the time it takes a single packet of data to travel from a user's PC to a third-party server and back again, and therefore a measure of responsiveness, was an average of 117 milliseconds. Nearly two thirds of tests took more than 100 milliseconds, indicating that mobile broadband connections may not be optimal for some online games.

1.7 Average mobile broadband speeds and other key performance indicators varied significantly by time of day, with services on average around a quarter slower in peak evening periods than in the off-peak early hours of the morning. This indicates that there is contention for services in mobile broadband networks, although this study does not attempt to establish where the contention lies.

1.8 There were some differences in average performance between operators which are outlined below. Key findings for each operator are expressed as a 95% confidence interval around the mean; we do this in order to acknowledge the limited statistical accuracy of the research - a 95% confidence interval means that if we repeated the research again with a different sample assembled in the same way there would be a 95% probability that the mean value would be in the range shown. From this analysis, we conclude:

- O2, Vodafone and 3 delivered on average faster download speeds over a 24-hour period than Orange and T-Mobile; O2 was faster than all the other operators in the peak evening period of 8-10pm.

- O2 had on average lower latency than 3, Orange and Vodafone over a 24-hour period.

- Web page download tests (downloading the full HTML – but not the images – from some of the UK's most popular web sites) found that on average O2 delivered pages faster than the other four operators.

Variation by regions (drive testing)

1.9 Our drive test research analysed performance from all available connections (2G, 3G and HSPA bearers) and showed a significant variance in service quality across rural, urban, semi-urban and inner city areas.

- Urban areas outperformed rural areas in mobile broadband performance, in the areas we tested. More than 50% of connections in the rural/semi-rural area surveyed (Herefordshire and Shropshire) had speeds of less than 500kbit/s, compared to 25% of tests in the city we surveyed (Birmingham).This is likely to be largely driven by network availability of 2G and 3G/HSPA: over 95% of tests in Birmingham connected to a 3G/HSPA bearer, compared to under 60% of tests in Herefordshire/Shropshire.

- Despite the potential for good mobile broadband speeds in the urban city locations covered, the measured performance was highly variable across the city, with no guarantee of good performance offered by a city centre location.

Consumer panel results

1.10 Our consumer panel survey included data from all connections (2G, 3G and HSPA bearers) to examine the service levels actually experienced by consumers.

- The average download speed experienced by the consumer panel based on all connections was 1.5Mbit/s. Seven percent of consumers received average speeds of less than 0.5Mbit/s and 6% received average speeds of more than 3Mbit/s.

- Panelists were able to download basic web pages from popular websites in an average of 8.5 seconds, with fewer than 10% of pages downloading in less than 2 seconds.

- Average latency was 192 milliseconds and around a third of tests delivered latency of higher than 200 milliseconds, making the connection not suitable for internet services which require a high degree of responsiveness, such as online gaming or VoIP telephony.

Mobile broadband services generally perform below fixed services

1.11 For some consumers, mobile broadband, given its costs and added flexibility is already proving to be an adequate substitute for fixed broadband. This is despite the fact that average speed, latency and web page download times for mobile broadband perform at levels lower than those typically delivered by fixed broadband services. The average mobile broadband speed of 1.5Mbit/s based on the consumer panel results compares with the average fixed broadband speed of 6.2Mbit/s.[6]

[6] http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/bbspeeds2011/bb-speeds-nov-2010.pdf

1.12 It should be noted, however, that the actual speeds available through fixed and mobile broadband depend very much on a combination of location and network quality. Consumers should therefore check the speed available on their individual fixed line as well as the level of mobile broadband coverage before making any choice between the two.

1.13 Network latency on mobile broadband services is almost double the average delivered on some fixed line services. This means that webpage browsing is typically considerably slower using a mobile broadband connection rather than a fixed broadband connection. The lower latencies required by activities such as online games may also make mobile broadband unsuitable for some types of internet use.

Conclusions and next steps

1.14 Geographic location is likely to be the largest single determinant of mobile broadband performance. There are very significant differences in performance by the type of network connection (2G, 3G or HSPA), and our drive testing indicates that the availability of 2G, 3G or HSPA networks, and the performance delivered, vary significantly even within small geographic areas. Before purchasing mobile broadband, consumers are advised to check the network availability in the locations where they expect to use the service using operators' own postcode-based coverage checkers.

1.15 In areas where there is good 3G/HSPA coverage, our research finds that there are some differences between operators in the performance delivered. Consumers should be aware that service quality will differ based on their location and choice of provider.

1.16 Mobile broadband networks and services, and broadband services in general, are evolving rapidly, and it is essential that consumers have information which enables them to make informed choices about the services available to them. Ofcom will continue to work with industry with the objective of ensuring that up-to-date information about the following is available:

- robust and reliable comparative information on network coverage by postcode, including where 3G/HSPA services are available;
- the performance of mobile broadband services delivered via dongles/ datacards, including its relative performance compared to fixed-line broadband service; and
- the performance of mobile broadband services delivered to smartphones and other devices.

Section 2

Introduction

2.1 Ofcom's objective is to ensure that consumers have the clearest possible information about broadband services. This is in line with Ofcom's duties under the Communications Act to further the interests of UK citizens and consumers and to have regard, among other things, to the interests of consumers in respect of price, quality and value for money.

2.2 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 ISP package[7]. The latest fixed broadband speeds report was published in March 2011[8].

2.3 The purpose of this mobile broadband performance research was to gather performance data on the UK's main mobile operators ('3', O2, Orange, T-Mobile and Vodafone[9]) in order to gain insight into average performance and how performance varies by a number of factors including time of day and location.

2.4 Consumers with laptops and PCs now have an alternative to fixed-line broadband services by connecting to the internet over mobile networks using USB modems ("dongles") or data cards. Consequently, this research focused on collecting data using dongles (as opposed to smartphones) to provide information for consumers to compare fixed and mobile broadband services.

2.5 While the use of smartphones is becoming an increasingly popular way to access the internet, the performance of mobile broadband delivered to mobile phones is out-of-scope for this research. The performance delivered to phones may vary from the performance delivered to dongles/datacards as a result of the different capabilities of the handset, and different traffic management policies/profiles applied by operators.

Rationale for report

2.6 The performance of mobile broadband networks is becoming an increasingly important consumer issue for the following reasons.

- Ofcom research indicates that mobile broadband take-up is increasing and more households are using mobile broadband as their only internet connection. In Q1 2011 around 17% of UK households used PCs with USB modems ("dongles") or datacards to connect to the internet with 7% of UK households having it as their only means of internet access, compared to just 3% in Q1 2009.

- Large screen mobile devices other than laptops such as tablets which have the ability to connect to the internet via mobile networks and have the potential to

[7] Our duties include the requirement to carry out research into consumers' experiences of the way services are provided and to publish and take account of the results of such research, Communications Act 2003, Section 14.
[8] http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/bbspeeds2011/bb-speeds-nov-2010.pdf
[9] Although T-Mobile UK and Orange UK merged into Everything Everywhere in July 2010, they were tested separately and are reported on separately.

generate high data traffic per device have seen recent rapid adoption. For the iPad alone, some analysts estimate pre-Christmas sales of around 500,000 in the UK since its launch in May 2010 and further sales of several million in 2011.[10]

- Mobile broadband does not require rental of a fixed voice line, unlike most fixed broadband, and is also available on a pay-as-you go basis. It may therefore represent a lower-cost way for some households to get online.[11]

2.7 In the open and competitive UK mobile market, it is important that consumers are knowledgeable of the difference in performance of broadband services delivered over different networks and between different mobile network operators (MNOs).

2.8 At the time the research was commissioned there was evidence of higher levels of dissatisfaction with the performance of mobile broadband networks than with fixed broadband. Ofcom research in Q1 2010 found that 73% of mobile broadband users were satisfied with the speed of their connection compared to 80% of fixed broadband users.[12] However, we note that satisfaction with mobile broadband services has been increasing and was on a par with satisfaction with fixed broadband services in Q1 2011.

Scope of research

2.9 This project sought to gather a dataset that would assess the performance of mobile broadband delivered via dongles and datacards and allow comparison with the performance of fixed line broadband services (which is the subject of separate Ofcom research). The research for this project was conducted from September 2010 to December 2010. Data was collected from three sources: a test application embedded in the computers of consumer panellists; static test probes sited in 97 locations of good 3G network coverage around the country; and drive testing in four areas of different demographic characteristics.

2.10 We collected a range of performance data including download speed, latency, web page download times and other related packet-level metrics. Our analysis also assesses the impact of these measurements on the consumer experience of mobile broadband.

2.11 Radio metrics were also collected including radio signal strength (RSSI), Ec/Io and Receive Signal Code Power (RSCP) measurements for 3G services and the Channel Quality Indicator (CQI) for HSPA services.

2.12 The data collected for this research was taken from dongle-equipped test devices or consumers using dongle-equipped computers with the exception of drive test results which used smartphones with an embedded test application.

2.13 For the static-probe testing, only consumer packages were assessed using pre-paid or pay-as-you-go (PAYG) packages from the MNOs in the UK, with the exception of Orange which does not offer PAYG data packages. In this case the Orange Dolphin data plan was adopted. The packages selected represented the lowest cost tariff which provided a minimum of 3GB of data user per month. All operators have

[10] Source: Enders Analysis, The mobile internet, apps and the route to market, Jan 2011
[11] Analysis of lowest cost fixed broadband options and stand-alone mobile broadband contracts, Ofcom Communications Market Report, August 2010, p 354 - 355
[12] Ofcom research, Q1 2010, The Communications Report Market 2010, p. 256

confirmed that the performance delivered to these tariffs are representative of the performance delivered to all consumer mobile broadband (dongle/datacard) tariffs.

Outside the scope of research

2.14 This research concentrated on the connectivity to mobile broadband services using dongles or datacards. Analysis of mobile broadband services delivered to mobile phones was out of scope, with the exception of the case studies in performance where measurements were conducted using a high-end Android-based smartphone (although the SIM card used was a data-only mobile broadband SIM).

2.15 The extent of 3G coverage across the UK was not an objective of the report and was not researched.

2.16 MVNOs were not covered in this research as some do not offer mobile broadband services via dongles/PC datacards and those that do are estimated to hold a share of less than 1% of users.

2.17 Though T-Mobile and Orange combined their UK operations into Everything Everywhere in June 2010, the two networks were tested separately in recognition that they continue to operate as separate brands and had not fully integrated their networks. The performance delivered to Orange and T-Mobile customers may now be different as the two networks become integrated.

2.18 Research did not investigate mobile voice services. Circuit Switched Data (CSD), High Speed Circuit Switched Data (HSCSD) or text (SMS) services are not within the scope of the report.

2.19 The assessment of mobile broadband packages from Mobile Virtual Network Operators (MVNOs), such as Virgin Media and BT Mobile were not assessed[13].

2.20 In-motion testing such as in a car, train or bus was not part of this project scope.

2.21 All testing was on the traditional cell site-based network. Analysis of mobile broadband services provided via WiFi or femtocells is outside of the scope of this report. However, it is important to note that WiFi services are included in some mobile broadband tariffs, and as the coverage of Wi-Fi networks improves and mobile data traffic increases, access to these Wi-Fi networks may become increasingly important components of mobile broadband service packages.

[13] Virgin Mobile's and BT Mobile's share of mobile broadband users is deemed to be relatively small based on Ofcom research.

Section 3

Objectives & Methodology

Aims and objectives of the research

3.1 The aim of the research was to compare the performance of the networks operated by the UK's five MNOs in the provision of mobile broadband services, including how this varies by MNO, geography and time of day.

3.2 With consumers increasingly considering mobile broadband as an alternative to fixed line services, this project further sought to collect a dataset that would allow comparison between the two types of services. Data was primarily collected using computers that connected to the internet using USB modems ("dongles").

3.3 The research was conducted from September 2010 to December 2010 with the following objectives;

- To understand the network performance delivered by the UK's five mobile network operators ("MNOs") ('3', O2, Orange, T-Mobile, and Vodafone) in the provision of mobile broadband services.
- To understand how the quality of the network performance impacts on the consumer experience of users accessing data services via dongles and datacards.
- To understand the variance in service quality throughout typical UK urban, semi-urban and semi-rural areas.

Overview of the data collection methodologies

3.4 Three data collection methodologies were employed for this research, providing different perspectives on network performance, consumer experience and coverage for specific case studies of performance across the UK:

- Static probes: PC-based probes deployed to 97 sites indoors across the UK, measuring network performance for all five MNOs, 24 hours per day.
- Drive testing: vehicle mounted, handset-based probes, enabling measurement for case studies of performance in four specific regions of the UK.
- Consumer panel: software-based probes installed to a panel of mobile broadband users in the UK.

3.5 Data collection from the consumer panel and static probes took place between 22 September 2010 and 19 December 2010. Drive testing was carried out between 15 November 2010 and 15 December 2010, with five days of testing for each of the four case studies.

3.6 The following sections describe each of the three methodologies in more detail. The technical methodology, common to all three methodologies, describing how specific measurements were made is in Annex 2.

Static probes

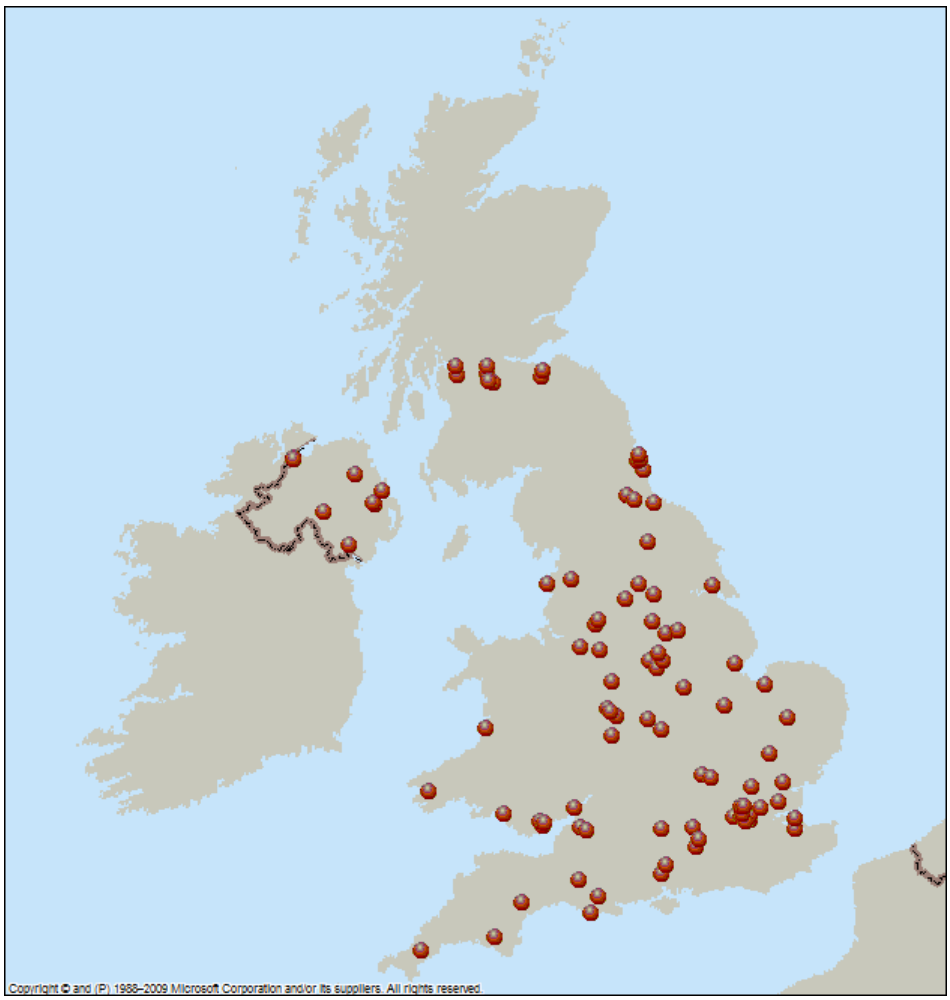
3.7 The footprint of static probes consisted of 25 rigs, with each rig containing five Epitiro probes – one probe dedicated to the measurement of each of the five MNOs considered by the research.

3.8 All probes were equipped with the same Sierra Wireless AirCard USB 309 modem to connect to the mobile network under test. This is an HSPA+ device capable of supporting download speeds of up to 21.1Mbit/s, and of connecting to all the 3G, HSDPA and HSUPA networks being operated in the UK. The use of a single USB modem for the research is not reflective of the different devices supplied by each MNO to consumers. However it did provide a consistent basis for the measurements of mobile broadband delivery by removing any differences in hardware, and also enables the accurate and consistent measurement of the radio conditions at the point of each individual test.

3.9 The SIM cards deployed with the probes were for the consumer pre-pay (Pay As You Go) mobile broadband services offered by each MNO. The exception was Orange, who at the time of the data collection did not offer a pre-pay mobile broadband service and therefore the SIM card from an Orange Dolphin mobile broadband plan was used. Mobile broadband SIMs were procured on behalf of Epitiro using operators' own retail channels. During the period of data collection, Epitiro ensured that pre-pay services were topped-up in order to maintain the necessary schedule of testing without exceeding any data caps or fair usage policies.

3.10 At the start of the data collection, the 25 probe rigs were deployed to sites indoors across the UK, with one rig at each site to enable measurement of all five MNOs. During the course of the data collection period, rigs were then relocated three times enabling measurement from 97 unique UK sites in total. Each rig remained at each site for between 2 and 3 weeks before being relocated to the next. The 97 test sites provided measurement of mobile broadband delivery with connections using more than 1,400 unique serving cells. The geographic spread of the selected static probe test sites is shown in Figure 3.1.

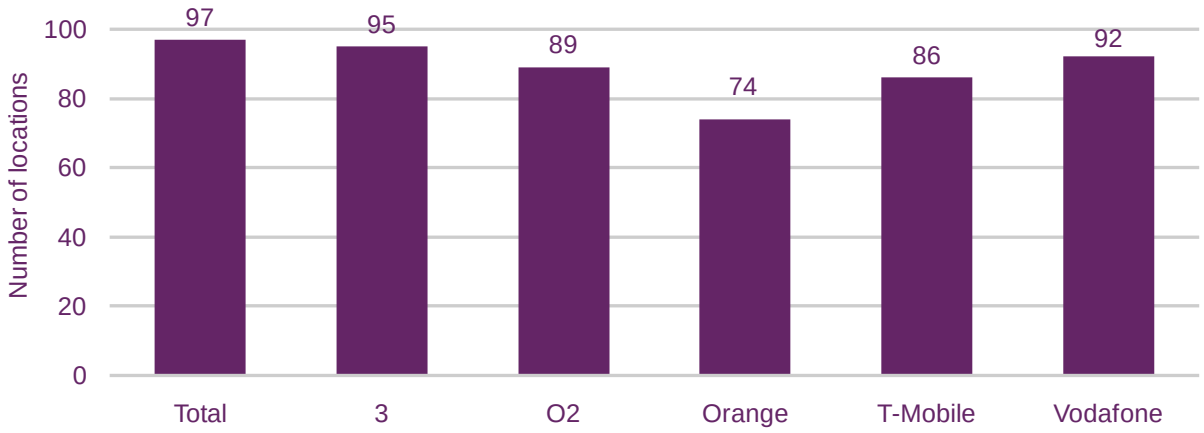
Figure 3.1 Geographical distribution of static probes



Source: Epitiro

3.11 The sites where the static probes were deployed were selected from a pool of over 600 candidate sites in the UK. The majority of the candidate sites were supplied by an Epitiro partner with sites in urban centres and retail districts of towns and cities across the UK. Sites were targeted to provide geographic coverage of key urban centres in all 12 regions of the UK. More than 160 of the 600 candidate sites were surveyed to determine what coverage of 3G/HSPA services were provided by each of the five MNOs. Sites where good 3G/HSPA coverage was available for the majority of MNOs were prioritised for deployment of probes. Not all locations offered good 3G/HSPA coverage for all operators. Figure 3.2 details the number of locations from which each operator was tested.

Figure 3.2 Number of locations for testing 3G/HSPA coverage with static probes



Source: Epitiro

3.12 All probes were configured to execute tests 24 times per day on an hourly schedule. Each hourly test consisted of connecting the probe to the mobile broadband service under test and, upon successful connection, proceeding with a series of broadband performance measurements. Those measurements included, but were not limited to, measures of download and upload speeds, network latency, web page download times, packet loss and jitter. The tests and measurements carried out by the probes are described in more detail in Annex 2.

3.13 In addition to the broadband performance measurements, the radio network conditions were recorded at the start of each connection and individual test. Radio network conditions were characterised in terms of Bearer (GPRS, EDGE, 3G, HSDPA, and HSUPA), Cell ID, LAC, MNC, MCC, and measures of signal quality - RSSI, RSCP, Ec/Io and CQI as appropriate to the connected bearer.

Drive tests

3.14 The aim of the drive testing component of the methodology was to form some case studies measuring mobile broadband performance in four specific regions of the UK. The four regional case studies, chosen to represent different levels of urbanisation, were as follows:

- Dense urban city – Birmingham;
- Urban sprawl – specifically the area along the M62 motorway between Manchester and Liverpool;
- High density provincial town – Swansea and the surrounding area; and
- High density rural or semi-rural counties – the West Midlands counties of Herefordshire and Shropshire, between Hereford in the south and Whitchurch in the north.

3.15 Each of the four case studies was carried out for a period of five days with eight hours of measurement each day, during the working hours of each day.

3.16 All measurements for the case studies were made using five static vehicle-mounted HTC Desire handsets running Epitiro's ipQ software. The Android-based HTC Desire is an HSPA-capable handset, supporting speeds up to 7.2Mbit/s downstream and 2Mbit/s upstream.

3.17 The SIM cards deployed and tariffs used with the ipQ handsets were the same as those used for the static probe testing (note that, for consistency, we used mobile broadband tariffs rather than mobile phone tariffs). New SIM cards were employed for each individual case study to ensure that sufficient data usage was available to support the frequency of testing required.

3.18 Testing for each case study was conducted along routes through a series of predetermined waypoints. All tests were run when the vehicle was stationary, so the driver was required to stop and park the vehicle before beginning tests, with a single set of tests executed at each location for each of the mobile operators. A minimum of 50 locations were tested during each day of the drive testing.

3.19 The measurements executed by the ipQ handset included measures of download and upload speeds, network latency, and web page download times. The tests and measurements carried out by the software are described in more detail in Annex 2. The ipQ software running on the Android handsets also recorded the GPS coordinates for each test and measured radio conditions in terms of bearer and RSSI.

Consumer panel

3.20 In order to support the measurement of mobile broadband performance from end users, software-based probes (the Epitiro Broadband Test Application) were deployed to a panel of users who use USB modems to access mobile broadband services from their PCs.

3.21 For this component of the research, Epitiro partnered with YouGov who supplied a screened panel of mobile broadband users. The YouGov panel was supplemented by an existing Epitiro panel of UK broadband users. In total, 1,179 users contributed performance measurements to the research.

3.22 Users taking part in the research were asked to download and install the Epitiro Broadband Test Application onto the Windows-based PC or laptop from which they access their mobile broadband service.

3.23 The Broadband Test Application software was scheduled to execute tests of network performance up to four times per day. The actual schedules and quantity of measurements made were dependent upon the frequency with which the users in the panel chose to use their PC and access their mobile broadband service.

3.24 The software was configured to ensure that testing was only conducted when the user was connected to the relevant broadband service and when certain conditions relating to CPU and network conditions were met. This avoided any impact on results from user activity by only running tests at times when suitably minimal CPU and network usage were observed.

3.25 The measurements executed by the Broadband Test Application included measures of download and upload speeds, network latency, web page download times, packet loss and jitter. The tests and measurements carried out by the software are described in more detail in Annex 2.

3.26 Users in the panel were using their own devices and USB modems to connect to the mobile broadband service, and typically used the software connection manager supplied with that device to initiate the connection. As such, no information on bearer, cell or signal strength is available with the measurements made from the consumer panel. However, the type and name of the device or USB modem, and the Mobile Operator (based on the assigned IP address) were always recorded.

Applications and metrics used across all three test methodologies

3.27 Each test methodology was configured to collect metrics in such a way that conclusions could be drawn in the context of typical consumer use of internet services and applications. The applications and associated metrics are listed in the Figure 3.3 below:

Figure 3.3 Association between applications and metrics

Application	Description of Tests
Web browsing	The time taken to download the HTML body from a web page in seconds. DNS resolution time is also measured as an important factor in the user's experience of browsing the web.
File download	Download speed in Mbit/s as a measure of the rate at which a large file such as an audio or video file could be downloaded.
File upload	Upload speed in Mbit/s as a measure of the rate at which a file such as a photo or email attachment could be uploaded.
Online gaming	Network latency as a round trip time in milliseconds, as an indicator of the suitability of the service for some online games that demand low latency.
VoIP and Video Streaming	The perceived quality of these services is affected by a combination of metrics including latency, UDP packet loss, UDP jitter and speed in both in directions.

3.28 The data collected allowed the examination of mobile broadband performance with respect to time of day and period of day. We do not publish operator-specific findings from the drive tests or consumer panel as test results are heavily influenced by coverage levels and the panels were not recruited to be representative of operators' network coverage (assessment of coverage is out of scope for this project). Operator- specific findings are presented from the static probes as the tests measured performance in areas with good 3G/HPSA coverage from all five mobile operators. A full description of each metric is located in Annex 2. The metrics described in Figure 3.4 were captured throughout the testing, although not all are covered in the analysis in this report.

Figure 3.4 Metrics collected

Metric	Description
Bearer †	The bearer (GPRS, EDGE, 3G, HSDPA, HSUPA) on which the mobile broadband service is connected.
Download Speed	The measured rate of achievable data transmission in the downstream direction over TCP (Mbit/s).
Upload Speed	The measured rate of achievable data transmission in the upstream direction over TCP (Mbit/s).
ICMP Ping	The round trip time from the connected probe to a known point in the network (milliseconds).
Web Page Download Time	The time taken to download the HTML body of a specific web page (seconds).
DNS Resolution Time	The time taken to resolve a fully qualified domain name to a corresponding IP address.
RSSI †	Received Signal Strength Indicator.
RSCP † ‡	Received Signal Code Power.
Ec/Io † ‡	The ratio of the received energy and the level of radio interference.
CQI † ‡	Channel Quality Indicator.
Packet Loss ‡	A measure of the loss of packets during transmission over an IP network.
Jitter ‡	A measure of the variation in the arrival of packets during an IP based data transmission.

† *Not measured during consumer panel testing*
‡ *Not measured during drive testing*

Overview of the statistical methodology

3.29 This report collected results from over 4.2 million test from three data collection methodologies:

- a deployment of static probes;
- drive testing; and
- a consumer panel

3.30 The data sets have been analysed separately, with each conclusion drawn from a data set pertaining to one of the data collection methodologies.

- We present data only when sample sizes were substantial such that accurate analysis and conclusions could be made. Measurements comparing the performance of different operators are presented with a 95% confidence interval around the mean in order to ensure that it is clear when differences are statistically significant.
- For the static-probe network testing, significant effort was taken to ensure all five operators were tested from the same locations, at the same time and using identical test apparatus.

3.31 As bearers can change throughout a session at the discretion of each operator, we have not separately analysed 3G and HSPA in the dataset collected from the static probes. Lower speed 2G services are not included in the static probe analysis unless specifically stated. We were not able to identify which bearer was used for tests run from the consumer panels, so data from all bearers (2G, 3G and HSPA) is included.

3.32 Marketing research specialist YouGov provided the principal statistical analysis of the data collected from the fixed probes and drive tests, while Ofcom provided the analysis from the consumer panel. Annex 3 contains a detailed explanation of the statistical methodology.

Section 4

The Consumer Context

Mobile broadband from a consumer context

4.1 The take-up of mobile broadband has increased significantly in the last three years. Our research finds that there were around 4.8 million active mobile broadband subscribers using datacards or dongles at the end of 2010 compared to 2.6 million at the end of 2008.[14]

4.2 An increasing number of households are also using mobile broadband as their only means to connect to the internet: our research finds that 7% of UK households used mobile broadband as their only internet connections, compared to just 3% of households in Q1 2009 With fixed-broadband levelling off at around 65%, it appears that the growth in overall household broadband take-up (up 68% in Q1 2009 to 75% in Q1 2011) is now being driven by households getting online for the first time via mobile broadband.[15]

4.3 Mobile broadband has therefore entered the mass market and is set to continue to be a highly significant component of the UK's communications infrastructure.

- Mobile broadband does not require rental of a fixed line, unlike fixed broadband, and may therefore represent a lower-cost way for some households to get online.[16]
- Recent research from Ofcom shows that 86% of mobile broadband dongle users access the service while at home.[17]
- The same research indicates that mobile internet usage using a dongle or datacard is not significantly dissimilar to fixed internet usage. Surfing the internet, email and watching short video clips are as likely to be conducted via dongles/USB sticks (particularly in the home) as on a fixed broadband connection.
- The launch of tablet devices with larger screens, more powerful hardware and superior battery life give the potential to generate high data traffic per device. For the iPad alone, some analysts estimate pre-Christmas sales of around 500,000 in the UK since its launch in May 2010 and further sales of several million in 2011.[18]

[14] Based on information supplied to Ofcom by mobile operators and MVNOs
[15] Ofcom Communications Market Report, August 2010, pp291-294, http://stakeholders.ofcom.org.uk/binaries/research/cmr/753567/CMR_2010_FINAL.pdf
[16] Analysis of lowest cost fixed broadband options and stand-alone mobile broadband contracts, Ofcom Communications Market Report, August 2010, p 354-355
[17] Ofcom Mobile Broadband Research Summary Report, November 2010 http://stakeholders.ofcom.org.uk/binaries/research/consumer-experience/tce-10/mobile-broadband.pdf
[18] Enders Analysis, The mobile internet, apps and the route to market, Jan 2011

- According to forecasts by Cisco, worldwide mobile data traffic will increase by a factor of 26 over the next four years, driven by the take-up in the use of tablets and other internet-connected devices and increasing use of mobile video.[19]

Positioning of mobile broadband

4.4 The mobile broadband market has developed rapidly and its market positioning has evolved from being focused on business users, to becoming a mass market proposition.

4.5 Some mobile broadband providers clearly explain the different capabilities of mobile broadband services compared to fixed broadband and use practical examples of the type of usage each service is suited to. For example, O2 explains on its website that mobile broadband is suitable for emailing, social networking and online banking and shopping while fixed broadband and WiFi hotspots are more appropriate when downloading a big file, watching TV, playing games online or sending big attachments[20]. This is in recognition that fixed and mobile broadband have different characteristics and may address different needs. According to Ofcom research, around two thirds of households with mobile broadband use it in addition to a fixed-line broadband service[21].

4.6 Mobile broadband is not generally marketed on the basis of the speed of connection, in recognition that "headline" speeds (for example, "up to 7.2Mbit/s") have little meaning when performance varies so much by location as a result of different levels of network quality. In June 2009 UK mobile operators published 'Principles of Good Practice for Marketing Mobile Broadband Services'[22]. One of the principal aims of this code was the provision of clearer information for consumers that actual throughput speeds vary significantly and depend on a range of factors.[23]

4.7 At the same time, Ofcom published a consumer guide on mobile broadband to better inform customers on the factors they should consider when purchasing the service.[24]

4.8 Although this report only considers performance delivered over cellular networks, WiFi connectivity is becoming an increasingly important part of mobile broadband services. In response to rapidly expanding demand for mobile data services, an increasing number of mobile broadband tariffs now include WiFi allowances, whereby mobile broadband customers can benefit from the higher speed and greater capacity offered by fixed networks delivered via WiFi 'hotspots'.

Consumers as satisfied with the speed of mobile broadband as with fixed broadband

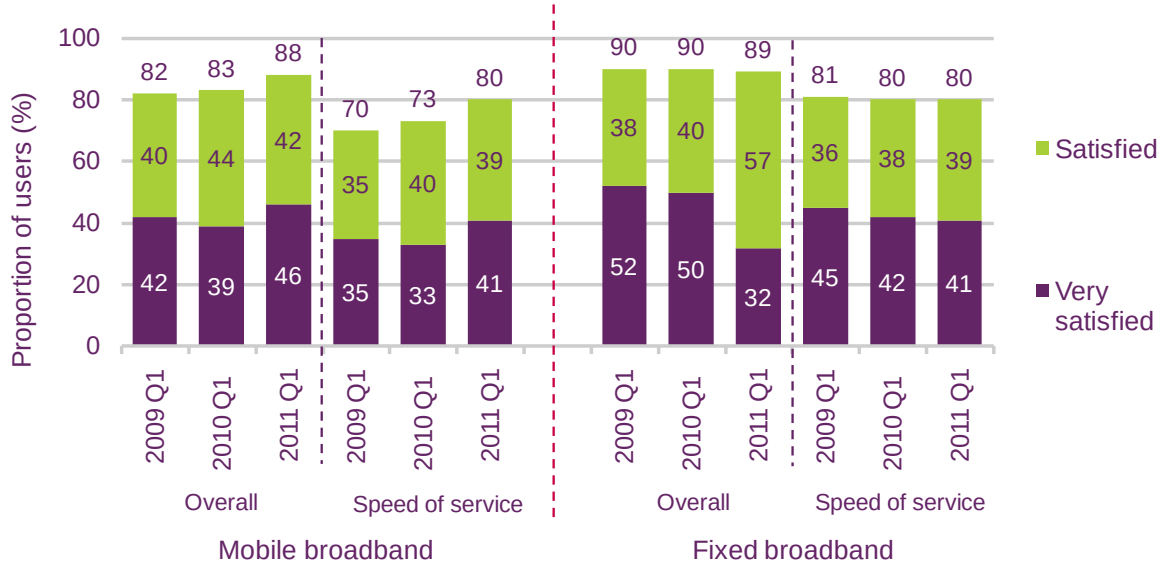
4.9 According to Ofcom consumer research, levels of satisfaction with mobile broadband services were similar to fixed broadband services in Q1 2011. Overall satisfaction

[19] The Cisco® Visual Networking Index (VNI) Global Mobile Data Traffic Forecast Update, 11 February 2011
http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html
[20] http://www.o2.co.uk/broadband/mobile/
[21] Ofcom technology tracker, Q1 2011
[22] O2, Orange, T-Mobile, Vodafone, 3UK and Virgin Mobile
http://www.mobilebroadbandgroup.com/documents/mbg_mobile_broadband_pr_010609.pdf
[23] One of the principal aims of this code was the provision of clearer information for consumers that actual throughput speeds vary significantly and depend on a range of factors.
[24] http://consumers.ofcom.org.uk/2009/08/what-to-look-for-when-choosing-mobile-broadband/

with mobile broadband was 88% in Q1 2011 compared to 89% for fixed while 80% of mobile broadband users were either very or fairly satisfied with the download speeds provided by their connection, the same level as that of fixed broadband users (80%).

4.10 Levels of satisfaction with mobile broadband services have risen since 2009, with a significant rise in satisfaction with the speed of the service in the year to Q1 2011 (up 7 percentage points). This may reflect improvements in the quality of service delivered to consumers, but also reflect greater consumer awareness as to the type of services suited to mobile broadband and more realistic expectations as to what levels of speed the service can deliver.

Figure 3.5 Residential consumer satisfaction with aspects of fixed and mobile broadband service, 2009 to 2011



Source: Ofcom research, Q1 2011Base: All adults aged 15+ with a mobile broadband connection
Note: Includes only those who expressed an opinion

4.11 Recent Ofcom research found that the main causes of dissatisfaction with mobile broadband via dongles/USB sticks were related to speed. Over one-third (34%) of laptop/dongle out-of-home users cited slow download speed as the main cause of dissatisfaction.

Figure 3.6 Satisfaction with fixed and mobile broadband services

Are there any problems using (X) to access the Internet?	Fixed line (WiFi)	Fixed line (no WiFi)	MBB at home	MBB out of home
Speed of connection is too slow	18%	24%	22%	34%
The internet connection is unreliable	7%	7%	12%	13%
Poor coverage – it's hard to get a connection	3%	2%	7%	9%

Source: Main problems experienced when accessing the internet using various access method, Ofcom Mobile Broadband Research Summary Report, November 2010.

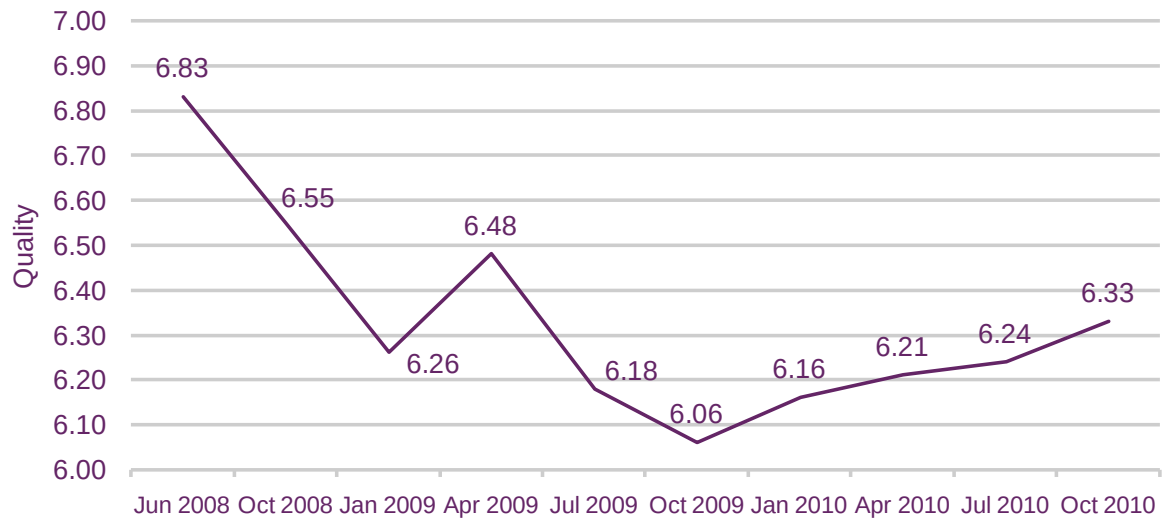
http://stakeholders.ofcom.org.uk/binaries/research/consumer-experience/tce-10/mobile-broadband.pdf
Base: All using each device/method as main device.

Consumer satisfaction with mobile broadband has fluctuated since 2008

4.12 Research from YouGov's quarterly Dongle Tracker study[25] shows that satisfaction with mobile broadband has fluctuated over time since 2008 (Figure 3.7). In June 2008 when the research was first carried out, the average satisfaction level was 6.83 for overall quality (measured on a 10-point scale). Over time, with mobile broadband penetration increasing, the service has experienced challenges concerning reliability and connectivity (possibly also related to changing user expectations). Consequently satisfaction with services declined. In October 2009, the industry average for overall quality fell to its lowest at 6.06.

4.13 Satisfaction levels have risen steadily since October 2010. While ratings vary by MNO, performance for overall quality has risen from 6.06 in wave 6 (October 2009) to 6.33 in wave 10 (October 2010). Increasing levels of satisfaction may be a result of improvements in networks, but may also be the consequence of a shift in consumer expectations, for example as operators market the service as ideal for 'lighter' internet activities such as email and browsing rather than 'heavier' activities such as streaming content or sending big attachments.

Figure 3.7 Mobile broadband perceived quality over time



Source: YouGov all mobile broadband respondents (dongles and datacards).
Notes: (1) Response to the survey question; "On a scale where 1 is very poor and 10 is excellent, how would you rate the quality of the mobile broadband service you receive from [current operator]? Please consider all aspects for quality such as the installation, network coverage, connectivity, reliability, speeds, ease of use, customer services, and billing as well as any other quality factors when rating the mobile broadband service from [current operator]." (2) A higher score indicates higher user opinion.

[25] YouGov's Dongle Track programme is a satisfaction, usage and attitude study looking at the views of 2,000 UK mobile broadband users each quarter. This is a perception-based study where dongle users give their opinion on the service received from their mobile network operator.

Factors that influence consumer experience of mobile broadband

4.14 The most influential factor in achieving mobile broadband services is gaining access to the radio network. The availability of cell coverage in rural areas is an issue as is achieving connectivity within buildings, in-motion (trains, cars) and in underground areas such as car parks or basement flats. Mobile coverage is out of scope for this research, but Ofcom has been progressing a broad programme of work looking at mobile coverage issues. Mobile not-spots have been raised frequently by stakeholders as an issue of concern. We identified this issue as one of our priority areas in our 2010/11 Annual Plan and published a wide-ranging research report last November to develop insights into mobile not-spots and establish an evidence base to ensure mobile coverage issues are well understood across the UK.[26] For 2011/12 our work on mobile not-spots continues to be an annual plan major work area and we are considering the need to improve coverage information, examining the scope to facilitate coverage on the move, continuing to engage with government, and taking forward spectrum release.[27]

4.15 Where mobile service is available, the most significant factor that affects mobile broadband speed, and ultimately the consumer experience, is the type of bearer. Early mobile internet services were offered using the 2G family of bearers which could theoretically reach speeds of 20kbit/, making it useful for text-based email but impractical for web browsing or file downloading.

4.16 Since 2008 mobile operators have marketed higher speed 3G services and devices. The term '3G' is not representative of a specific speed but rather is a name applied to a selection of bearers (access technologies), each with its own speed limits. Figure 3.8 below shows the range of 3G bearers.

Figure 3.8 Theoretical maximum 3G bearer speeds

	UMTS	HSDPA	HSPA
Theoretical maximum speed	384kbit/s	7.2Mbit/s	14.4Mbit/s

4.17 Our research shows that the type of bearer provided to a mobile broadband user may change throughout the period of connectivity. For example, at the point of connectivity an operator may assign a lower speed 3G bearer, then upgrade it to a higher speed bearer depending on bandwidth availability, signal strength, end user device capability and the benefit to the requested task.

4.18 We observed that there is not a standard format for informing end-users of available 3G bearers. Devices may indicate the availability of higher speed 3G services as 3G+, 3.5G or HSPA, for example. Consequently we have defined two terms for this report as follows;

- The term 3G applies to the slower UMTS and non-HSXPA bearers.
- The term HSPA refers to higher-speed 3G services.

4.19 Contention for bandwidth also affects the consumer experience of mobile broadband services. Contention may occur at the radio access point where many subscribers

[26] http://stakeholders.ofcom.org.uk/market-data-research/telecoms-research/mobile-not-spots/.
[27] http://www.ofcom.org.uk/files/2011/04/annplan1112.pdf

are competing for service on a single cell, or in the backhaul if that connectivity has limited capacity for handling mass demand.

4.20 Though not specifically part of this research, in-motion use of mobile broadband services can affect the consumer experience due to the complexities with cell handoff. Reliability and speed may vary when travelling on a train, for example.

4.21 In addition to network availability, operator policies in handling traffic will impact on the consumer experience. For example, in order to optimise the service delivered to users, some operators compress images in order to reduce the bandwidth demand and increase the speed at which the web page loads.

Why speed is important

4.22 Most consumers have been introduced to broadband through fixed-line broadband where, along with price, 'speed' is a key metric used to market those services. Consequently mobile broadband consumers are not only familiar with the term 'speed', but also have views as to what is 'good' performance, based on the time it takes to perform typical tasks. Figure 3.9 provides an indication of the theoretical time taken to perform certain application tasks in relation to speeds of broadband services.

Figure 3.9 Theoretical time to download files

Application Activity	1Mbit/s	2Mbit/s	8Mbit/s	14Mbit/s
Download 250kB Web Page	2 seconds	1 second	0.3 seconds	0.17 seconds
Download 5MB Music Track	42 seconds	21 Seconds	5 seconds	3 seconds
Download 25MB Video Clip	3 minutes 30 seconds	1 minute 45 seconds	26 seconds	15 seconds
Download Low Quality Film (750MB)	104 minutes	52 minutes	13 minutes 6 seconds	7 minutes 8 seconds
Download DVD Quality Film (4GB)	9 hours 36 minutes	4 hours 48 minutes	1 hour 11 minutes	38 minutes 57 seconds

Section 5

Findings: Mobile Network Performance as measured from Static Probes

5.1 In this section we examine mobile broadband service levels delivered over 3G/HSPA networks to high-end mobile broadband modems. Data was collected from 97 probes located in areas of good network coverage around the UK.

5.2 The measurements in this section on average reflect better performance than those collected from the consumer panel for the following reasons:

- The sites for the deployment of the static probes were selected based on having good 3G/HSPA coverage. As a result the overwhelming majority of tests were run on 3G/HSPA bearers (and in order to facilitate comparison, for much of the reporting we have excluded 2G tests). By contrast, we had no control over the location of tests run by our consumer panel, and it is likely that a significant proportion used 2G bearers (our methodology does not allow us to ascertain the bearer used for consumer panel tests).

- The static probes used high-end hardware (a Sierra Wireless modem) capable of running speeds of up to 21Mbit/s. Our consumer panel will have used a wide range of mobile broadband modems ('dongles') and it is likely that hardware limitations were sometimes a constraint on performance.

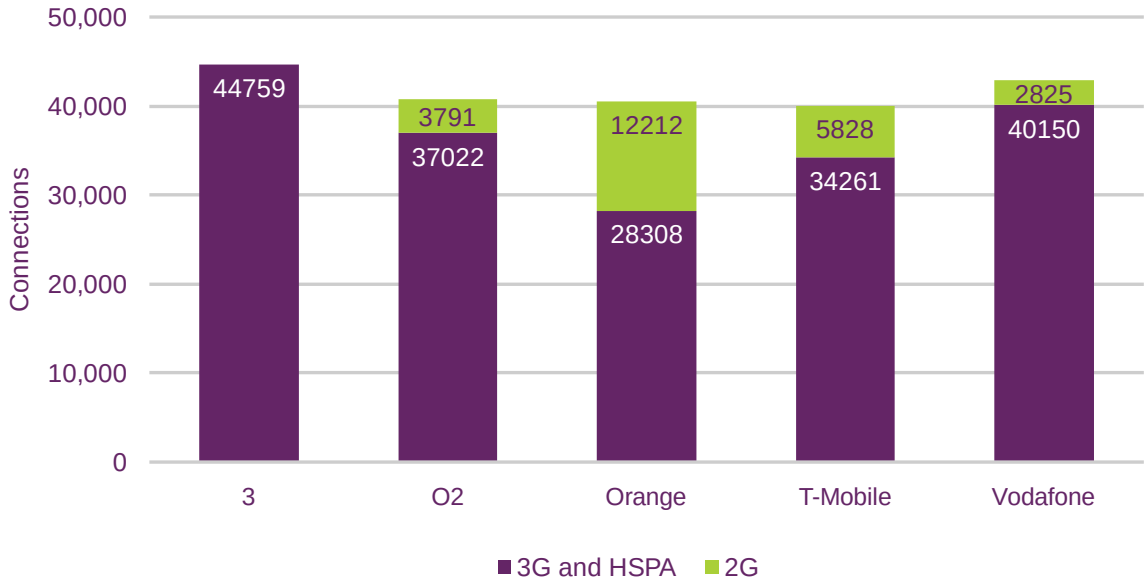
Sample sizes

5.3 We installed test probes in 97 locations (from a target of 100) throughout the UK and tested all five operators using identical dongles and test apparatus.

5.4 Tests were conducted hourly on all static probes from September 2010 to December 2010, creating a sample size of over 3.8 million test results run from over 200,000 test connections.

5.5 Throughout the test period we endeavoured to collect comparable amounts of data from each operator from locations where 3G and HSPA were available for all operators. As seen in Figure 3.10, not all operators were able to connect from all sites, with '3' connecting the most times overall and the most often by higher speed 3G and HSPA technology. Orange had the least amount of 3G and HSPA connections.

Figure 3.10 Connections by operator and type of bearer



Source: Epitiro measurement data for all static probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 2G, 3G or HSPA bearer at time of connection; (3) Sample size of 209,156 successful connections.

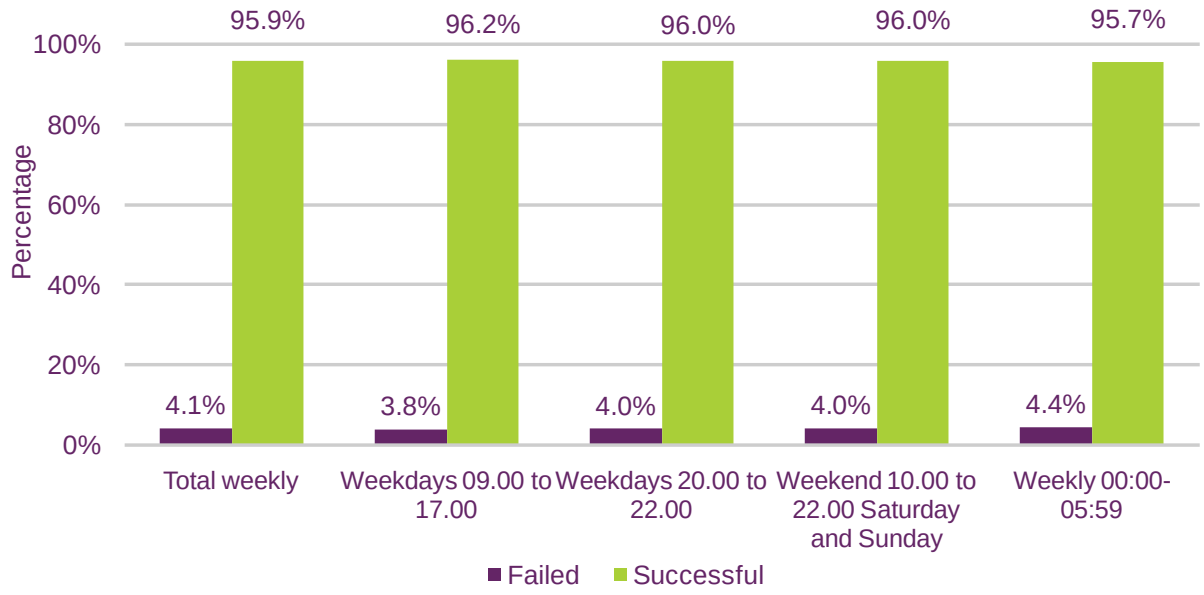
Successful first time connections

5.6 The ability to acquire a satisfactory service on demand is important to mobile broadband users. Unlike a fixed-line broadband service, a mobile broadband service (using a dongle) is not 'always on' and requires the user to initiate the connection using software.[28]

5.7 We measured that, on average, 96% of connection attempts were successful on the first attempt. On average, a user of mobile broadband services via a dongle would have had to make a second attempt to connect 1 in every 25 times. There was little variation by time of day (Figure 3.11).

[28] Note that the need to manually re-attempt to connect is primarily a requirement for dongle and datacard users. Smartphones and tablets generally have the capability to automatically re-attempt to connect.

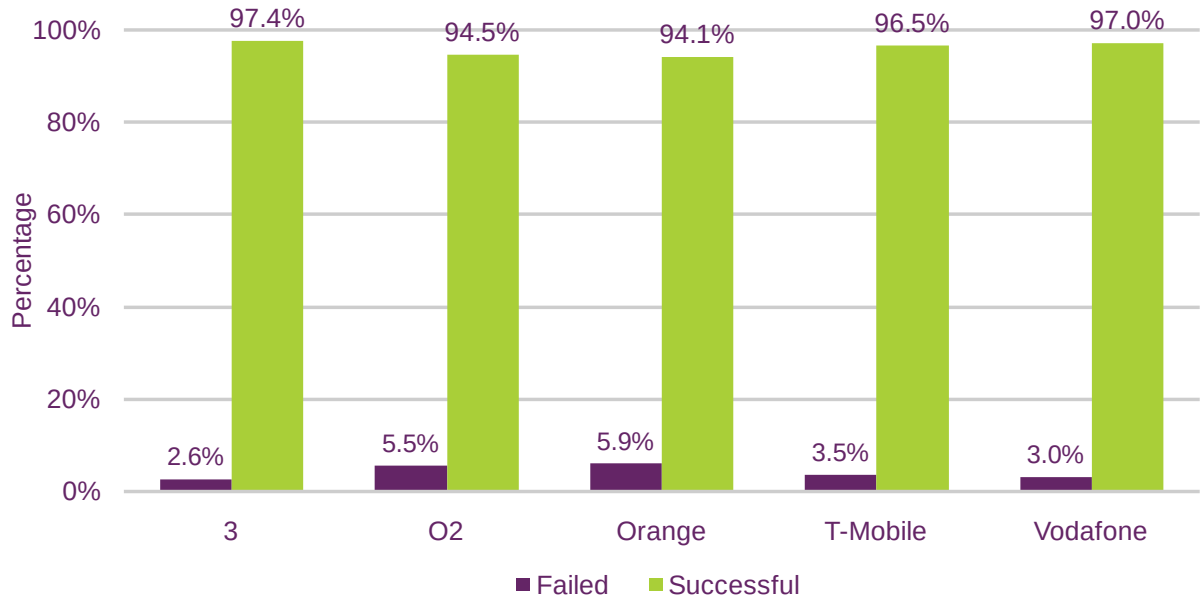
Figure 3.11 Successful first time connections for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 2G, 3G or HSPA bearer at time of connection; (3) Sample size of 470 static probes (4) Higher successful first time connection percentages indicates better service.

5.8 Successful first time connection attempts varied slightly between operators, as shown in Figure 3.12. '3' had the highest proportion of first time connections, failing to connect only 1 time in 39 attempts. Orange failed to connect 1 in 17 times.

Figure 3.12 Successful first time connections by operator

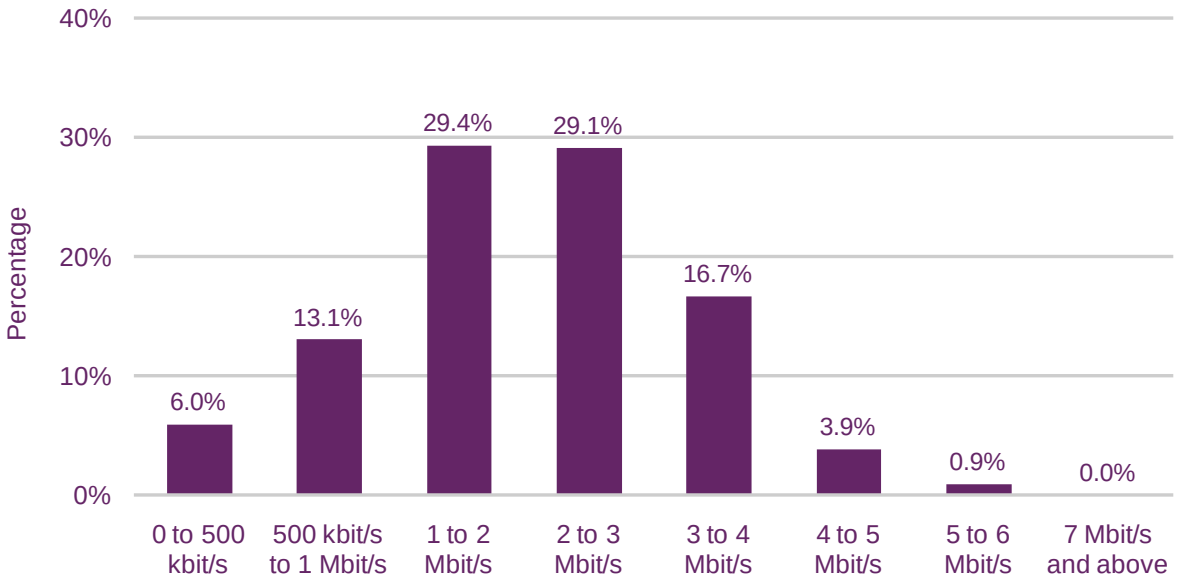


Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.

Notes: (1) Data is based on 2G, 3G or HSPA bearer at time of connection; (2) Sample size of 470 static probes; (3) Higher successful first time connection percentages indicates better service. Mobile broadband download speeds vary significantly.

5.9 Considering only the tests which used 3G/HSPA bearers, among all the five MNOs tested, three-quarters of download speed tests (75%) measured speeds of between 1 and 4Mbit/s. Speeds of less than 1Mbit/s comprised 19% of the tests while 5% of all speeds measured were in excess of 4Mbit/s (Figure 5.4).

Figure 3.13 Distribution of average download speeds for all operators

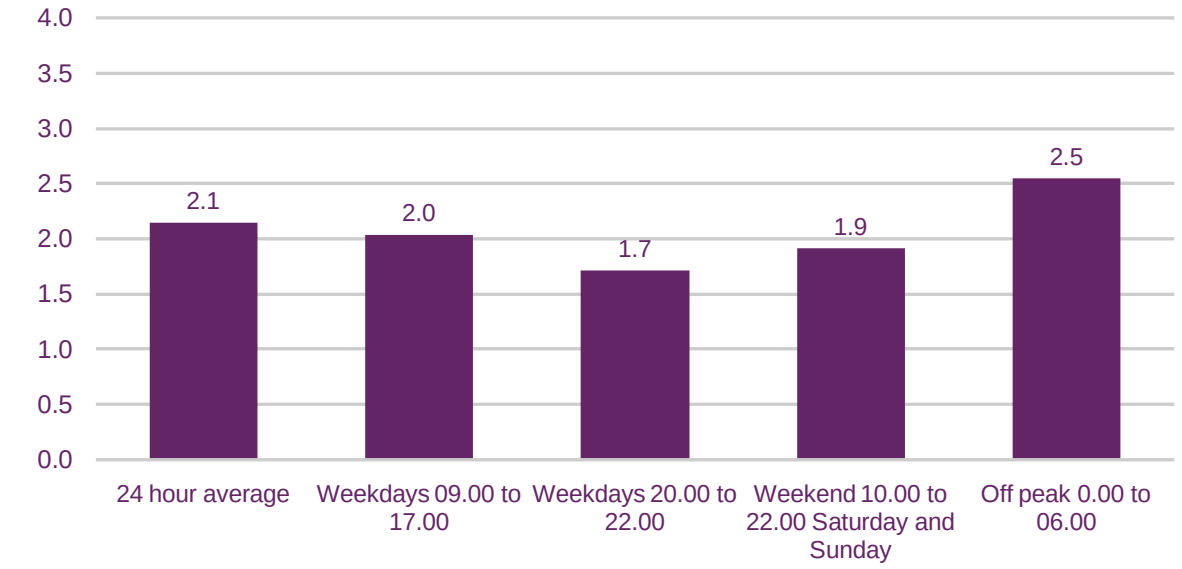


Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) Higher speeds indicate better performance.

5.10 Download speeds changed significantly during peak periods. Figure 3.14 shows that the average speed over 24 hours was 2.1Mbit/s. However, in the peak period of 8-10pm weekdays average speeds were 1.7Mbit/s, 33% lower than average speeds in the off-peak period of 12am to 6am (2.5 Mbit/s).

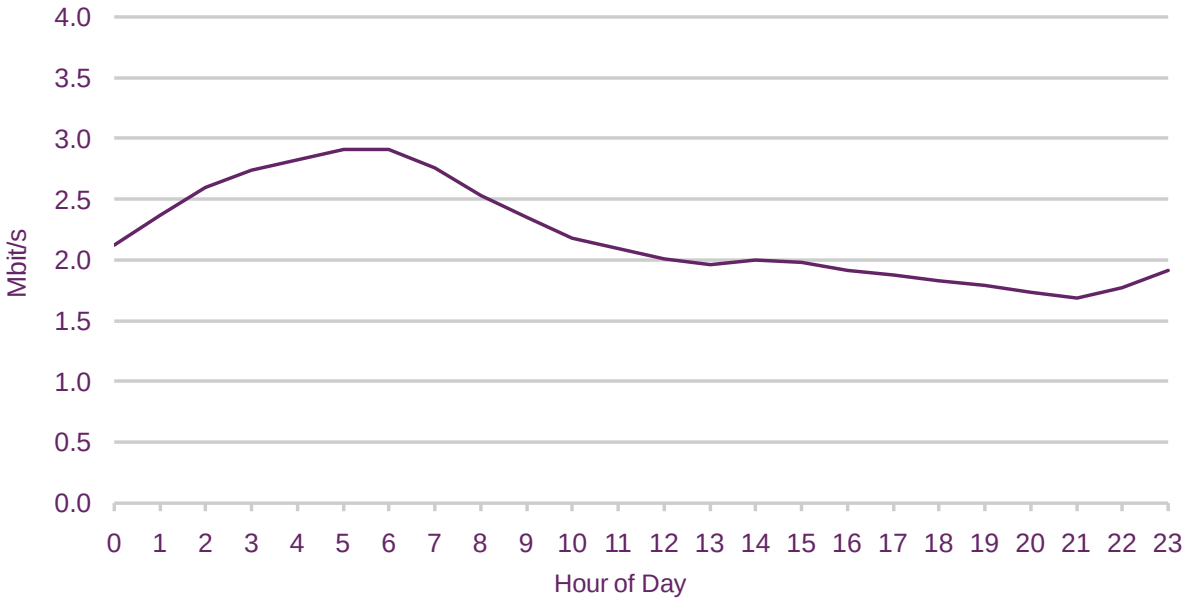
5.11 Figure 3.15 shows how average speeds varied over 24 hours. The slowdown coincides with periods when consumers are more likely to be connected (as indicated by data from our consumer panel which captured the time of day that panellists were connecting – see Figure 7.1 below). This indicates that contention in the networks is constraining speeds during peak times.

Figure 3.14 Average download speeds by period of day for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) Higher speeds indicate better performance.

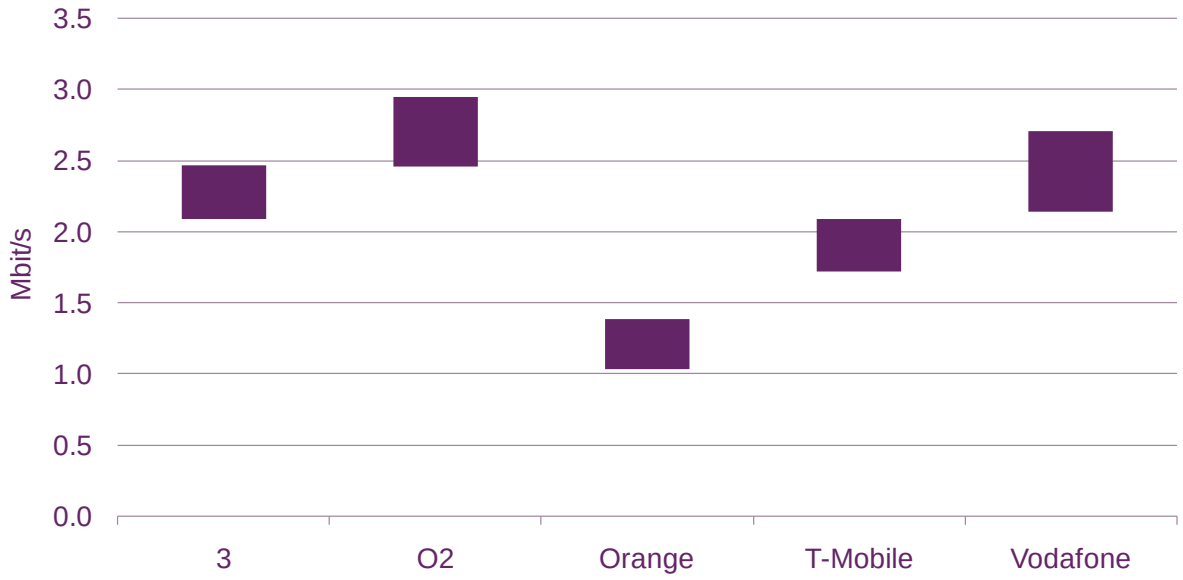
Figure 3.15 Average download speeds by hour of day for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) Higher speeds indicate better performance.

5.12 Our data also found that there were significant differences in the average speeds delivered by operators. 3, O2 and Vodafone were on average faster than T-Mobile and Orange, while Orange was significantly slower than all the other operators.

Figure 3.16 Average download speeds by operator



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Higher speeds indicate better performance

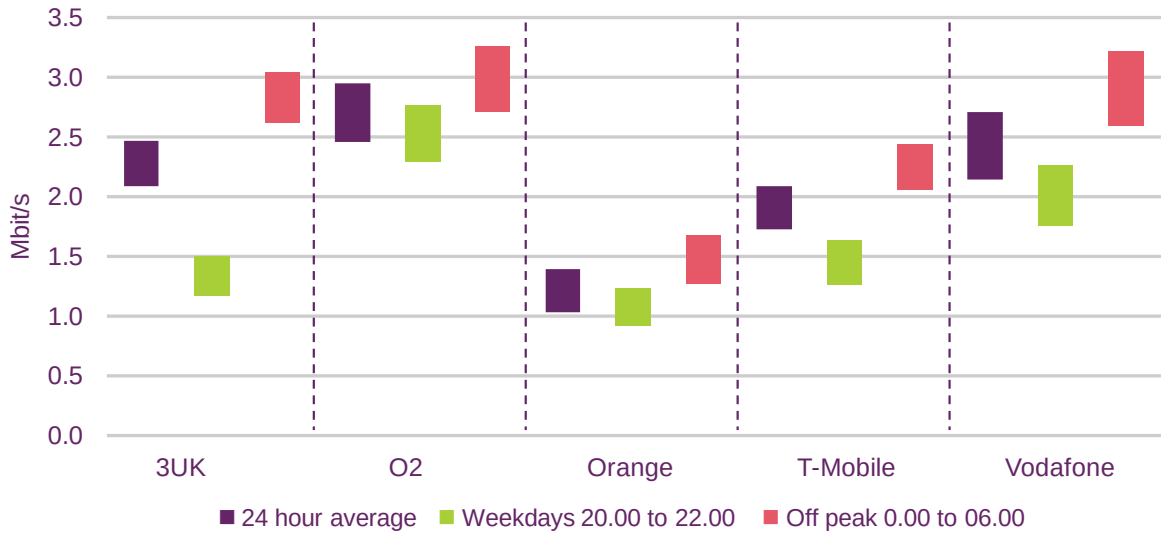
Figure 3.17 Significant differences in average download speeds between operators to a 95% level of confidence

	Is slower than...	Is faster than...
3		Orange, T-Mobile*
O2		Orange, T-Mobile,
Orange	3, O2, T-Mobile, Vodafone	
T-Mobile	3*, O2 and Vodafone*	Orange
Vodafone		Orange, T-Mobile*

**Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 probes.

5.13 All operators delivered slower average download speeds in the peak weekday evening hours of 8-10pm than in the off-peak hours of 12am -6am. 3 suffered the greatest slowdown with speeds in the peak evening period around 50% slower than off-peak speeds, and O2 delivered the fastest speeds during the peak period (Figure 3.18).

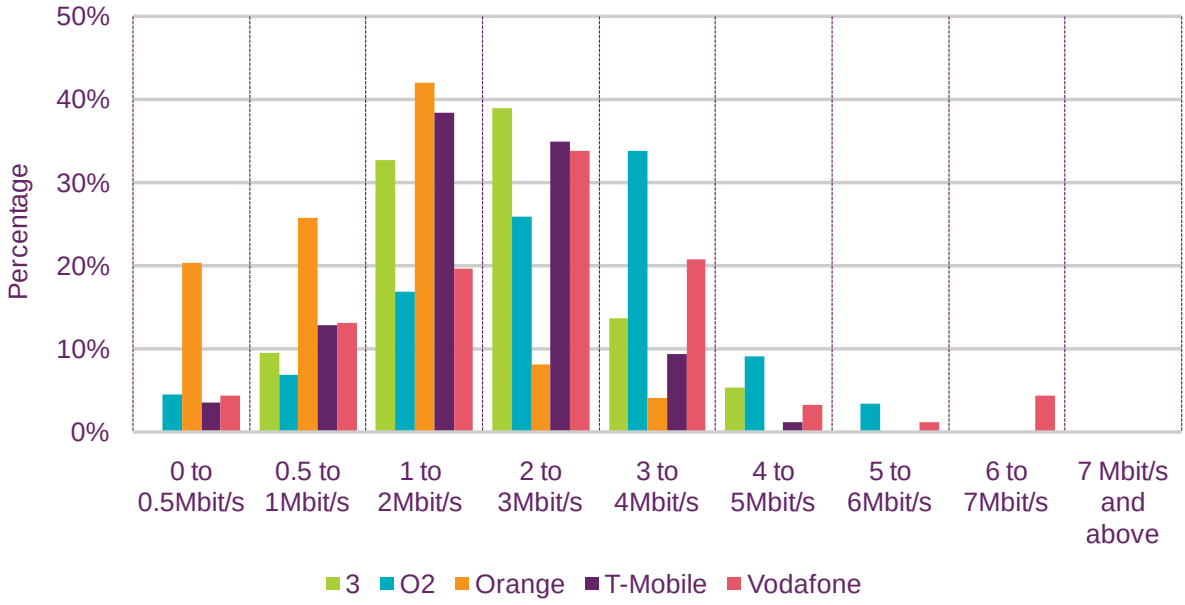
Figure 3.18 Average download speeds by operator and period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Higher speeds indicate better performance.

5.14 Analysis of the distribution of average speed delivered provides further insight. Nearly half (46%) of O2's average download speeds were higher than 3Mbit/s; conversely, the majority of average speeds measured for Orange and T-Mobile were less than 2Mbit/s (Figure 3.19).

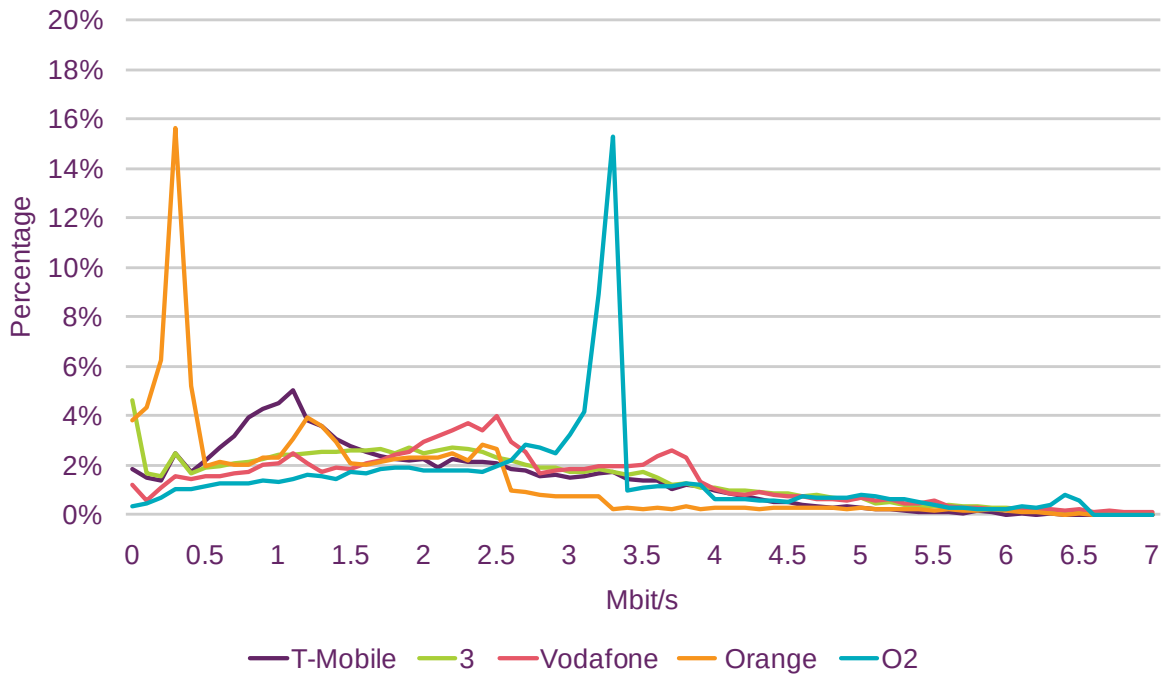
Figure 3.19 Distribution of download speeds by operator



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) Higher speeds indicate better performance.

5.15 Figure 3.19 shows the distribution of all test results (i.e. every 3G/HSPA test result from every probe rather than the average for each probe). It is notable that some operators have a large number of speeds at a particular value, perhaps indicating network management policies whereby under certain conditions speeds are capped at a particular value in order to improve overall network performance: around 15% of Orange test results were measured at around 0.3Mbit/s, and around 15% of O2 test results were measured at around 3.3Mbit/s.

Figure 3.20 Distribution of download speed tests by operator



Source: Epitiro measurement data for all static probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 175,204 tests; (4) Higher speeds indicate better performance.

Signal strength and download speed

5.16 Our test methodology ensured that all operators were tested at the same time and the same location. However, it was not possible to ensure that network conditions for each operator were identical: signal levels varied in accordance with different network deployments in the locations we tested.

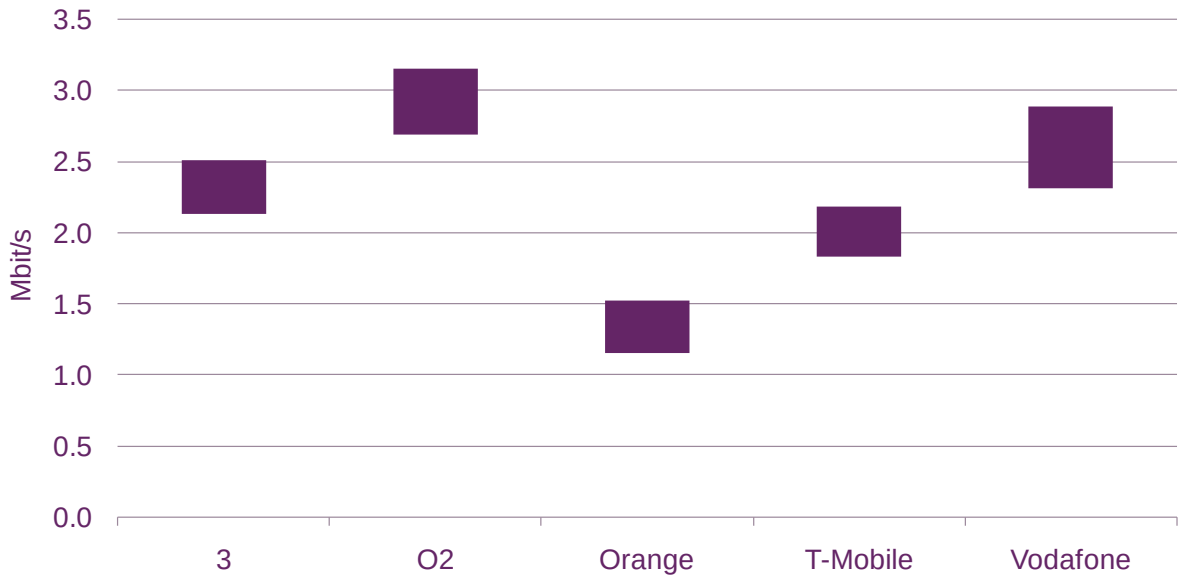
5.17 In order to better understand how each operator performed under common radio conditions we analysed a sub-set of data that was collected under equally favourable conditions for all operators. The parameters that defined favourable conditions were as follows:

- 3G or HSPA bearer during the test.
- Better than -12dB Ec/Io levels to ensure a good signal to noise ratio.

5.18 Analysis of the favourable conditions data resulted in an improvement of average speeds for all operators (Figure 3.21). This indicates that radio network conditions are an important determinant of performance. However, there were the same differences between operators as when 3G/HSPA test results under all radio

conditions were included (Figure 3.22). This indicates that different radio network conditions was not a key driver of differences in overall average performance between operators.

Figure 3.21 Average download speeds under favourable radio conditions by operator



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 398 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Higher speeds indicate better performance.

Figure 3.22 Significant differences in average download speeds between operators under favourable radio conditions

	Is slower than...	Is faster than...
3		Orange, T-Mobile
O2		Orange, T-Mobile,
Orange	3, O2, T-Mobile, Vodafone	
T-Mobile	3*, O2 and Vodafone	Orange
Vodafone		Orange, T-Mobile

**Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 448 probes; (3) The range shown represents a 95% confidence interval around the mean.

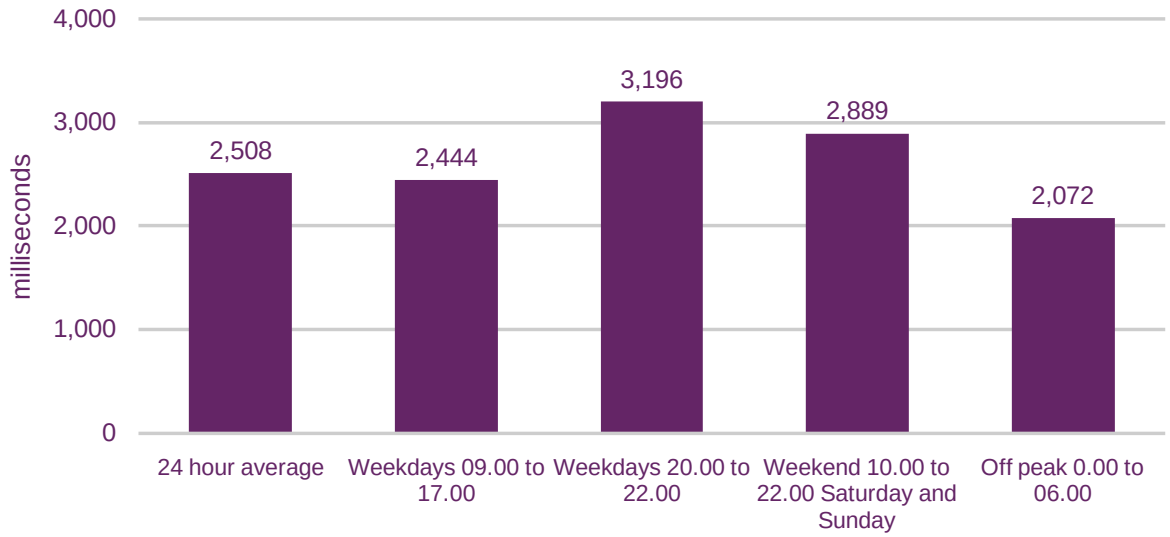
Web page download time

5.19 According to YouGov's Dongle Track survey, web browsing, after email, is the second most popular activity amongst dongle users, with 69% of survey participants browsing, shopping or banking online at least once per week.29

5.20 The webpage download test involved measuring the time taken to download the html 'skeleton' of three popular UK websites. The time taken to download the associated media assets, such as images and graphics were not included. We believe that this is a fair measure of performance, because images on web sites may be cached on the handset and therefore not have to download every time, and also because some operators use image compression (see Section 5.27 below) which makes like-for-like comparison between operators impossible. However, it should be noted that the web page download times measured may be significantly faster than the time it would take to download a full web page with all images.

5.21 Our results show that web pages downloaded in 2.5 seconds on average, slowing to 3.2 seconds in peak periods (Figure 5.12). As with the download speed data above, this data only includes tests run on 3G/HSPA bearers. It is notable that identical tests run on our consumer panel delivered an average download time of 8.5 seconds (See Section 7 below).

Figure 3.23 Web page download times for all operators

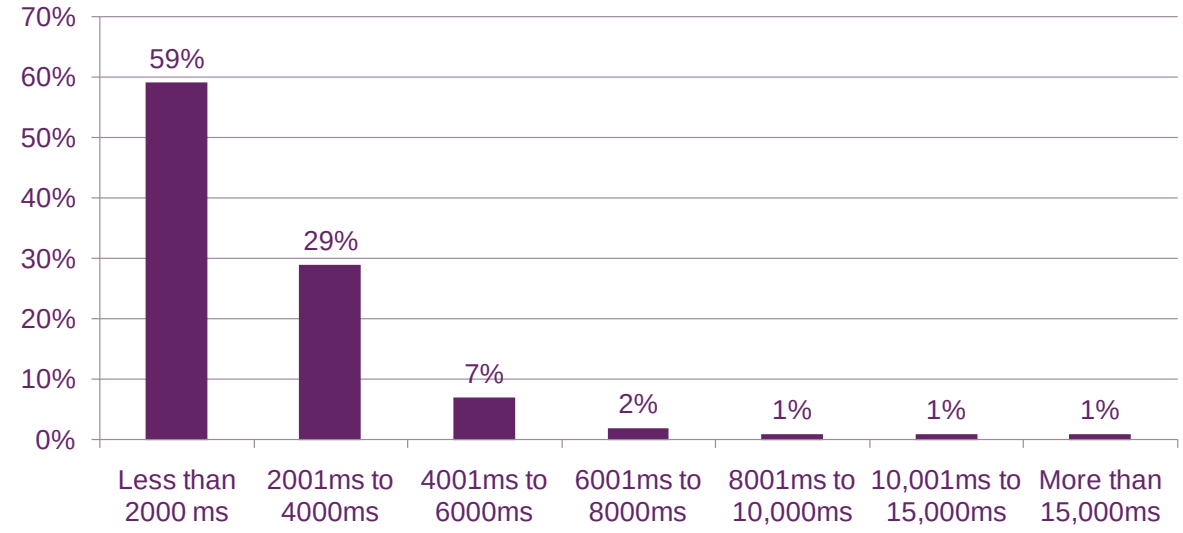


Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 415 probes; (4) Lower download times indicate better performance.

5.22 Our results show that more than half of the probes tested (59%) delivered web pages in an average of less than 2 seconds (Figure 3.24).

[29] YouGov Dongle Track report October 2010

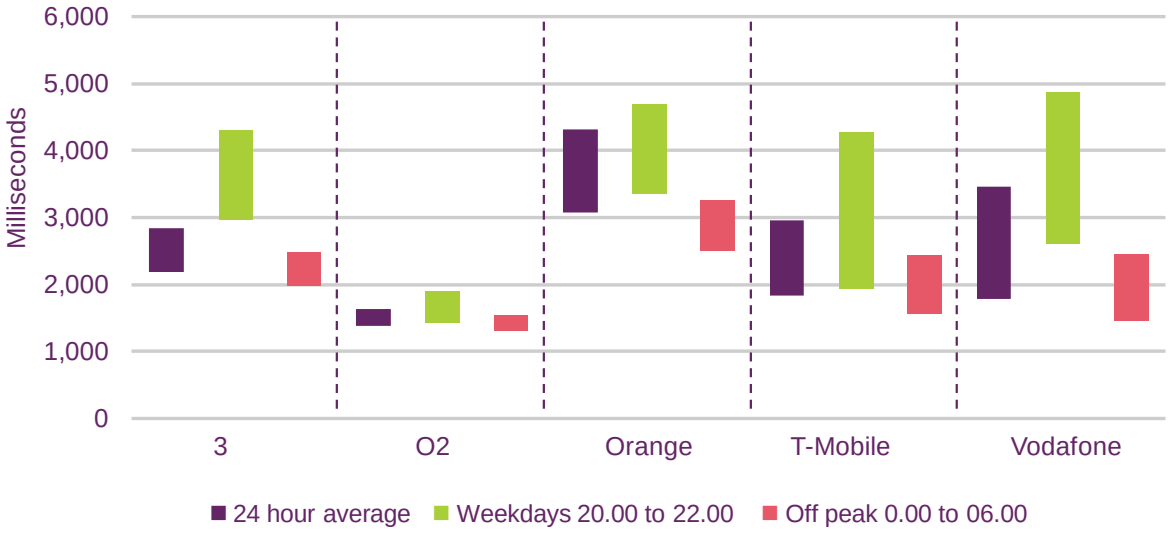
Figure 3.24 Distribution of web page download times for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) Lower times indicate better performance.

5.23 As with download speeds, there were some significant differences in the average web page download time between operators. While the overall average download time was 2.5 seconds, O2 was the fastest at around 1.5 seconds. It is also notable that for all operators there was a significant degradation in performance in peak hours.

Figure 3.25 Web page download times by operator and period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 434 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower download times indicate better performance.

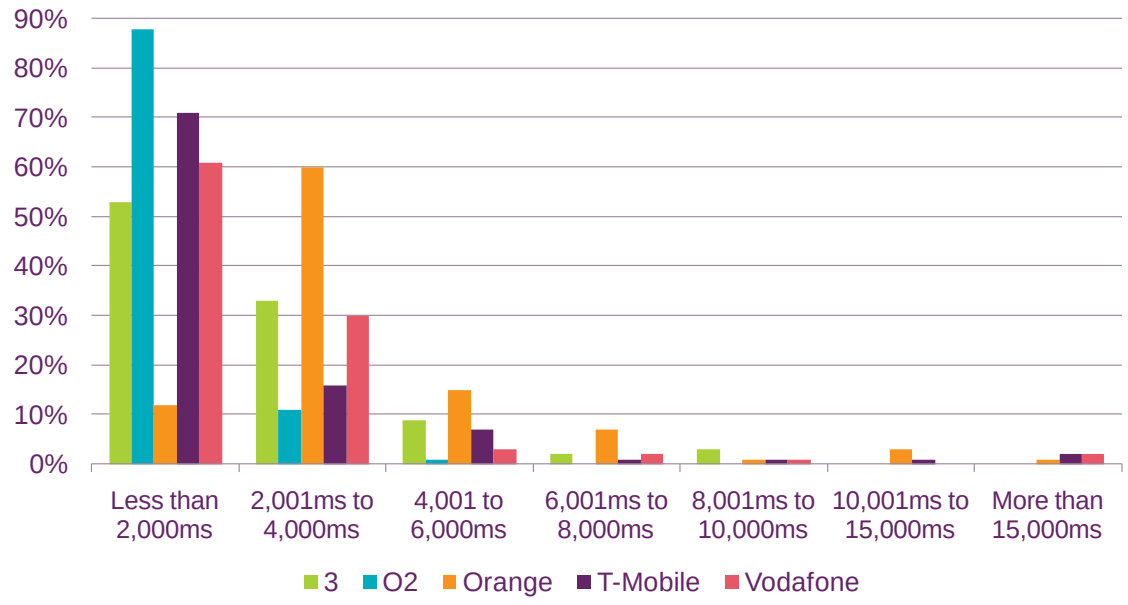
Figure 3.26 Significant differences in 24-hour average web page download times to a 95% level of confidence

	Is faster than...	Is slower than...
3	Orange	O2*
O2	3*, Orange, T-Mobile, Vodafone	
Orange		3, O2, T-Mobile
T-Mobile	Orange	O2
Vodafone		O2

Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 434 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower download times indicate better performance.

5.24 There were some marked differences in the consistency of web page download times between operators. On around 88% of occasions the web pages we tested were downloaded in less than 2 seconds to the O2 connection; in contrast, fewer than 10% of web pages were downloaded in less than 2 seconds to the Orange connection. Around 15% of Orange web page downloads took longer than 15 seconds, while all successful web page downloads to the 3 connection were completed in less than 10 seconds (Figure 3.27).

Figure 3.27 Distribution of web page download time by operator



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 434 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower download times indicate better performance.

5.25 Of course, web page download times which take longer than a certain period of time may be considered as failures. Figure 3.28 details the average download times for all operators once all downloads talking longer than 10 seconds (representing 16% of all tests) have been removed. It indicates that Orange delivered the slowest download times (around 3-3.5 seconds), around 1.5 seconds slower than O2 (around 1.5-2 seconds).

Figure 3.28 Web page download times by operator, excluding downloads taking longer than 10 seconds

Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 394 probes.

Some operators compress images to improve response times

5.26 While these measured web page download times provide an assessment of the consumer experience of accessing web pages, operators also use other methods to reduce web page loading times. A technique used by some operators is image compression – however the web browsing tests used in this research only measure the time to download the HTML parts of the page, not the time taken to download the images.

5.27 Image compression is implemented by operators by employing web proxies that intercept requests for web content over HTTP and deliver compressed versions of the images requested by the user's web browser.

5.28 When connecting to smaller screen smartphones, image compression can achieve the desired effect of decreased download times without a noticeable sacrifice in image quality. However image compression may become noticeable on the larger screens of dongle-equipped PCs.

5.29 Figure 3.29 shows an example of the affect that compression can have on the quality of the image delivered to the user.

Figure 3.29 An example of the affect of image compression

Source: Epitiro
Notes: (1) Original JPEG image (left) vs. the same image after compression and delivery over mobile broadband (right).

5.30 Using a number of known test images and downloading those images using the static probes, the presence of image compression techniques was detected for the following operators. We again emphasise that this image compression had no impact on the results of our web page download tests as we only measured the time to download the HTML parts of the page, not the time taken to download the images.

Figure 3.30 Operators that employ image compression techniques

	Level of Compression
O2	47-75%
T-Mobile	56-74%

Source: Epitiro
Notes: (1) Range of compression levels describes the levels of compression measured on the three test images used during the research.

5.31 There are ways in which users can control the level of image compression.[30] This allows users to choose between the faster download times that image compression may offer, and the improved image quality when compression is disabled and images are delivered to the user unmodified.

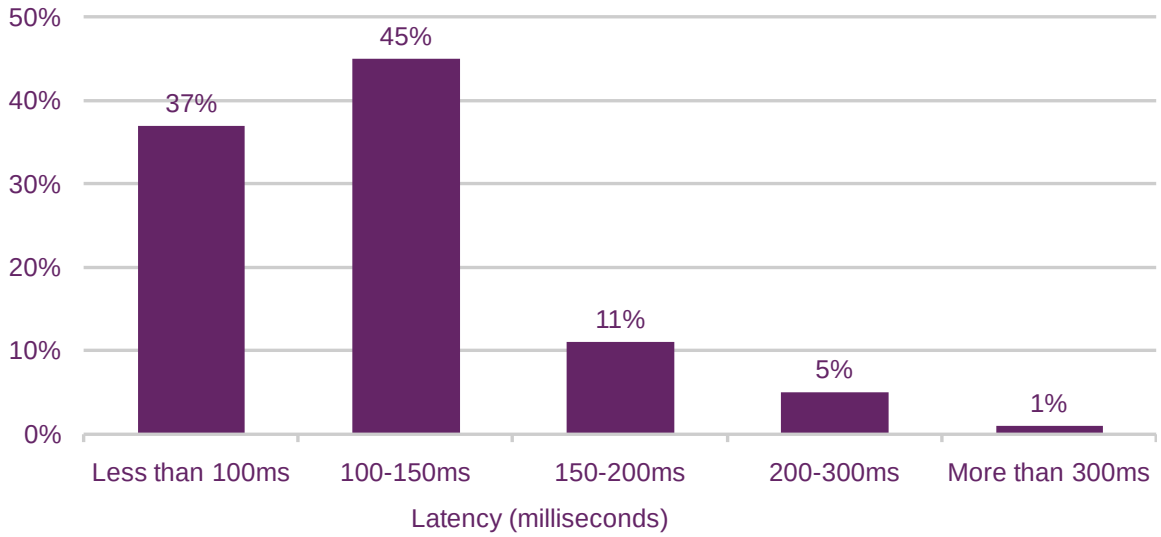
[30] T-Mobile provides a simple way for users to change image compression settings: http://support.t-mobile.co.uk/help-and-support/index?page=devicedetail&cat=USB_STICK_110_NEW&tab=3&id=GP230

Latency times affect consumer experience

5.32 Latency is the time it takes a single packet of data to travel from a user's PC to a third-party server and back again. A connection with low latency will feel more responsive for simple tasks like web browsing, and high latency can be detrimental to services which require high levels of responsiveness such as some online gaming and VoIP telephone calls. We measured latency using ICMP echo (ping) requests to well-peered and known test servers. The data shown is the full round trip time (RTT) as measured in milliseconds.

5.33 With 63% of measurements greater than 100ms (Figure 3.32), mobile broadband services on 3G and HSPA bearers is higher than most fixed broadband packages[31] and may not provide satisfactory performance for some online games.[32]

Figure 3.31 Distribution of latency for all operators

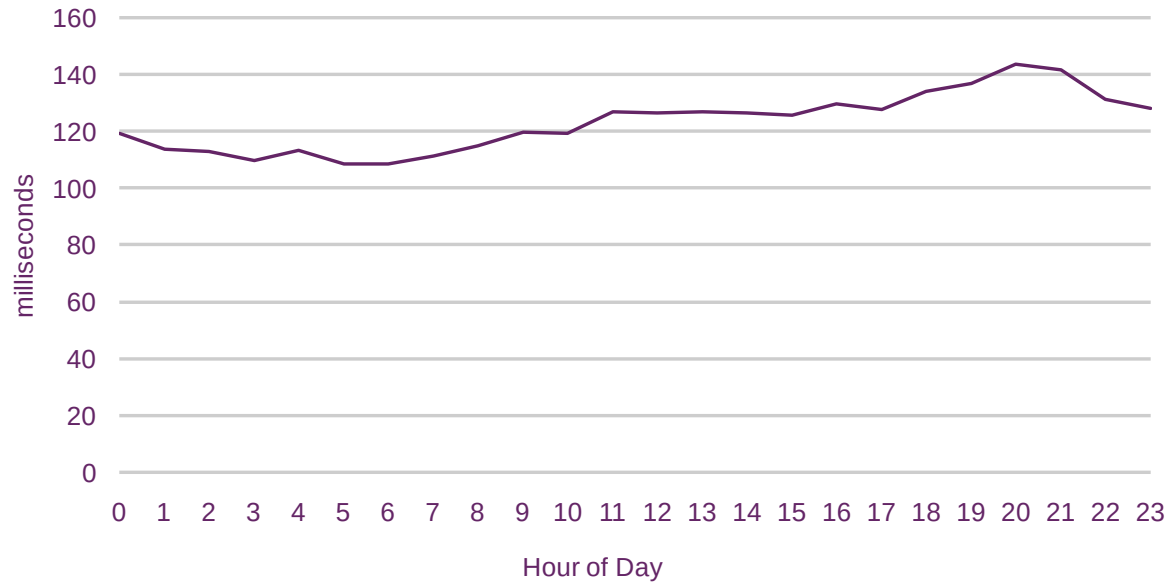


Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 475 probes; (4) Lower times indicate better performance.

5.34 Latency varied by time of day, with higher latency at times of peak usage. The profile is very similar to that of download speeds, with latency around 30% higher on average in the peak evening periods than in the off-peak period of the early hours of the morning (Figure 3.32).

[31] Latency for 8Mbit/s and 10Mbit/s ISP packages from BT, Plusnet and Virgin averaged under 50 milliseconds and was even lower for higher speed fixed broadband services, Figure 9.4, UK fixed broadband speeds, November/December 2010.
[32] Research has shown that latency over 100ms may lead to unsatisfactory performance of online games which require high levels of responsiveness, Network Characteristics for Server Selection in Online Games (Mark Claypool), in Proceedings of ACM/SPIE Multimedia Computing and Networking (MMCN), January 2008, http://web.cs.wpi.edu/~claypool/papers/game-server/paper.pdf

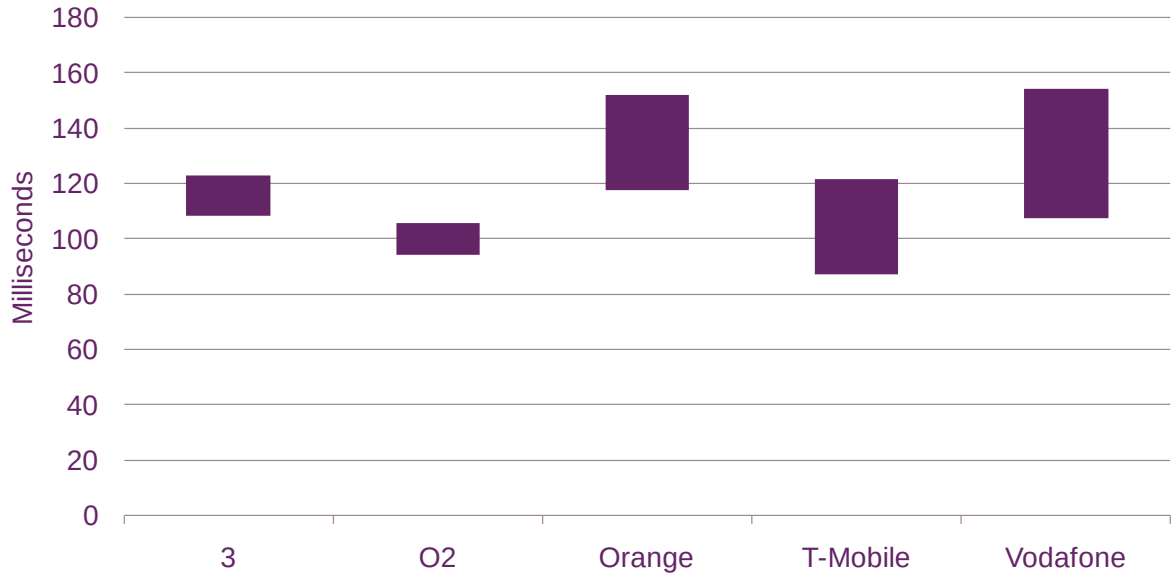
Figure 3.32 Latency by hour of day for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 475 probes; (4) Lower latency times indicate better performance.

5.35 There was some variation in average latency among operators, with O2 delivering significantly lower latency than Orange (Figure 3.33). Latency was generally higher in peak periods than in off-peak periods, with 3 experiencing the greatest relative difference between the peak weekday evening hours of 8-10pm and the off-peak hours of 1-6am (Figure 3.35).

Figure 3.33 Latency times by operator



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.

Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 475 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower latency times indicate better performance.

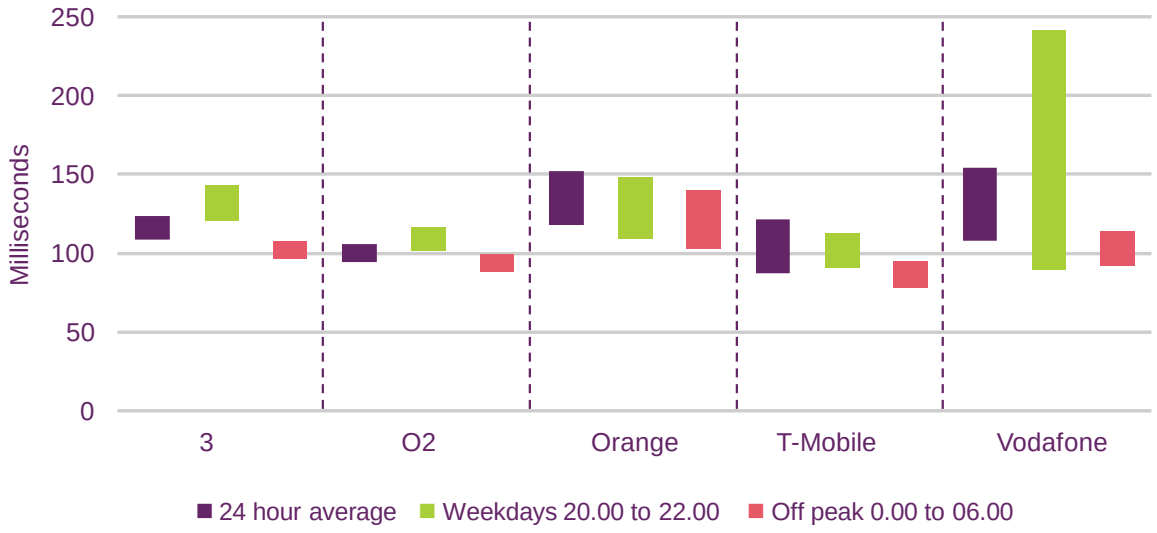
.

Figure 3.34 Significant differences in average latency to a 95% level of confidence

	Is lower than...	Is higher than...
3		O2*
O2	3*, Orange, Vodafone*	
Orange		O2
T-Mobile		
Vodafone		O2*

** Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 475 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower latency times indicate better performance.

Figure 3.35 Latency times by operator and period of day



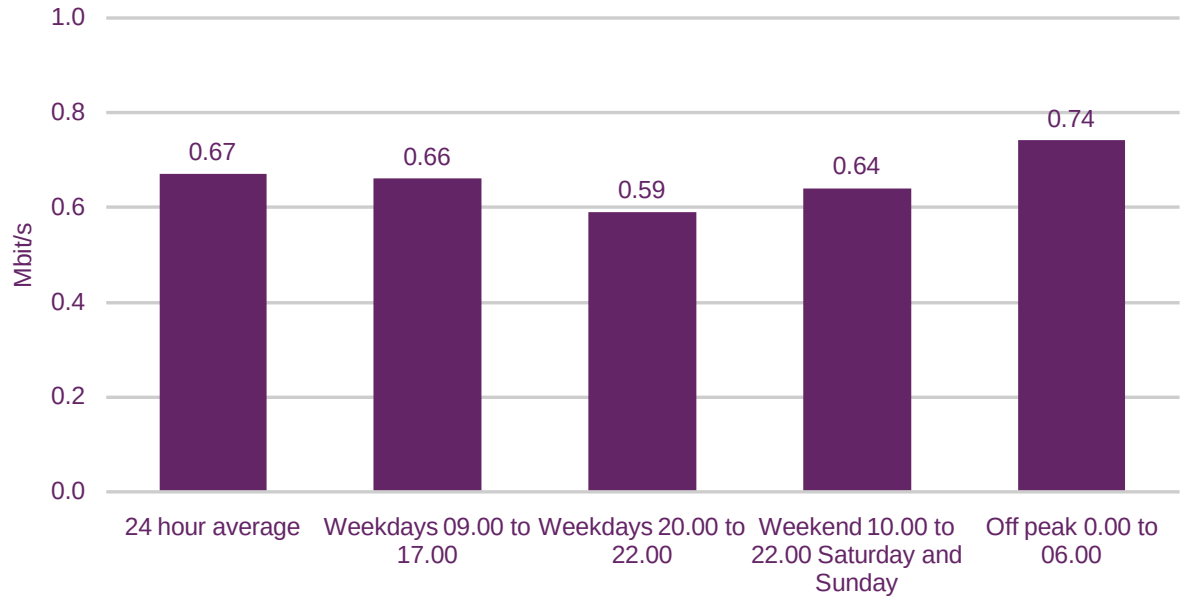
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 475 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Higher speeds indicate better performance.

Upload speeds

5.36 Like download speeds, upload speeds are also affected by contention and are slower during peak evening periods (Figure 3.36), although the impact to consumers would be minimal. For example, successfully sending an email with a 500KB file attachment would on average take about 5 seconds between 0-6am and about 7 seconds during the peak hours of 8-10pm weekdays.

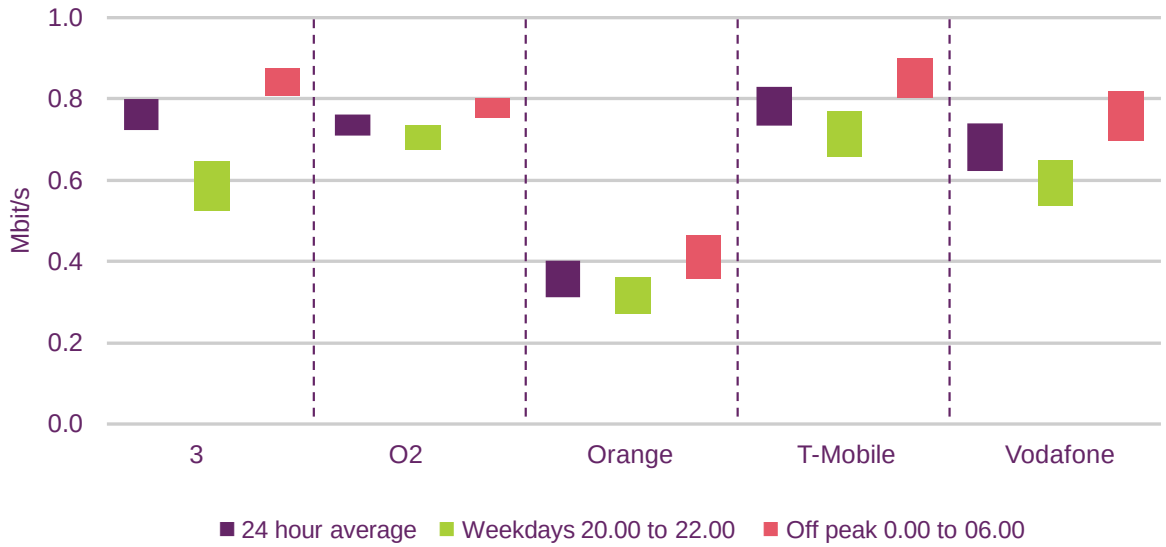
5.37 The average upload speed across all five operators was 0.67Mbit/s; this compares with an average upload speed of around 0.5Mbit/s for 'up to' 8Mbit/s fixed broadband packages[33]. Analysis of upload speeds by operator and period of day (Figure 3.37) showed that performance fell slightly during peak times for most operators although for 3UK the decline was greater. Orange delivered the slowest upload speeds.

Figure 3.36 Average upload speeds for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 static probes; (4) Higher speeds indicate better performance

Figure 3.37 Upload Speeds by operator and period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.

[33] Section 8.37, UK fixed broadband speeds, November/December 2010

Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 412 Probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Higher speeds indicate better performance.

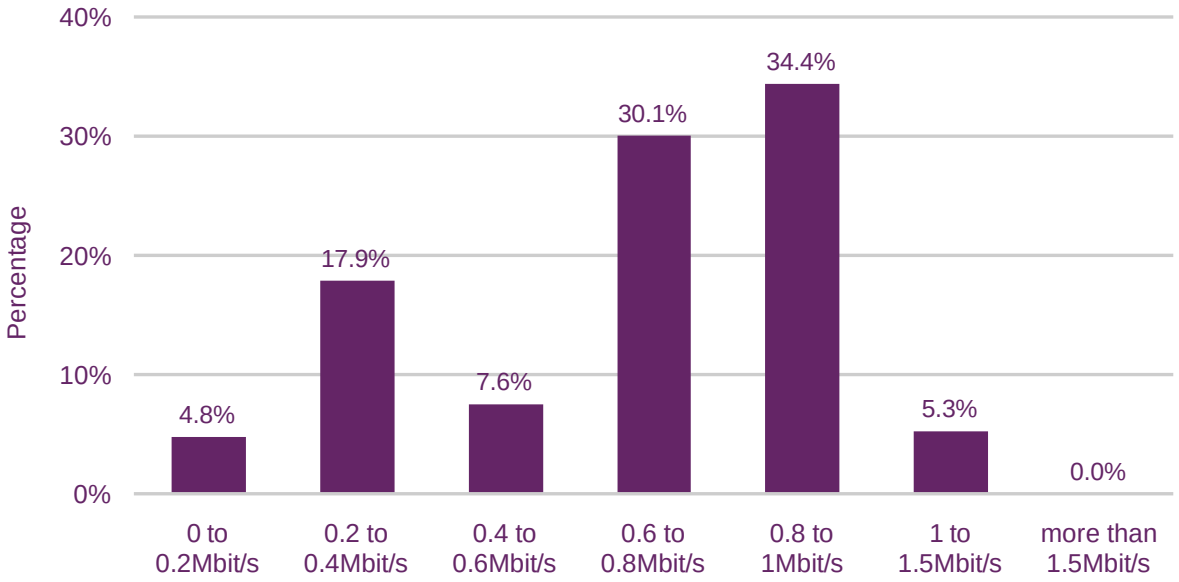
Figure 3.38 Significant differences in 24-hour average upload speeds to a 95% level of confidence

	Is slower than...	Is faster than...
3		Orange
O2		Orange
Orange	3, O2, T-Mobile, Vodafone	
T-Mobile		Orange
Vodafone		Orange

Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 412 Probes; (4) The results represent a 95% confidence level.

5.38 There was a wide range of distribution of average upload speeds among the 436 probes which had a 3G/HSPA connection. Nearly 70% of probes had average upload speeds of more than 0.6Mbit/s, and 5% averaged speeds of more than 1Mbit/s, indicating that consumers can experience HSUPA upload speeds in some situations (Figure 3.39).

Figure 3.39 Distribution of average upload speeds



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 412 static probes; (4) Higher speeds indicate better performance.

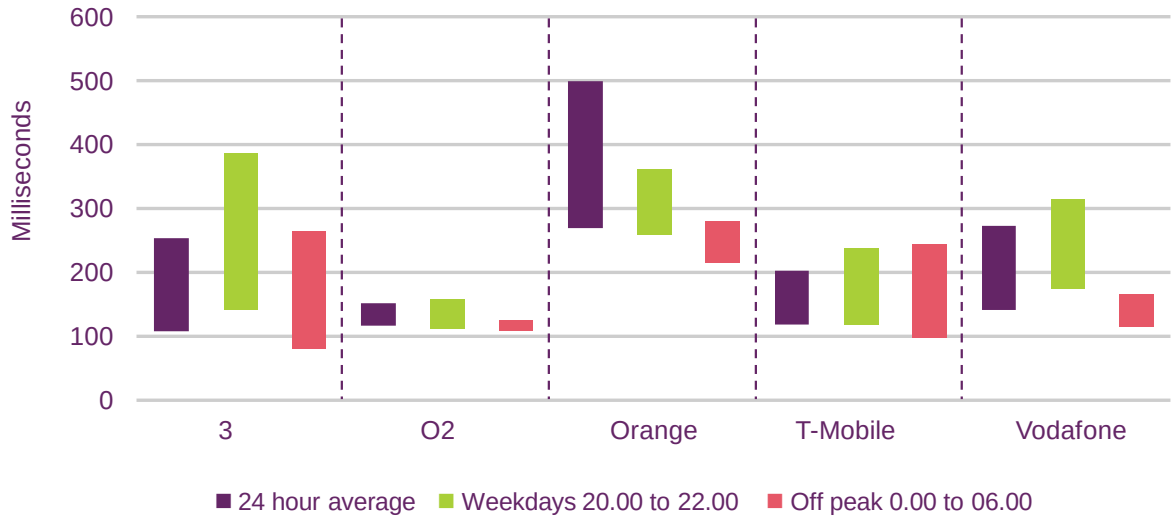
DNS resolution time

5.39 The DNS (domain name service) resolution time is the time required for the MNO to translate a domain name (such as facebook.com) into the IP address used to route traffic (e.g. 80.77.246.42.). This time taken contributes directly to the waiting period a user experiences when requesting a web page.

5.40 Measurements for DNS resolution were taken from several popular web sites as part of the web page download time analysis.

5.41 Figure 3.40 shows that DNS resolution times range from an average of around 100ms to nearly 500ms per operator. Most fixed-line broadband services have average DNS resolution times of less than 60ms, meaning that DNS resolution times on mobile broadband services are generally slower than fixed broadband service.

Figure 3.40 DNS resolution times by operator and period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 437 Probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower times indicate better performance.

Figure 3.41 Significant differences in average DNS resolution time to a 95% level of confidence

	Is faster than...	Is slower than...
3	Orange*	
O2	Orange	
Orange		3*, O2, T-Mobile
T-Mobile	Orange	
Vodafone		

Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
** Not significant at a 99% level of confidence*
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 437 static probes; (4) The results represent a 95% confidence level.

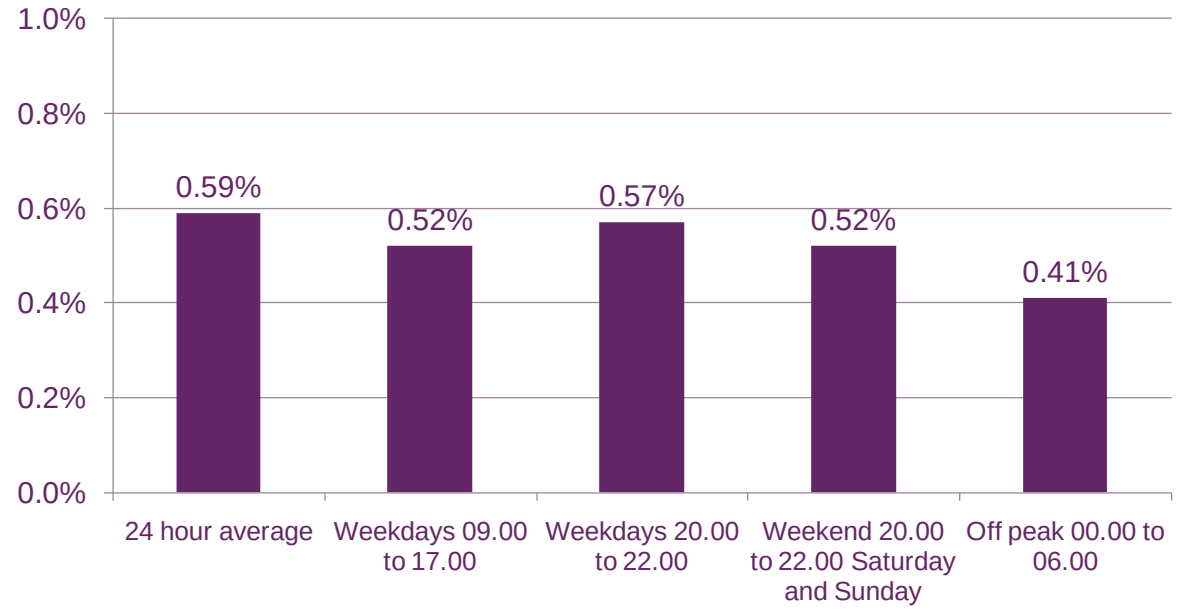
Packet Loss and Jitter

5.42 Packet loss and jitter are important in real-time communications such as VoIP telephony and video streaming where any interruption to the data stream will result in an unsatisfactory experience for users.

5.43 In order to draw conclusions on how well networks handle such traffic and to measure the levels of packet loss and jitter experienced, we used streams of data packets that are representative of typical VoIP or video traffic. These stream tests were transmitted in both the upstream and downstream directions to acquire an understanding of the bi-directional communication quality and to capture accurate measurements of packet loss and jitter in both directions. In the results that follow, lower levels of packet loss and jitter indicate better performance and an improved experience for the user.

5.44 The average downstream packet loss, as shown in Figure 3.42, increased during the peak periods of the day. However, the average across all five operators was still less than 0.6% at peak times. Packet loss at these levels would have an insignificant impact on real-time communications.

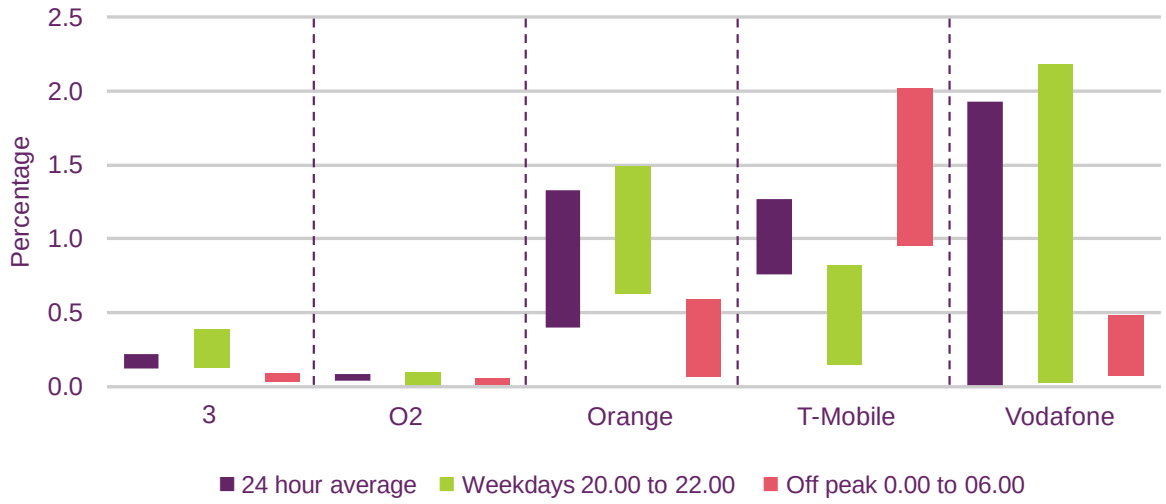
Figure 3.42 Downstream packet loss by period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 probes; (4) Lower percentage packet loss indicates better performance.

5.45 The average downstream packet loss for each operator was typically low at less than 1%, and comparable to loss on fixed line networks. However, the wide confidence intervals indicate that there was a large range of performance for many of the operators with some registering higher levels of packet loss at some probes.

Figure 3.43 Downstream packet loss by operator and period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.

Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower percentage packet loss indicates better performance.

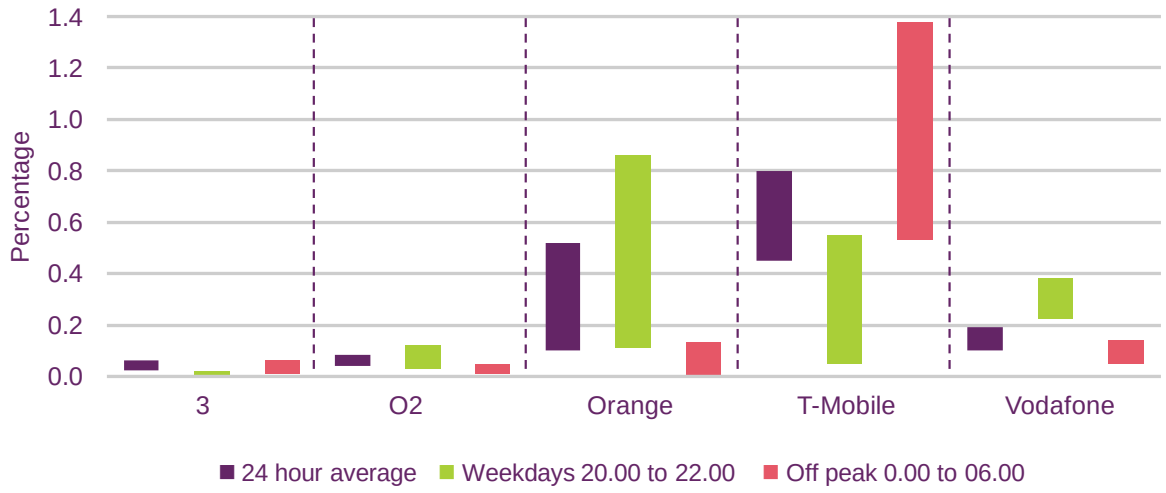
Figure 3.44 Significant differences in 24-hour average downstream packet loss to a 95% level of confidence

	Is lower than...	Is higher than...
3	Orange, T-Mobile Vodafone	O2*
O2	3*, Orange, T-Mobile Vodafone	
Orange		O2, 3
T-Mobile		O2, 3
Vodafone		O2, 3

** Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 static probes (4) The results represent a 95% confidence level.

5.46 Figure 3.45 shows the levels of upstream packet loss measured for each of the five operators. All upstream packet loss was lower than the average levels of downstream packet loss measured.

Figure 3.45 Upstream packet loss by operator and period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower percentages indicate better performance.

Figure 3.46 Significant differences in 24-hour average upstream packet loss to a 95% level of confidence

	Is lower than...	Is higher than...
3	T-Mobile*, Vodafone	
O2	T-Mobile, Orange, Vodafone	
Orange		O2
T-Mobile		3*, O2, Vodafone*
Vodafone	T-Mobile*	O2, 3

** Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 static probes (4) The results represent a 95% confidence level.

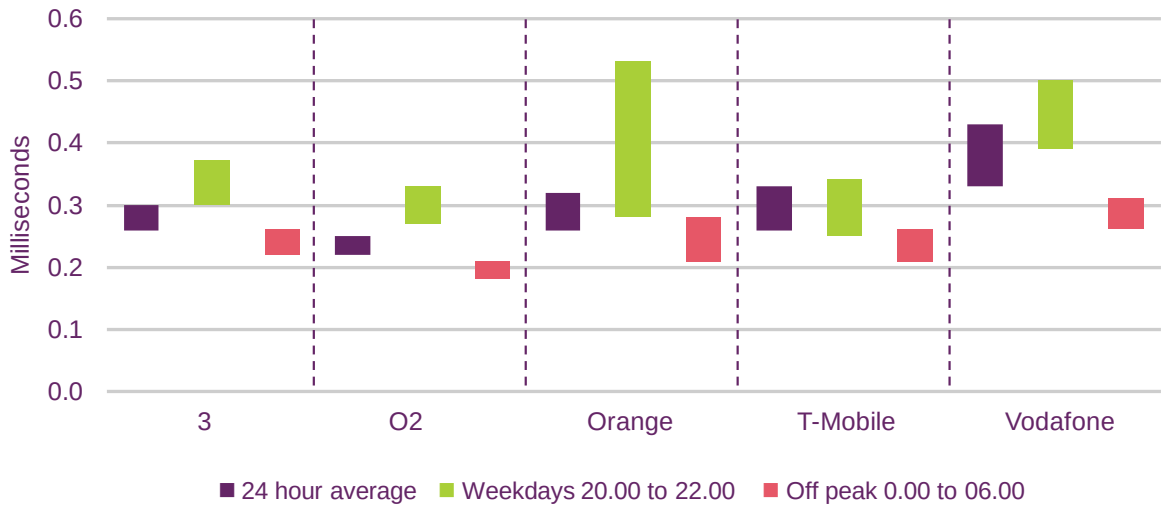
5.47 Jitter, or packet delay variation, is measured as the variance in the arrival times of the individual data packets that comprise the stream. If the latency in a network varies sufficiently such that data cannot be delivered in a reliable and timely fashion, then jitter can reach levels where the quality of services such as VoIP may be impacted. Most VoIP applications and devices employ jitter buffers intended to reduce the effects of jitter on call quality.

5.48 The results shown below are based upon measures of the average jitter recorded through the course of a UDP test stream.

5.49 The levels of jitter measured for each operator in the downstream and upstream directions are shown in Figure 3.47 and Figure 3.49. Average downstream jitter on mobile broadband was recorded as typically below 0.5 milliseconds.

5.50 Average jitter in the upstream direction is higher than downstream jitter. However, average upstream was still under 1 millisecond for all operators.

Figure 3.47 Downstream jitter by operator and period of day



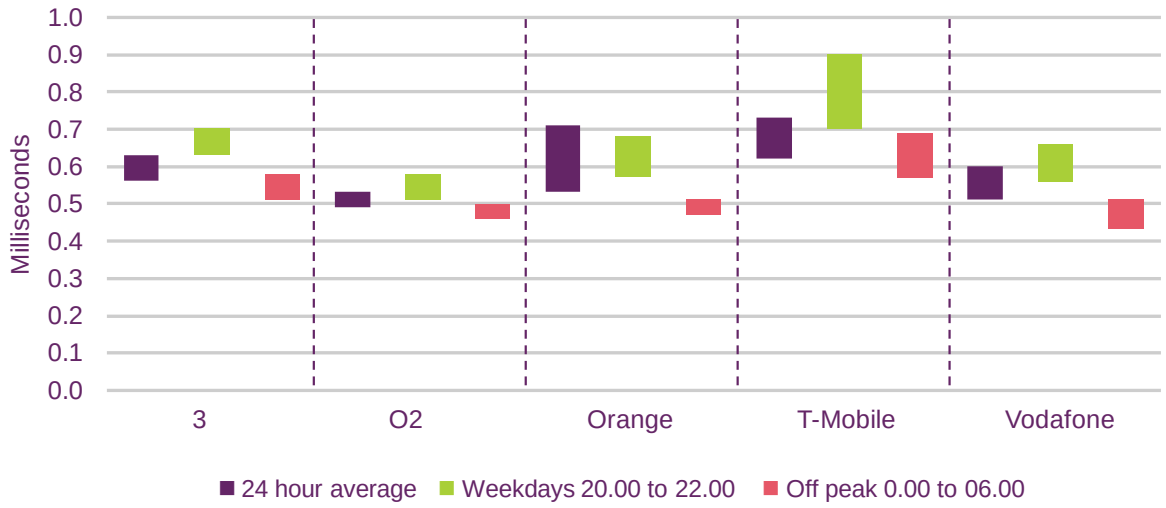
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower jitter indicates better performance.

Figure 3.48 Significant differences in 24-hour average downstream jitter to a 95% level of confidence

	Is lower than...	Is higher than...
3	Vodafone*	
O2	Vodafone	
Orange		
T-Mobile		
Vodafone		3*, O2

** Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 static probes; (4) The results represent a 95% confidence level.
.

Figure 3.49 Upstream jitter by operator by period of day



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 Probes; (4) The range shown represents a 95% confidence interval around the mean; (5) Lower jitter indicates better performance.

Figure 3.50 Significant differences in 24-hour average upstream jitter between operators to a 95% level of confidence

	Is lower than...	Is higher than...
3		O2
O2	3, Orange*, T-Mobile	
Orange		O2*
T-Mobile		O2, Vodafone*
Vodafone	T-Mobile*	

** Not significant at a 99% level of confidence*
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 433 static probes; (4) The results represent a 95% confidence level.

Mobile broadband performs below fixed broadband service levels

5.51 Our research finds that on average, mobile broadband services perform worse than all the fixed-line broadband services we measured in the same period.[34] Average mobile broadband download speeds are around a third of the average speeds offered by 'up to' 20/24Mbit/s DSL broadband services (the most commonly retailed fixed-line broadband service). However, of at least equal significance are slower web page loading times and higher latency – meaning that mobile broadband may not on average deliver a satisfactory performance for simple tasks like web browsing, and may not be appropriate for internet services which require high levels of responsiveness, such as some online games.

5.52 It should be noted, however, that the actual speeds and performance available through fixed and mobile broadband depend very much on a combination of location and network quality. Consumers should therefore check the speed available on their individual fixed line as well as the level of mobile broadband coverage before making any choice between the two.

[34] Our latest fixed-line broadband research report detailed the performance of ADSL, cable and FTTH broadband services in November and December 2011, http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/bbspeeds2011/bb-speeds-nov-2010.pdf

Figure 3.51 Comparison of fixed and mobile broadband performance

	Download speed (Mbit/s)		Upload speed (Mbit/s)		Latency (milliseconds)		*Web page download (milliseconds)	
	24-hour	Peak (8-10pm)	24-hour	Peak (8-10pm)	24-hour	Peak (8-10pm)	24-hour	Peak (8-10pm)
Mobile (3G & HSPA connections)	2.1	1.7	0.7	0.6	117	128	2,508	3,196
ADSL 'up to' 8Mbit/s	3.4	3.1	0.5	0.5	47	50	430	473
ADSL 'up to' 20/24Mbit/s	6.2	6.0	0.7	0.7	41	44	227	299
Cable 'up to' 10Mbit/s	9.6	9.2	0.5	0.5	30	37	190	236
Cable 'up to' 20Mbit/s	18.0	17.3	0.9	0.9	32	37	190	213
Cable 'up to' 50Mbit/s	45.8	45.1	2.3	2.6	27	29	164	177
FTTC 'up to' 40Mbit/s	30.4	26.3	7.4	7.5	25	27	139	157

** Results for webpage downloading are not directly comparable as the mobile broadband tests measured only the time to download the html code of the web pages, while the fixed-line broadband tests included downloading a test page containing both html and images. The data may therefore indicate slower performance for fixed-line web page download than would be the case if identical tests to those used for mobile broadband had been deployed.*

Source (Mobile Broadband): Epitiro measurement data for all static probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Source (Fixed Broadband): Ofcom, UK Broadband Speeds, November/ December 2010

Signal strength may affect speeds achieved

5.53 There is no standard way in which consumers can accurately use the "bars" on the device display to accurately gauge the likely quality of service. Smartphone and dongle manufacturers use different thresholds to apply measured signal strength to the visual indicators ("bars") consumers see on their devices.

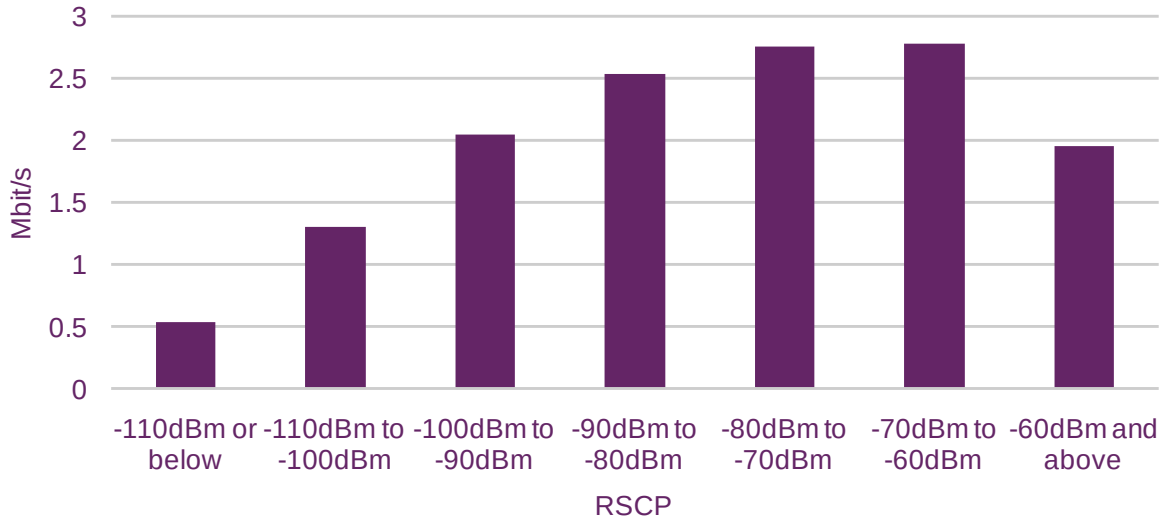
5.54 Furthermore, there are different aspects of signal measurement that either the device manufacturer or operator may choose to use as its indication of signal strength;

- The most common method for driving "bars" on devices is termed RSSI (received signal strength indicator).This is a measurement of the signals from all cells in vicinity, but does not necessarily represent the signal strength of the actual cell to which a consumer would be connected.

- A less common but more informative method of driving signal strength is RSCP (received signal code power) which is the actual strength of the signal for the user's connection.

5.55 On average, faster speeds were recorded with stronger signals. Signal strength is measured in "-dBm" where the larger the negative number the weaker the signal. Generally, a very strong signal is approximately -40dBm down to -75dBm. A weak signal is -95dBm or lower.

Figure 3.52 Average signal strength vs. average download speed for all operators



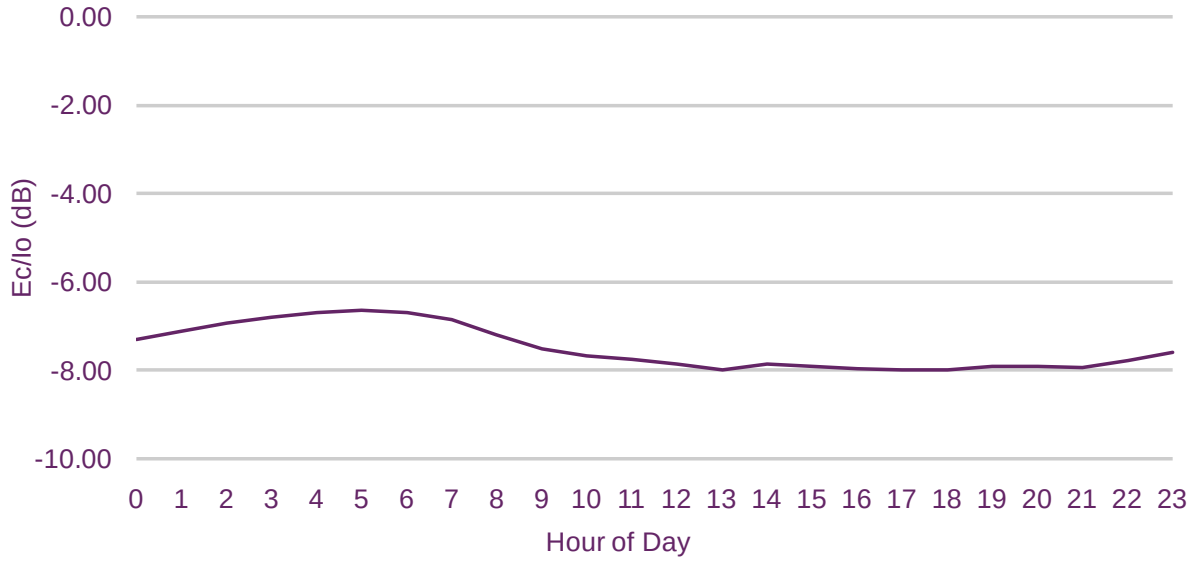
Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 probes.

5.56 A challenge within radio–based communications is to distinguish a particular connection (channel) for a single user from the total surrounding signals (energy) being broadcast. The Ec/Io measurement shows how a single channel power relates to varying total energy levels.

5.57 The total energy level will rise or fall depending on the number of simultaneous users, however it is always graphed at 0dBm and the channel power is plotted in relation accordingly, as per Figure 3.53.

5.58 Figure 3.53 indicates that there was more total energy, and therefore more active users of mobile service, from 10am to 10pm. During the hours of 1 to 5am the average HSPA and 3G channel power recorded was at its highest in relation to the total broadcast signal energy, and lowest from 10am to 10pm. The curve of the graph closely follows average speeds by hour of the day, further indicating that contention in mobile networks is present.

Figure 3.53 Ec/Io by hour of the day for all operators



Source: Epitiro measurement data for all dedicated probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on 3G or HSPA bearer connection at time of test; (2) 2G data is excluded; (3) Sample size of 436 probes.

Section 6

Case studies: Variation in mobile broadband performance within specific areas

Overview

6.1 The four regional case studies, chosen to represent different levels of urbanisation, were as follows:

- Dense urban city – Birmingham.
- Urban sprawl – specifically the area along the M62 motorway between Manchester and Liverpool.
- High density provincial town – Swansea and the surrounding area.
- High density rural or semi-rural counties – the West Midlands counties of Herefordshire and Shropshire, between Hereford in the south and Whitchurch in the north.

6.2 Drive testing was carried out in each of the locations for a period of five days with eight hours of measurement each day, during working hours. Testing for each case study was conducted along routes through a series of predetermined waypoints.

6.3 All tests were executed when the vehicle was stationary. The driver was required to stop and park the vehicle before executing tests, with a single set of tests executed at each location for each of the mobile operators.

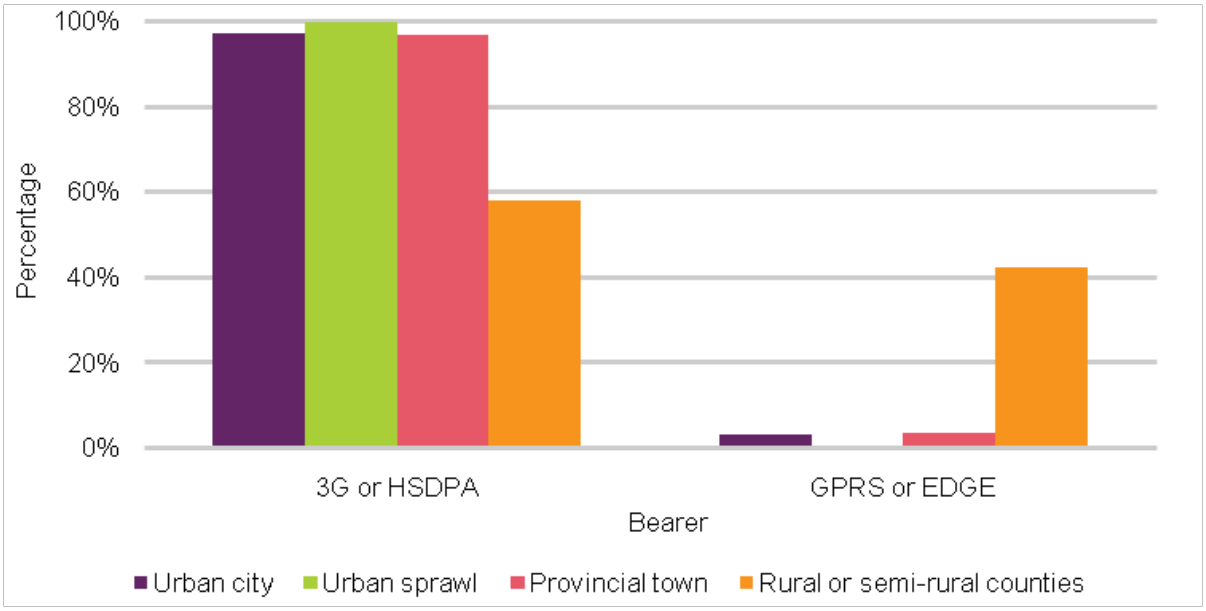
6.4 The case studies were conducted between 15 November and 15 December 2010, with over 45,000 tests executed across all five mobile operators.

6.5 The results from the four case studies are presented in a series of charts and geographical heat maps showing the regional variation in download speeds measured by the ipQ handsets employed during the drive testing.

Performance is better in urban areas

6.6 Figure 6.1 shows the distribution of different radio bearers experienced during testing of the four case studies. During the case study of rural or semi-rural counties, a 3G or HSDPA bearer was only available 58% of the time, with GPRS or EDGE being the only available bearer 42% of the time. The other three cases studies all provided a 3G or HSDPA bearer over 96% of the time.

Figure 6.1 Distribution of bearers by case study for all operators



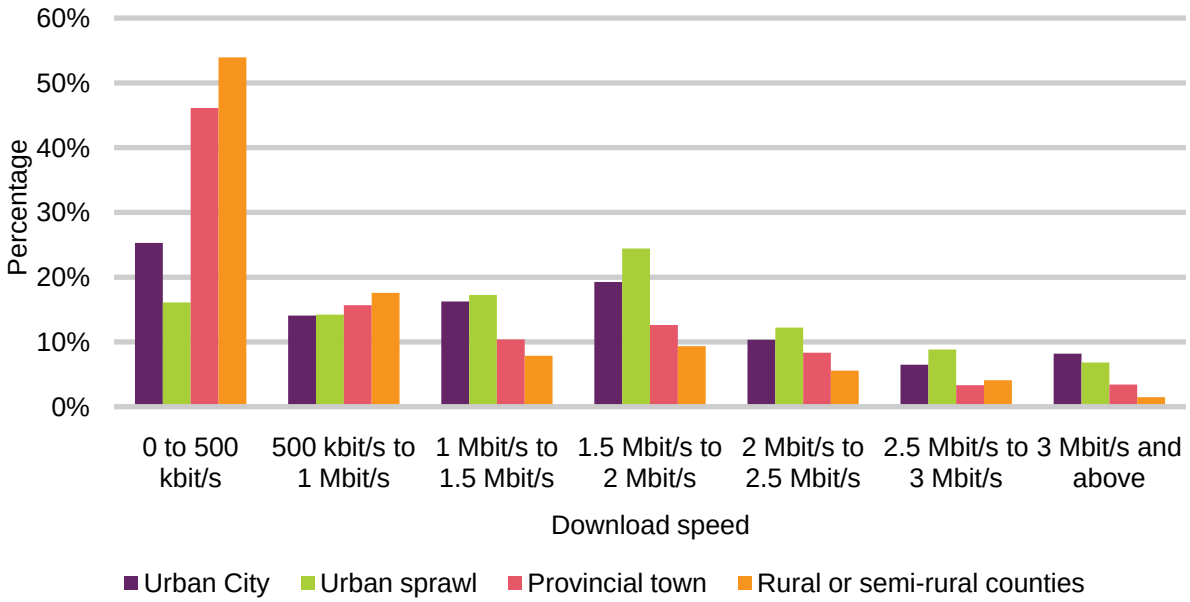
Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 3,923 tests.

6.7 The distribution of download speeds measured during the four case studies is shown in Figure 6.2. Over 70% of the speeds recorded during the rural or semi-rural counties case study were less than 1Mbit/s. Similarly, 61% of download speeds were less than 1Mbit/s during the provincial town case study of Swansea.

6.8 Despite the good availability of HSDPA bearers seen in the provincial town case study, the distribution of download speeds recorded was similar to that of the rural or semi-rural counties study. This suggests that other attributes such as backhaul capacity could be a limiting factor in the delivery of mobile broadband into provincial areas like Swansea, where the supporting network infrastructure may not be as well developed as in denser urban centres.

6.9 In contrast to the case studies of provincial, rural or semi-rural areas, the two urban case studies both reported over 60% of measurements at 1Mbit/s or above. However it is notable that the distribution of speeds from the urban sprawl study between Liverpool and Manchester shows better performance than the results from the urban city study of Birmingham. Capacity can be significant factor in densely populated urban centres, and contention may have contributed to some of the slower speeds measured during the urban city study.

Figure 6.2 Distribution of download speeds by case study – all operators



Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 3,464 download speed tests.

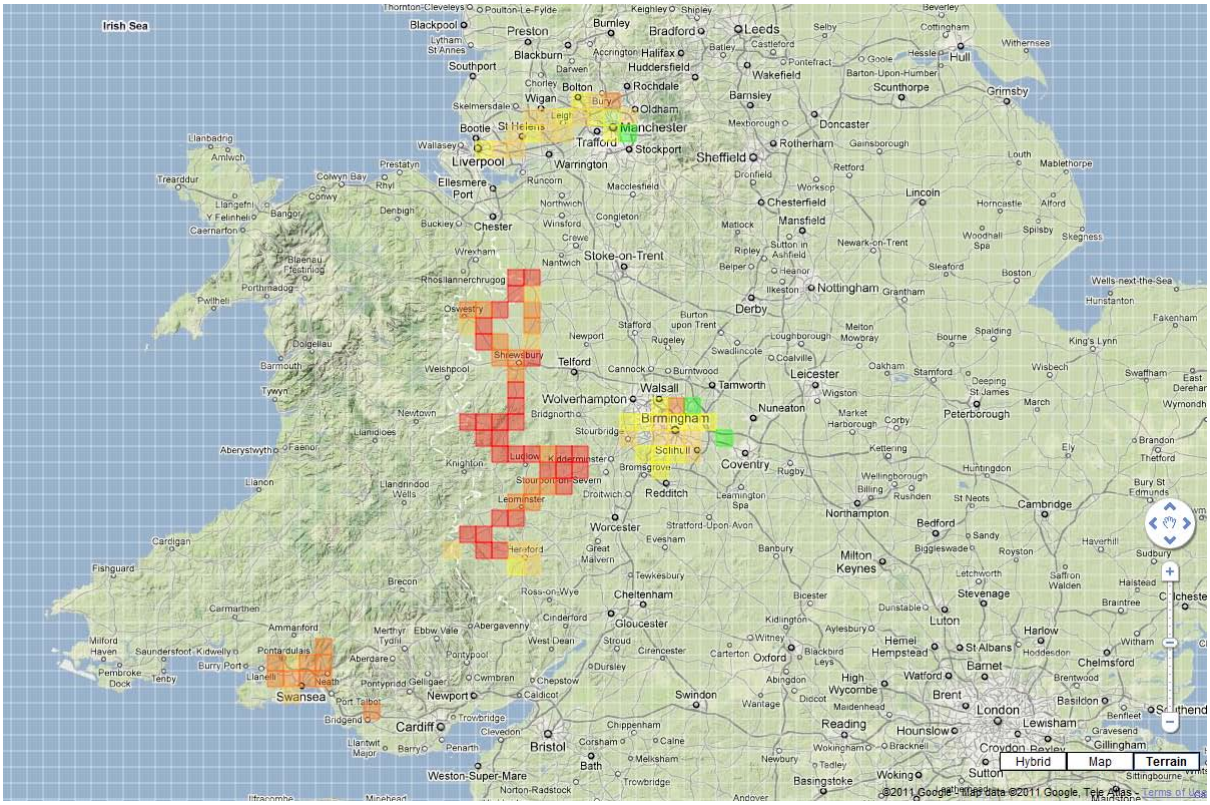
6.10 The download speeds represented in the heat maps below are the average measurements across all five MNOs tested during the drive testing. Areas where measurements were conducted are indicated on the maps by coloured squares, with the colour of the square describing the average of the download speed measurements captured at locations within the region covered by the square. The colours used to represent different speed ranges on the heat maps are listed in the legend in Figure 6.3.

Figure 6.3 Heat map Legend

Download Speed
0kbit/s to 500kbit/s
500kbit/s to 1Mbit/s
1Mbit/s to 1.5Mbit/s
1.5Mbit/s to 2Mbit/s
2Mbit/s to 2.5Mbit/s
2.5Mbit/s to 3Mbit/s
3Mbit/s and above

6.11 Figure 6.4 shows a high level view of the download speed results recorded during all four case studies. The heat map demonstrates significant variance in performance between urbanised city regions and rural or provincial regions, with rural regions showing poor mobile broadband performance when compared to urban regions.

Figure 6.4 Average download speed for all operators across from all case studies



Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 3,464 download speed tests; (3) Red indicates slowest performance, and green and blue faster performance – see the full legend in Figure 6.3.

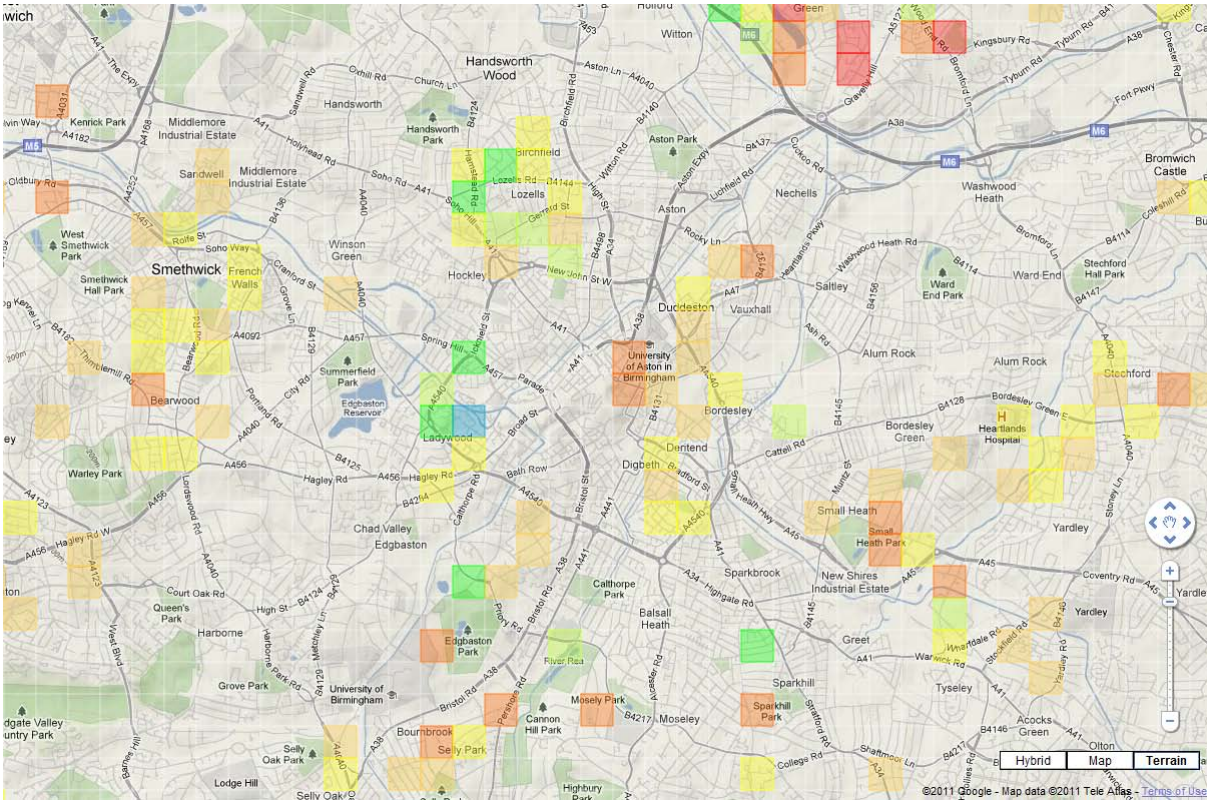
Case study of urban city performance

6.12 The average download speeds experienced during drive testing for the urban city case study in Birmingham are shown in Figure 6.5.

6.13 The majority of speeds recorded in the heat map are 1Mbit/s and above, with some average speeds recorded of 2.5Mbit/s and above. One exceptional site on the heat map records an average download speed of over 3Mbit/s. These averages are across all five operators. Where good performance is recorded on the map, it suggests that most of the operators were delivering good mobile broadband service at the point that the tests were executed.

6.14 Despite the potential for good mobile broadband speeds in the urban city locations covered, it is also notable that the measured performance is variable across the city with no guarantee of good performance offered by a city centre location.

Figure 6.5 Average download speed for all operators from the urban city case study



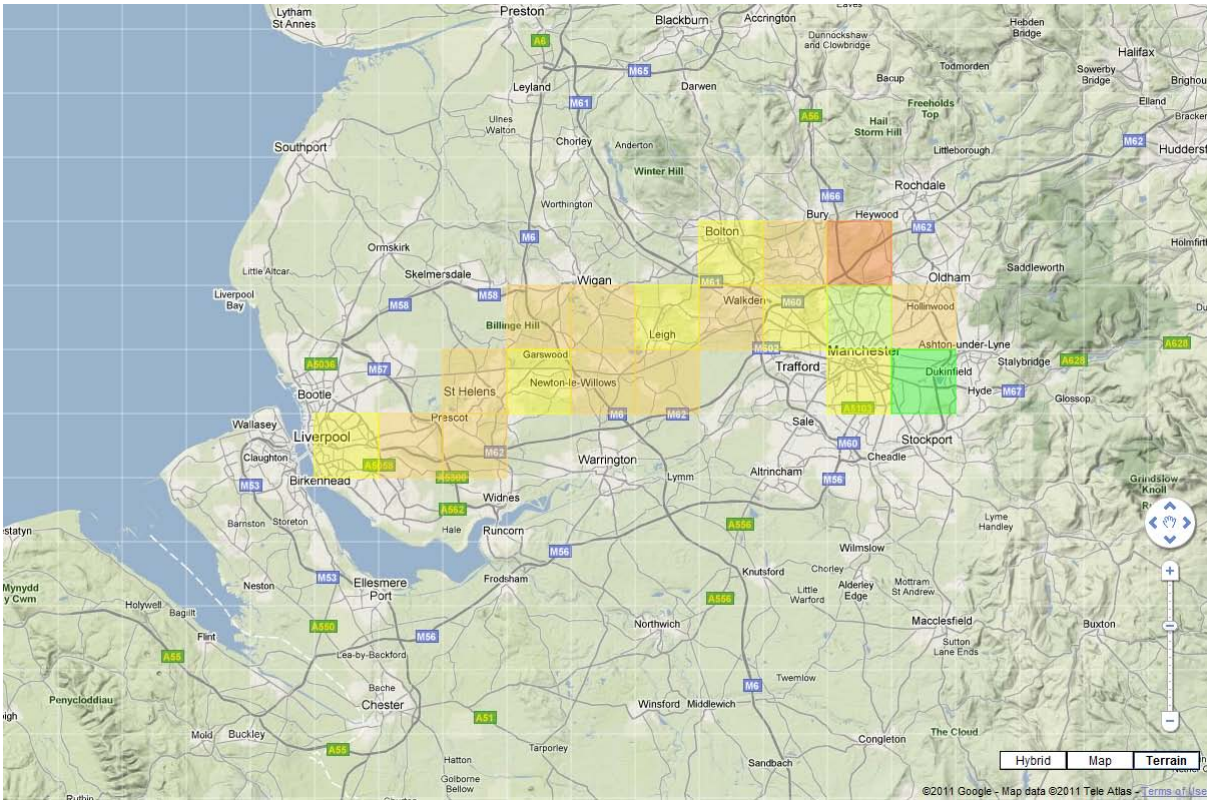
Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 830 download speed tests; (3) Red indicates slowest performance, and green and blue faster performance – see the full legend in Figure 6.3.

Case study of urban sprawl performance

6.15 Figure 6.6 shows download speeds as measured across the regions covered by the second case study of performance in the urban sprawl along the M62 corridor between the cities of Manchester and Liverpool.

6.16 As experienced in the urban city case study of Birmingham, the average speeds recorded across all five operators were generally at speeds of 1Mbit/s and above. Faster average speeds of 2.5Mbit/s and above were recorded in some of the city centre locations tested in Manchester and Liverpool.

Figure 6.6 Average download speed for all operators from the urban sprawl case study



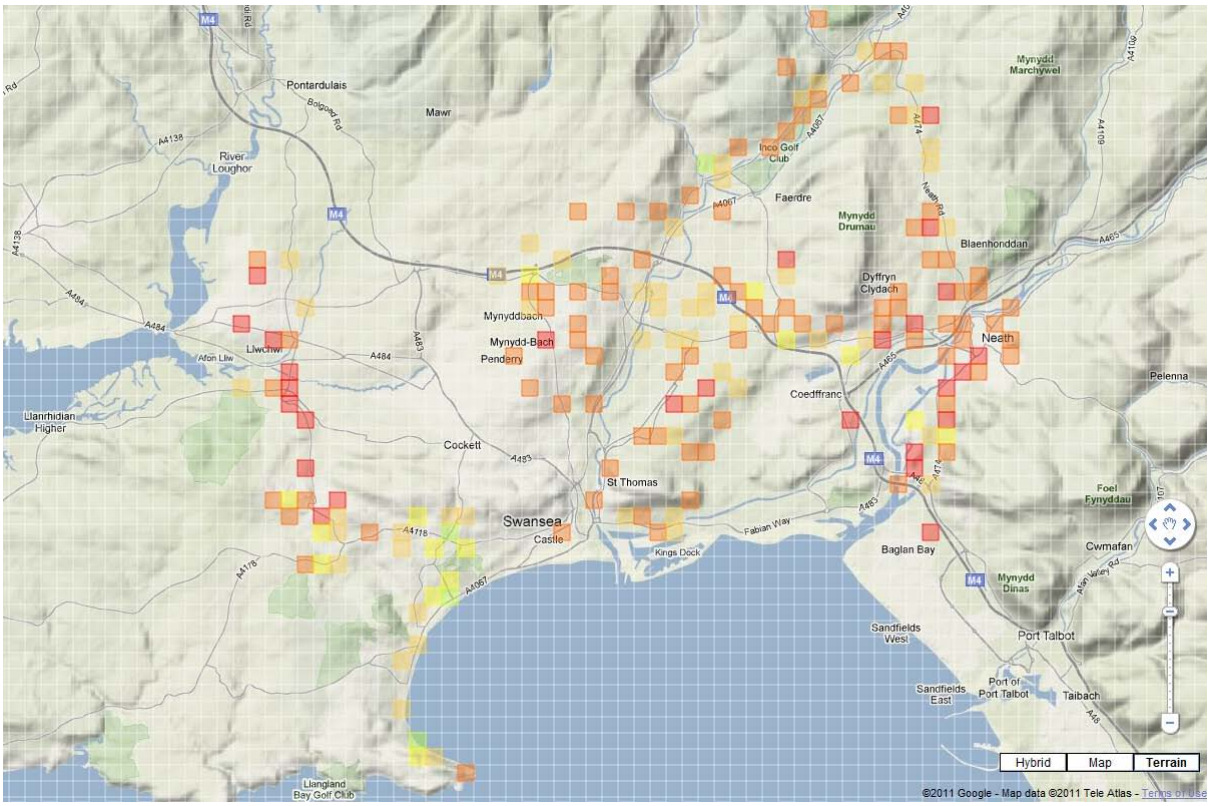
Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 949 download speed tests; (3) Red indicates slowest performance, and green and blue faster performance – see the full legend in Figure 6.3.

Case study of performance in a provincial town

6.17 During the case study of the high density provincial town of Swansea, the download speeds measured were slower than those recorded in the city and dense urban locations covered in the first two case studies.

6.18 As shown in the heat map in Figure 6.7, the average speeds recorded in and around Swansea were often less than 1Mbit/s, with some areas delivering average performance of less than 500kbit/s.

Figure 6.7 Average download speed for all operators from the provincial town case study



Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 1,077 download speed tests; (3) Red indicates slowest performance, and green and blue faster performance – see the full legend in Figure 6.3.

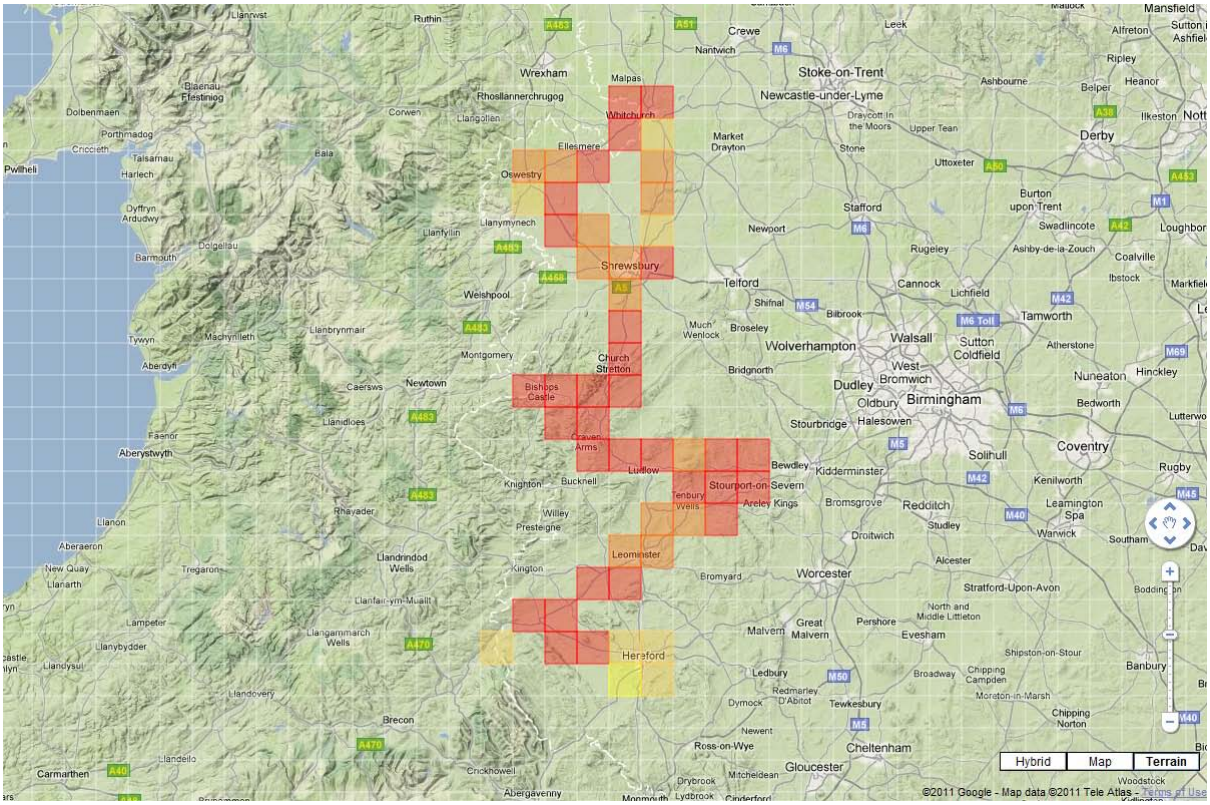
Case study of performance in rural and semi-rural counties

6.19 The final case study of rural and semi-rural regions in the counties of Herefordshire and Shropshire is shown in the heat map in Figure 6.8.

6.20 The rural areas measured for this case study do not offer the same coverage of 3G and HSDPA services as experienced in the urban and city regions of earlier case studies. As such, the average speeds recorded during this case study were significantly slower than the speeds recorded in other case studies. In the majority of

areas covered, the average speeds recorded were less than 500kbit/s. This suggests that the availability of HSDPA bearers is very limited, with connections and speeds limited to 2G or slower 3G rates in many cases.

Figure 6.8 Average download speed for all operators from the rural or semi-rural counties case study



Source: Epitiro measurement data for all ipQ handsets used during drive testing between 15th November 2010 and 15th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Total sample size of 608 download speed tests; (3) Red indicates slowest performance, and green and blue faster performance – see the full legend in Figure 6.3.

6.21 Insight from these four case studies indicates that consumers should expect to see wide variation in service quality depending on the location of the service and the coverage available. While rural users are likely to find 3G mobile broadband services not to be consistently available, urban users should also be aware that complete coverage of cities with consistently fast mobile broadband services is not yet a reality.

Section 7

Findings: The Consumer Experience of Mobile Broadband

7.1 In order to understand the actual service levels experienced by typical mobile broadband users we assembled a consumer panel of dongle or data card users who downloaded an application which made measurements directly from their PCs or laptops.

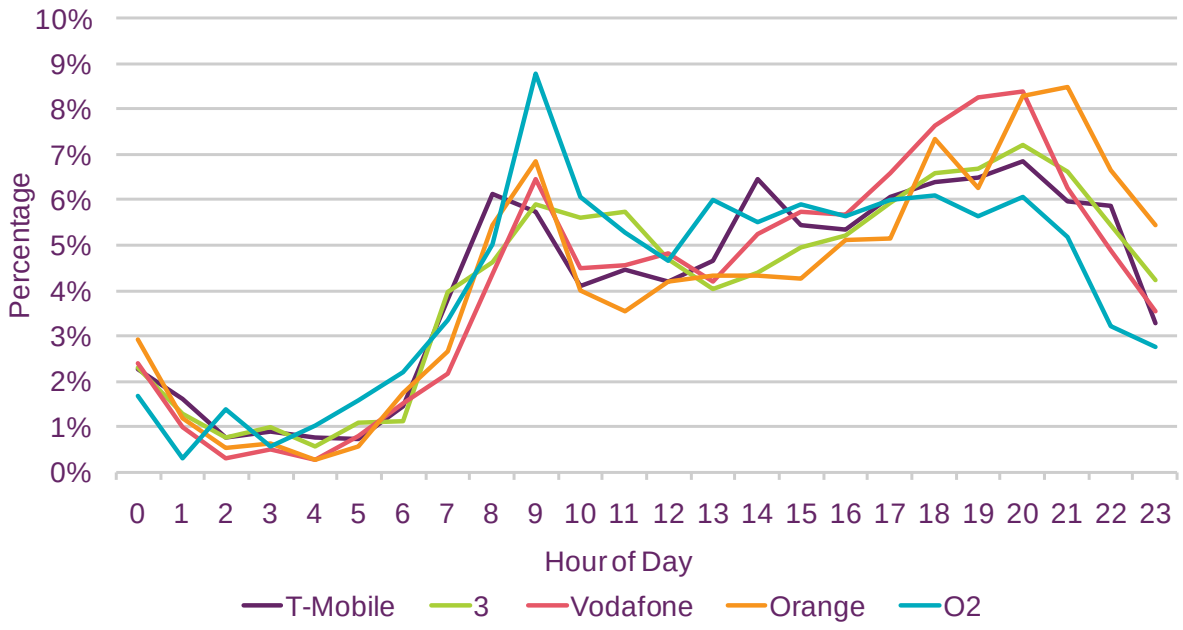
7.2 From September 2010 to December 2010 we measured mobile broadband performance from 1,179 dongle users, with 12 network tests executed up to four times per day. In total, over 330,000 measurements were made from the panel during the period of testing.

7.3 As the intent was to measure services as delivered – and not to selectively measure network capability - the results that follow include performance measurements made on all available bearers, including 2G as well as faster 3G and HSPA bearers.

Consumers use mobile broadband throughout the day

7.4 The time and frequency of the tests were dependent on the usage patterns of the users who made up the panel, as tests were only executed when the user's PC was running and connected to their mobile broadband service. Figure 7.1 shows the percentage of measurements that were made for each operator by hour of day. It indicates that usage patterns across the five MNOs were broadly similar with a peak in usage at 9am, and longer evening peak in usage between 6 and 9pm and little usage between 1am and 6am.

Figure 7.1 Tests by hour of the day and operator



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.

Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 27,264 tests.

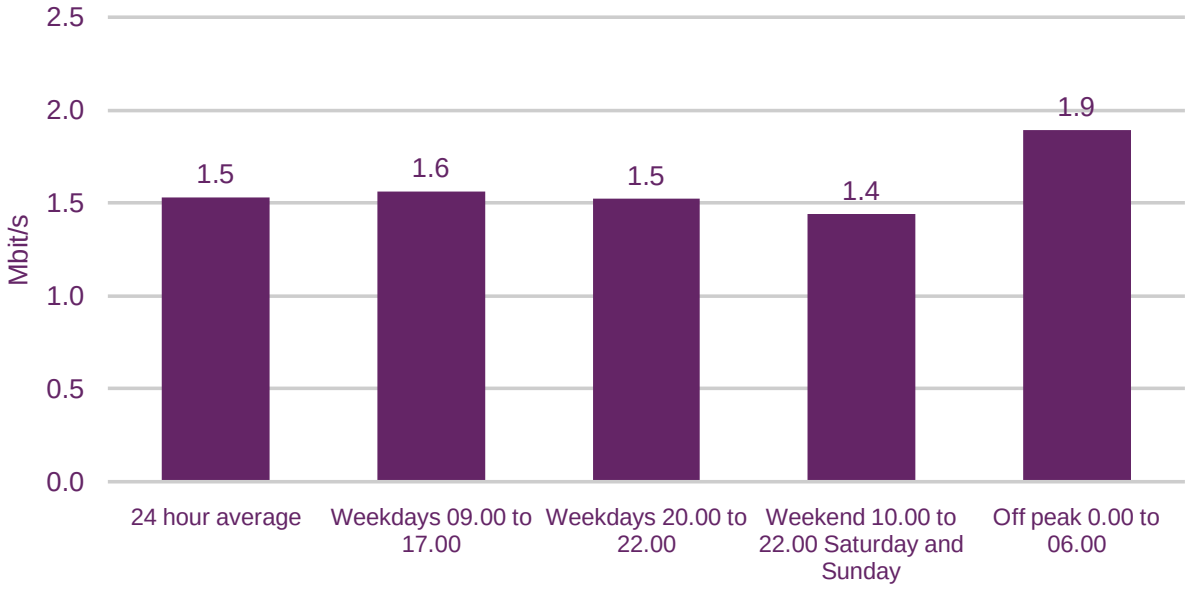
Download speed

7.5 Speed is an important metric as it is indicative of the waiting times consumers experience when performing tasks such as web browsing or downloading files.

7.6 From our consumer research we found that download speeds were measured during the day at an average of 1.5Mbit/s. Overall, there was no significant slowdown in the peak evening period of 8-10pm, but speeds did rise to an average of 1.9Mbit/s in the off-peak hours of 0am - 6am.

7.7 The average download speed of 1.5Mbit/s measured during this study is significantly faster than the 1Mbit/s average speed reported in a previous study of mobile broadband performance by Epitiro[35] in 2009. Although like-for-like comparison is not possible due to methodological differences, these faster speeds may be indicative of improved operator services and devices.

Figure 7.2 Average download speeds by period of day for all operators

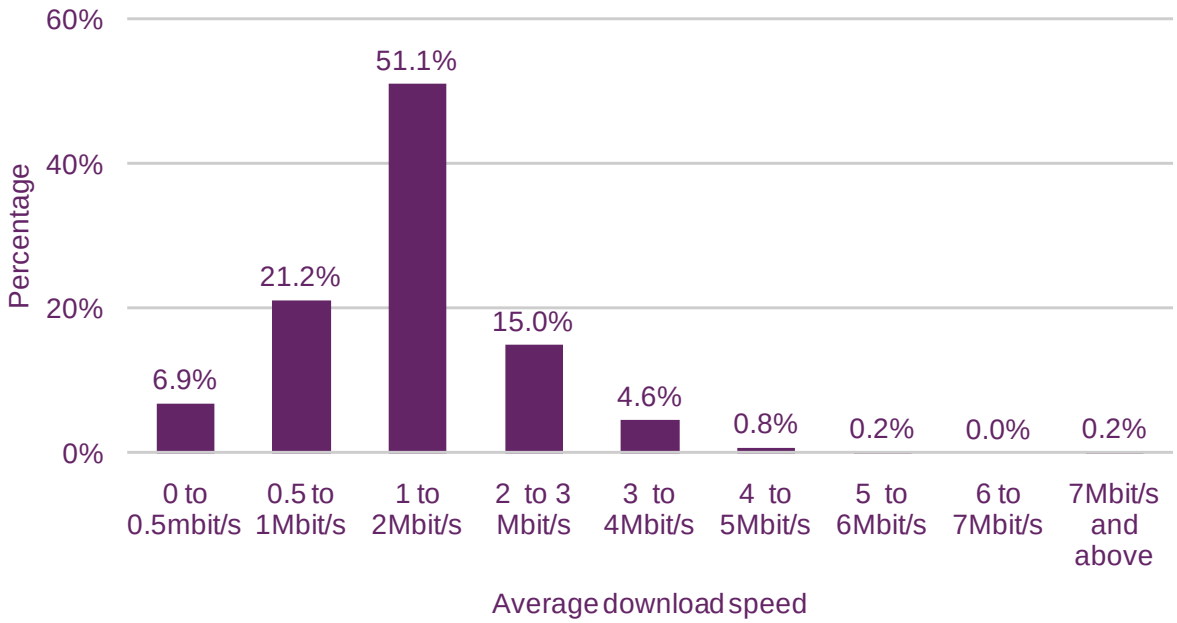


Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of between 505 (24 hour test) and 208 (off-peak) respondents.

7.8 Figure 7.3 shows the distribution of download speeds measured from the consumer panel during the period of testing. It shows that nearly 80% of panellists received average speeds of less than 2Mbit/s.

[35] Epitiro, UK Mobile Broadband Analysis, Initial Findings 2009

Figure 7.3 Distribution of average download speeds for all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 505 respondents.

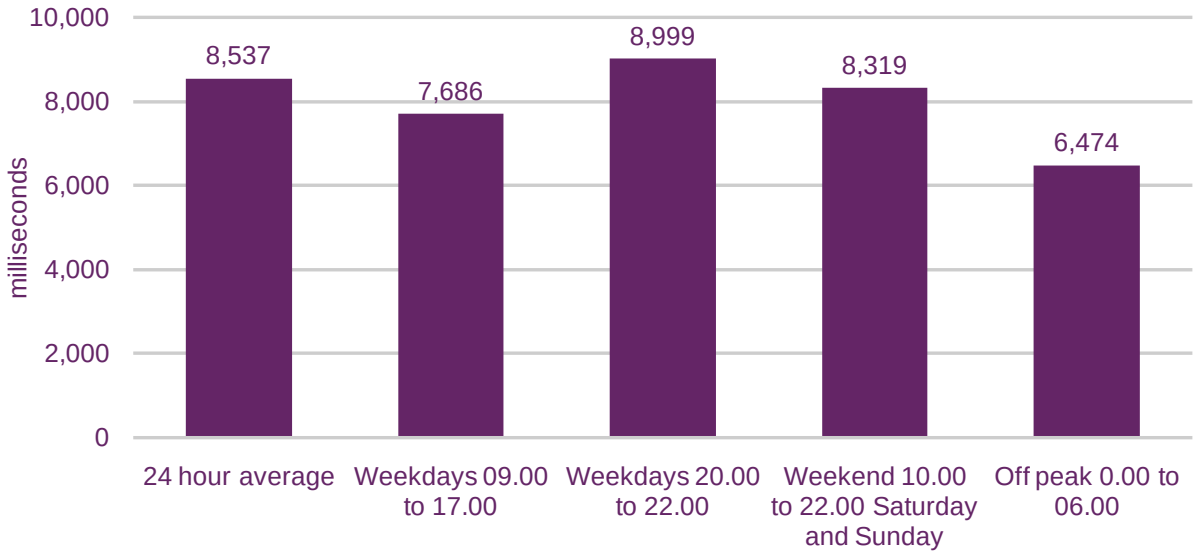
Web page download time

7.9 In Ofcom's publications on fixed broadband speeds we have noted that actual web page download times varied little between different ISP services, even when there was very large variation in the download speeds. This is due to the composition of web pages which typically have many small-sized artefacts (images, text, flash files) that must be downloaded individually. Consequently, web page download times are affected by both download speeds and the inherent latency for the delivery of each artefact.

7.10 The higher average latency in mobile networks is an important factor in explaining why web page download times are typically significantly longer than on fixed broadband service; consumers may generally experience web surfing to be slower than fixed broadband.

7.11 The web page download times experienced during the consumer panel testing are shown in Figure 7.4. The average web page download time across all operators was 8.5 seconds. There is a significant variance in the web page download times at different times of the day with download times during off peak hours at 6.5 seconds compared to the 9 second average recorded at peak hours. (Note that webpage download test results only include the download of the html code and not the images associated with the website. We believe that this is a fair measure of performance, because images on web sites may be cached on the handset and therefore not have to download every time, and also because some operators use image compression; however, it should be noted that the web page download times measured may be significantly faster than the time it would take to download a full web page with all images.)

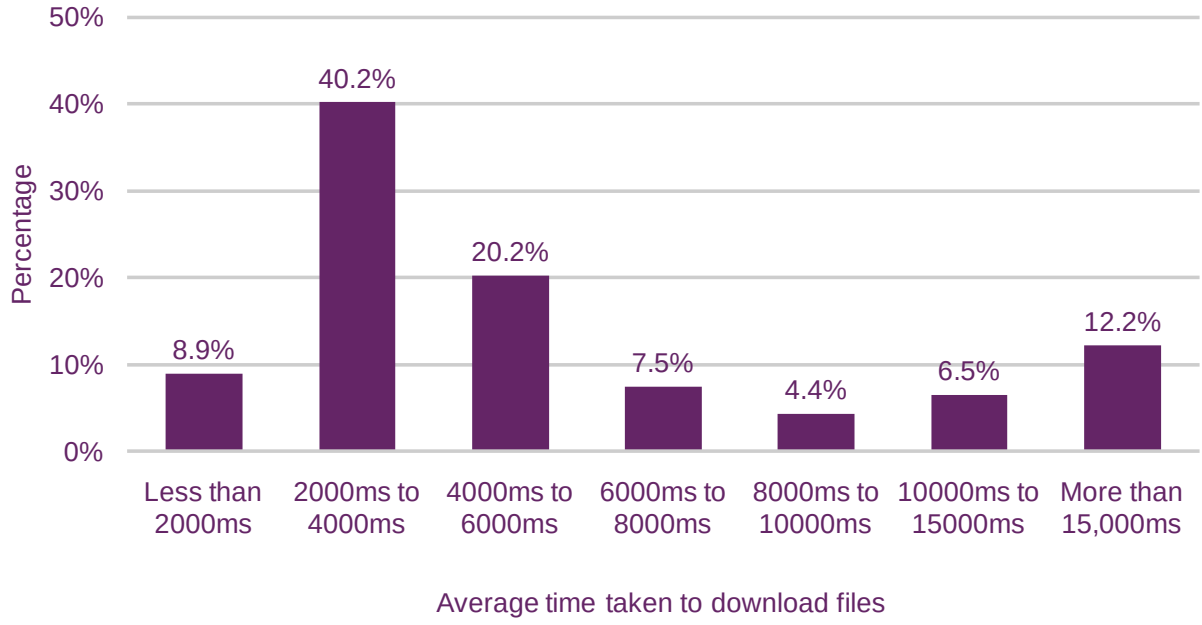
Figure 7.4 Average web page download times by period of day all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 1257 respondents.

7.12 The distribution of the web page download times recorded (Figure 7.5) shows that nearly 50% of panellists on average downloaded web pages in less than four seconds while around 19% of panellists had an average of over 10 seconds.

Figure 7.5 Distribution of average web page download times for all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 1257 respondents.

Latency

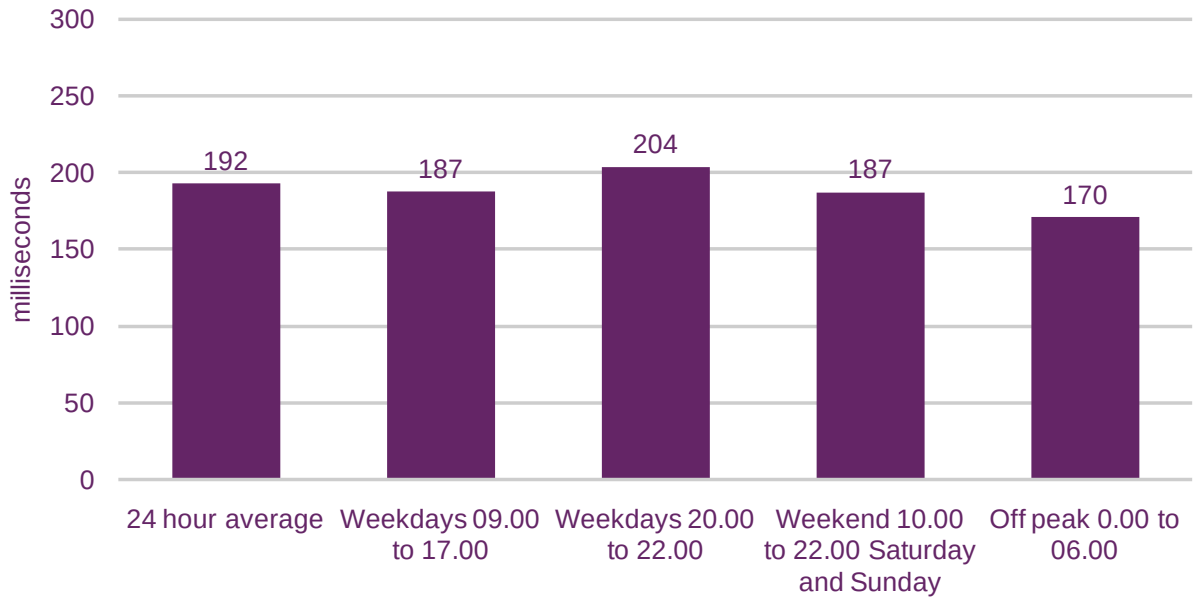
7.13 Latency is the time it takes to send a packet of data from point-to-point within a network, and is an indication of overall responsiveness. Lower latency leads to more satisfactory use of time-sensitive applications such as online game play, interactive web applications (e.g. instant messaging), VoIP telephony and video streaming. Research shows that latency times in excess of 100ms may lead to unsatisfactory performance of online game play.[36]

7.14 We measured latency by sending an ICMP Ping request to a known server and recorded the time taken to receive a response.

7.15 The average latency measure across all five operators from consumer panel results was 192ms (Figure 7.6), ranging from an average of 170ms during off peak hours, to an average of 204ms during weekday evenings.

7.16 With these latency times, many users would not have a service suitable for demanding online games or activities such as VoIP telephony. However, as shown in the results from the static probes in Section 5 above, those users connecting to 3G and HSPA bearers may have a significantly better experience of activities where latency is important.

Figure 7.6 Average latency by period of day for all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of between 964 (24 hr) and 269 (off-peak) respondents.

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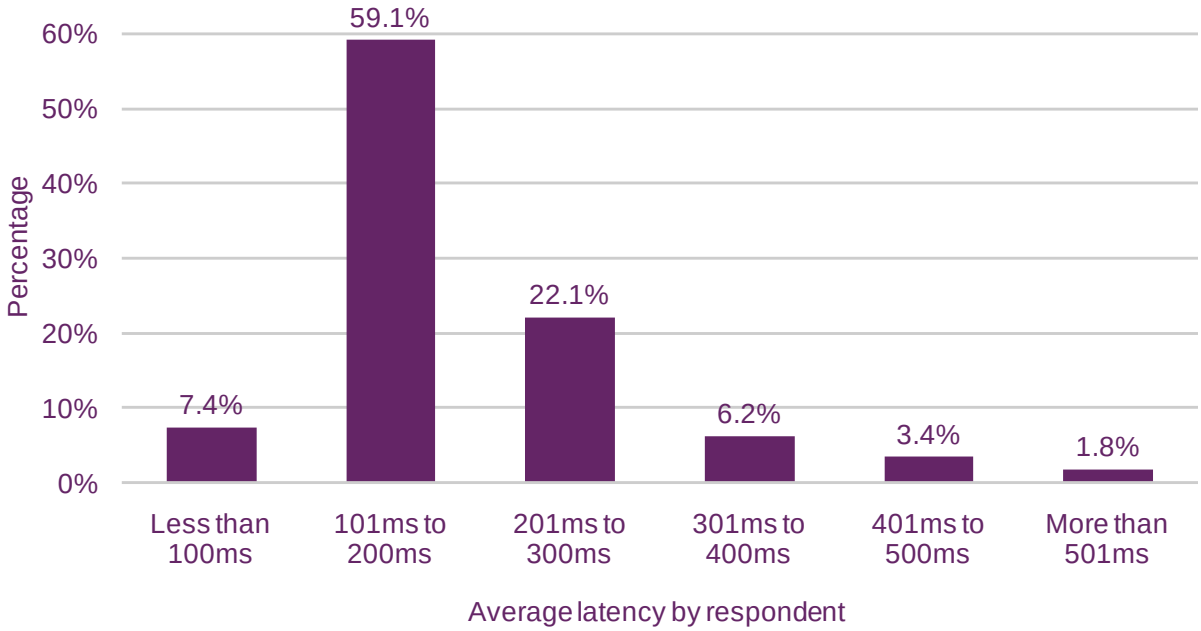
[36]Network Characteristics for Server Selection in Online Games (Mark Claypool), in Proceedings of ACM/SPIE Multimedia Computing and Networking (MMCN), January 2008

7.17 The distribution of latency measurements from the consumer panel is shown in Figure 7.7. More than 90% of panellists had average latency at over 100ms, and a third of panelists averaged over 200ms.

Figure 7.7 Distribution of average latency for all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 964 respondents.

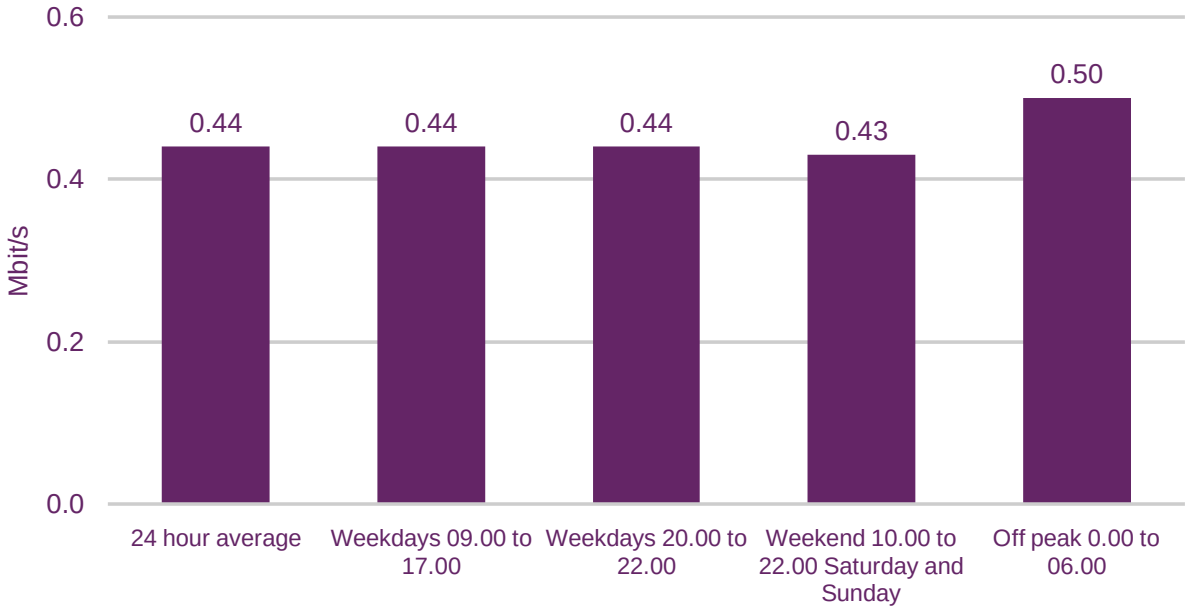
Upload Speed

7.18 Upload speed affects the time it takes to share a photo or send an email with an attachment, though upload speeds are unlikely to be a significant factor in the performance of sending a text-only email or requesting a web page.

7.19 Like download speed, upload speed is the rate at which data is transferred from a consumer device (computer or smartphone) to a destination. We measured upload speed by sending data of a known size from the consumer's computer to a known, controlled server.

7.20 Average upload speeds are adequate for most basic online services, including VoIP during all periods of the day. Upload speeds are comparable to the upload speeds delivered by basic fixed-line broadband services.

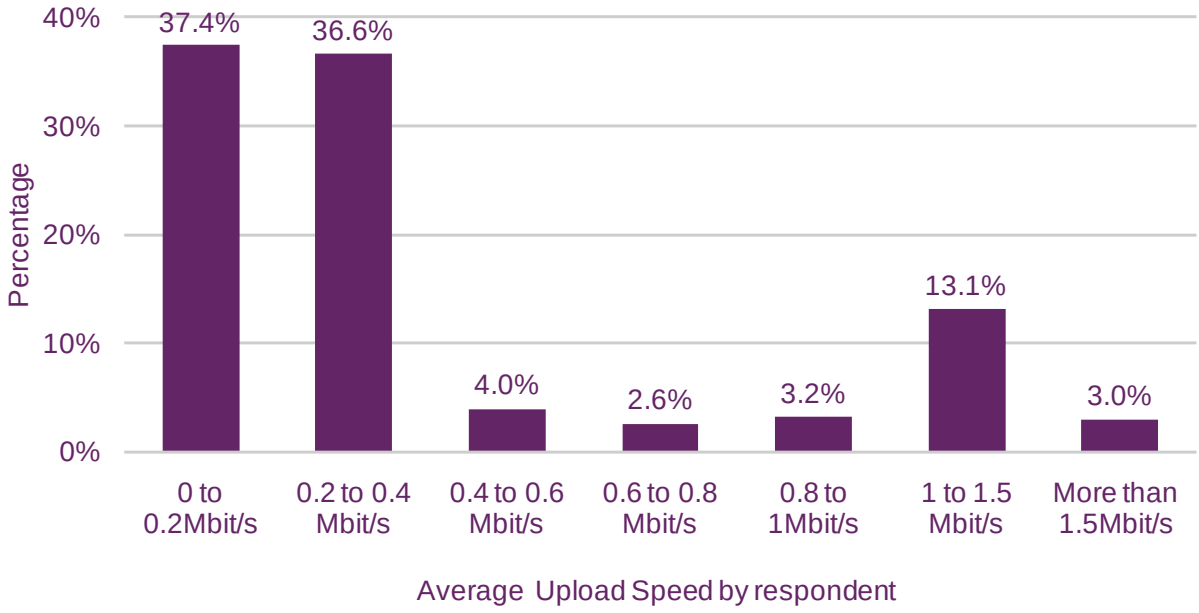
Figure 7.8 Average upload speed by period of day for all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.
Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of between 505 (24 hour test) and 208 (off-peak) respondents.

7.21 The large majority (74%) of upload speeds were 0.4Mbit/s or slower as shown in Figure 7.9. Interestingly, 16% of respondents averaged upload speeds of greater than 1Mbit/s indicating that consumers can experience HSUPA upload speeds in some situations.

Figure 7.9 Distribution of average upload speeds for all operators



Source: Epitiro measurement data for all consumer panel probes between 22nd September 2010 and 19th December 2010 for UK mobile operators '3', O2, Orange, T-Mobile and Vodafone.

Notes: (1) Data is based on all bearers including 2G, 3G or HSPA bearer at time of test; (2) Sample size of 505 respondents.

Section 8

Conclusion & Next Steps

Implications for consumers

8.1 This research report is a representative view of mobile broadband performance based on data collected by dongle-based measurement probes (with supplementary drive testing using high-end smartphones). As operators are continuing to enhance and expand their networks the results set out in this report will not necessarily reflect the future performance of networks and providers; nevertheless, we are able to draw conclusions based on the performance measured.

8.2 Our results indicate that there is a significant difference in performance between fixed and mobile broadband services. Mobile broadband performs below fixed broadband service levels in technical metrics such as download speeds, latency and DNS resolution time. For applications including web browsing, file downloading, VoIP, video streaming and on-line game playing, mobile broadband services are likely to perform at a lower standard than fixed broadband service.

8.3 Mobile broadband and fixed broadband do of course serve different needs: mobile broadband is suitable for those wishing to use broadband from different locations or in locations where a fixed-line is not available, and fixed broadband services may be more suitable for users wishing to use bandwidth-heavy services or download large amounts of data. Nevertheless, an increasing proportion of households are using mobile broadband as their only means of internet connectivity and we believe the information is useful for consumers who are choosing between fixed or mobile broadband as a sole source for internet connectivity.

8.4 Download speeds have been the most important technical metric by which fixed-line broadband services have been marketed. In contrast, mobile broadband speeds rarely feature in advertising from mobile network operators. This is appropriate, both because speeds vary so significantly from the theoretical maximum (7.2Mbit/s or 14.4Mbit/s), and also because download throughput speeds may not be the most important determinant of the consumer experience of mobile broadband services. Slow web page downloading is caused by a number of factors including high latency, and high latency may also cause a more significant constraint on the performance of online gaming and VoIP than slow download speeds.

8.5 Geographic location is likely to be the largest single determinant of mobile broadband performance. There are very significant differences in performance by the type of network connection (2G, 3G or HSPA), and our drive testing indicates that the availability of 2G, 3G or HSPA networks, and the performance delivered, vary significantly even within small geographic areas. Before purchasing mobile broadband, consumers are advised to check the network availability in the locations where they expect to use the service using operators' own postcode-based coverage checkers.

8.6 In areas where there is good 3G/HSPA coverage, our research finds that there are some differences between operators in the performance delivered. Consumers should be aware that service quality will differ based on their location and choice of provider.

Implications for Mobile Network Operators

8.7 Despite very large increases in mobile data use, there is some evidence that average speeds have not slowed between early 2009 and the end of 2010. Although because of methodological differences like-for-like comparison is not possible, the average download speeds measured from the consumer panel covered in this report (1.5Mbit/s) were significantly higher than the average speed measured by an Epitiro study in April 2009 (1.0Mbit/s). This indicates that network upgrades, perhaps also along with improvements to consumers' hardware, have overall been keeping pace with increasing demand.

8.8 Nevertheless, average mobile broadband speeds and other key performance indicators vary significantly by time of day, with services performing best during the off-peak hours of 0-6am. As performance varies by peak and off-peak hours, this indicates that there is contention for services in mobile broadband networks, though this study does not conclude if the contention is within the radio access network, or the backhaul infrastructure.

8.9 Mobile broadband performance is, on average, significantly below fixed-line performance and it is likely that this will continue to be the case until superfast mobile networks are launched using the LTE standard, which is unlikely to happen until 2013, following spectrum awards in 2012. Until then, MNOs could assist consumers in choosing between fixed and mobile broadband by emphasising the differences between the two services – the suitability of mobile broadband for those in areas of good 3G/HSPA coverage, who wish to use their service in different locations and who may not have a fixed-line telephone service; and the lack of suitability for those outside 3G/HSPA coverage or who wish to download large amounts of data or use high-bandwidth services such as video download, or services which benefit from a high level of responsiveness, such as online gaming.

8.10 Given limitations in the performance of mobile broadband, other service propositions may become increasingly important such as the inclusion of WiFi access in public 'hotspots', or technologies such as caching or page compression to improve web page download (although, it is of course important that consumers can understand when images are being compressed and can opt in or out as desired).

8.11 Network management will continue to be a primary focus in ensuring the optimal consumer experience. It may be that different approaches will need to be made for different types of consumer (e.g. business, consumer), different devices (e.g. dongle, smartphone, tablet, e-reader), different types of traffic (e.g. HTTP, video, peer-to-peer) and different time of day (e.g. peak, off peak). As this develops, it is essential that information is made available to consumers about what service quality they can expect and how this service quality will vary.

Next Steps

8.12 Mobile broadband networks and services, and broadband services in general, are evolving rapidly, and it is essential that consumers have information which enables them to make informed choices about the services available to them. Ofcom will continue to work with industry with the objective of ensuring that up-to-date information about the following is available:

- Robust and reliable comparative information on network coverage by postcode, including where 3G/HSPA services are available

- The performance of mobile broadband services delivered via dongles/ datacards, including its relative performance compared to fixed-line broadband service

- The performance of mobile broadband services delivered to smartphones and other devices.

Annex 1

Glossary

2G: 2nd generation radio and network technology.

3G: 3rd generation radio and network technology.

3GPP: 3rd Generation Partnership Project; Standards body for GSM, GPRS, EDGE, UMTS and HSPA.

ADSL: (Asymmetric Digital Subscriber Line) A digital technology that allows the use of a standard telephone line to provide high speed data communications.

Backhaul: The links by which data are transmitted from a base station back to the core packet network of the operator's network.

Bandwidth: The maximum amount of data that can be transmitted along a channel.

Bit-rate: The rate at which digital information is carried within a specified communication channel.

Broadband: A service or connection generally defined as being 'always on', providing a bandwidth greater than narrowband.

Broadband speed: The speed at which data are transmitted over a broadband connection, usually measured in megabits per second (Mbit/s).

Contention: A slowdown in performance caused when multiple users share the same limited bandwidth.

Contention ratio: An indication of the number of customers who share the capacity available in an ISP's IP network.

CQI: Channel Quality Indicator.

Download speed: The rate of data transmission from a network operator's access node to a customer, typically measured in Megabits per second (Mbit/s).

DNS: The Domain Name Service (or System) is a protocol that translates domain names (such as google.com) into the IP addresses that are actually used to route traffic (e.g. 80.77.246.42)

DSL: Digital Subscriber Line (Fixed Broadband Technology for copper line access).

Ec/Io: Signal to noise ratio in 3G systems.

EDGE: Enhanced Data rates for GSM Evolution – an improved data solution for GSM GPRS.

FTP: File Transfer Protocol.

GPRS: General Packet Radio Service.

GPS: Global Positioning System.

GSM: Global System for Mobile communication, the ETSI standardized 2G mobile system.

Headline speed: The speed at which a broadband service is marketed.

HSDPA/HSUPA: High Speed Downlink/Uplink Packet Access for 3G networks.

HSPA: High Speed Packet Access for 3G networks.

IP: Internet Protocol

ISP: Internet Service Provider. A company that provides access to the internet.

Jitter: A measure of the stability of an internet connection. The variation in latency.

kbit/s: Kilobits per second. 1,000kbit/s is the same as 1Mbit/s.

LAC: Location Area Code.

Latency: The time it takes a single packet of data to travel from a user's device to a third-party server and back again. Most commonly measured in milliseconds.

Mbit/s: Megabits per second.1Mbit/s is the equivalent of 1,000kbit/s.

MCC: Mobile Country Code.

MMS: Multi-media Messaging Service.

MNC: Mobile Network Code.

MNO: Mobile Network Operator.

MOS: Mean Opinion Score.

MPLS: Multi-Protocol Label Switching.

OFCOM: Office of Communications, the UK Communications Regulatory body.

Packet loss The loss of data packages during transmission over an internet connection.

PAYG: Pay-as-you-go, a term for pre-pay mobile.

PDP: Packet Data Protocol.

PS: Packet Switched.

RF: Radio Frequency.

RNC: Radio Network Controller.

RSCP: Receive Signal Code Power

RSSI: Receive Signal Strength Indicator.

SDH: Synchronous Digital Hierarchy.

SIM: Subscriber Identity Module.

Streaming content: Audio or video files sent in compressed form over the internet and consumed by the user as they arrive.

TCP: Transmission Control Protocol.

UMTS: Universal Mobile Telecommunications System, the 3GPP 3G system.

Upload speed: The rate of data transmission from a customer's connection to a network operator's access node, typically measured in Kilobits per second (Kbps).

USB: Universal Serial Bus.

USB modem: The 'dongle' computers use to access mobile broadband

VoIP: Voice over Internet Protocol. A technology that allows users to send calls using internet protocol, using either the public internet or private IP networks.

Annex 2

Technical Testing Methodology

Overview

Three data collection methodologies were employed for this research, providing different perspectives on network performance, consumer experience and coverage for specific case studies of performance across the UK:

- Static probes: hardware based probes deployed to 97 sites across the UK, measuring network performance for all five MNOs, 24 hours per day.
- Consumer panel: software-based probes installed to a panel of mobile broadband users in the UK.
- Drive testing: vehicle-mounted, handset-based probes, enabling measurement for case studies of performance in four specific regions of the UK.

All three of the above methodologies were supplied and implemented by Epitiro, Ofcom's partner in this research.

Hardware platforms

The static probes were running on a platform with the following specification:

- Tyan S3115 mainboard with Atom DC330 processor and 1GB DDR II RAM;
- Sierra Wireless AirCard USB 309 HSxPA modem;
- Windows XP SP3.

The measurement from the consumer panel employed a software based probe downloaded and installed to end user PCs running Windows XP, Windows Vista or Windows 7 (32bit and 64bit editions). Connectivity to the mobile broadband service under test was via the user's own device or USB HSxPA modem.

The drive testing probes were based on Epitiro's ipQ software deployed on HTC desire handsets running Android 2.1.

All three platforms were running Epitiro software and share the same broad testing and network measurement capabilities. All tests conducted as part of this research are outlined in the sections below.

Connection availability measurements

Connection availability was measured as part of the static probe methodology only. The static probes executed their tests once every hour, and at the start of each hourly testing cycle, the probe initiated a new connection to the mobile broadband service. The probe utilises Windows Dial-Up Networking to control the connection via the USB modem and measures the time taken to complete the connection and captures the status code

associated with any failure to connect. At the end of each testing cycle, the probe disconnected from the mobile broadband service.

Throughput measurements

Throughput measurements of download and upload speed, for all three methodologies, were all conducted from the probes to a static Epitiro endpoint server. The endpoint server was hosted in Telehouse North (a data centre in London's Docklands forming one of the central, carrier neutral, internet hubs in the UK) on bandwidth static to the purpose of throughput testing for this Ofcom research. Epitiro's endpoint servers are configured with awareness of the amount of bandwidth available for testing, and are able, based upon the bandwidth being consumed by active tests, to reject any test requests that would result in inaccurate measures due to insufficient server bandwidth.

All throughput tests were conducted over TCP and were single threaded with a single TCP connection. In order to ensure accurate results regardless of the speed being delivered by the mobile broadband service, all tests were configured as time bounded with both downstream and upstream speeds being measured for a period of 10 seconds each.

A lead-in period of 2 seconds (that did not contribute to the measured speed) was employed, to minimise the impact of TCP slow-start and any change in radio conditions or bearer that, depending on network management policies operated by the MNO, could be triggered by the flow of data.

Network latency measurements

The test of network latency employed ICMP Ping to measure the round trip time in milliseconds from the connected probe to the centrally located server hosted in Telehouse North.

In addition to the measurement using the Telehouse North server, latency was also tested to three popular UK websites.

Measuring web page download time

The webpage download test involved measuring the time taken to download the html 'skeleton' of three popular UK websites. The time taken to download the associated media assets, such as images and graphics were not included. We believe that this is a fair measure of performance, because images on web sites may be cached on the handset and therefore not have to download every time, and also because some operators use image compression (see Section 5.27) which makes like-for-like comparison between operators impossible. However, it should be noted that the web page download times measured may be significantly faster than the time it would take to download a full web page with all images.

This approach is consistent with the methodology for the fixed broadband research we published in May 2010[37], however for the fixed broadband research we published in March 2011[38] we used a different methodology in which a test page hosted on the Ofcom website which included html and a number of different media assets were used. Direct comparison

[37] http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/bbspeeds2010/bbspeeds2010.pdf
[38] http://stakeholders.ofcom.org.uk/market-data-research/telecoms-research/broadband-speeds/speeds-nov-dec-2010/

between our mobile broadband results and the fixed broadband results published in March should be treated with caution.

DNS performance measurements

DNS performance was measured as the time in milliseconds to resolve a fully qualified domain to a corresponding IP address. The DNS servers tested were those assigned by DHCP at the time that the connection to the mobile broadband service was established. DNS requests were made directly to the DNS servers being tested, with any client based caching of DNS resolutions being bypassed.

During this research, DNS performance was tested using the domain names of the same three popular UK websites.

Packet loss and jitter measurements

The packet loss and jitter measures captured as part of this research are based on measurements during delivery of a UDP data stream. The test is conducted between the connected probe and a Telehouse North hosted endpoint server, and consists of a UDP test stream sent for 10 seconds upstream from the probe and then for 10 seconds downstream from the endpoint server. Each UDP stream consists of 160byte packets delivered at a frequency of 1 packet every 20ms, resulting in a 64kbps test stream characteristic of a UDP VoIP stream using the G.711 audio codec.

The packet loss results are measured from the number of non-arriving packets in relation to the number of transmitted by the sender. Packet loss measurements were made for both the upstream and downstream directions.

The measurement of jitter is derived from the inter-arrival times of individual packets at the receiver. Jitter measurements were made for both the upstream and downstream directions. In the analysis for this research the average jitter recorded over the course of the entire stream has been reported on.

Packet loss and jitter were measured by the static probes and consumer panel, but were not included in the tests executed during the drive testing.

Measurements of Image Compression

The affect of any image compression implemented in an operator's network was measured by hosting a number of images that are representative of the photographic images of various sizes commonly used on content rich portals such and news websites. The three images hosted for testing are described in the table below:

Images Hosted for Image Compression testing

Image	File Size	Resolution
Small JPEG	7.96KB	140 x 130 pixels
Medium JPEG	36.8KB	460 x 276 pixels
Large JPEG	96.2KB	629 x 460 pixels

The images were downloaded over HTTP by the static probes to determine if compression techniques were employed on each operator network. The level of compression typically experienced on the images tested was quantified by comparing the size of the image that resulted from the download to the original size of the hosted image.

Measuring radio conditions

During the testing conducted by the static probes, the radio network conditions were recorded at the start of each connection and each individual test. Radio network conditions were characterised in the following terms: Bearer (GPRS, EDGE, 3G, HSDPA or HSUPA); Cell ID; LAC; MNC; MCC; signal quality (RSSI, RSCP, Ec/Io and CQI as appropriate to the connected bearer).

The handsets employed during drive testing captured Bearer, Cell ID, LAC, MNC, MNC, and signal quality in terms of RSSI.

Testing executed from the consumer panel used the user's own devices to connect to the mobile broadband service, so radio conditions were not captured for this component of the methodology.

Capturing location

During the period of drive testing, the location of each test was recorded by employing the GPS capabilities of the HTC desire handsets.

Annex 3

Statistical Analysis Methodology

Overview

The purpose of this study was to determine both the performance of mobile broadband services in the UK and also provide insight into the actual quality of services consumers typically experience.

For network analysis, data was extracted from measurements taken from static probes. Over 3.8 million tests were collected through hourly tests which ran from September 2010 to December 2010. As the purpose of this aspect of testing was to understand network capability and performance with 3G (or better) service, all 2G test results were removed.

Consumer experience tests included all data, all tests in order that a view of mobile broadband could be analysed as delivered. Over 330,000 tests were collected through hourly tests which ran from September 2010 to December 2010.

Drive testing was used to collect the data used to analyse the range of mobile broadband performance within different levels of urbanity. Over 45,000 tests were conducted in drive tests which occurred between 15th November and 15th December 2010.

Consumer panel recruitment

YouGov recruited respondents who use mobile broadband (through dongles, modem sticks, and datacards) from its online panel of over 300,000 people. These respondents participate in a perception based survey for market research purposes every quarter (YouGov's Dongle Track programme). Further panellists were recruited from Epitiro's existing panel of UK broadband users.

In order to recruit people for this research, YouGov approached all panellists identified as mobile broadband users and asked them if they wish to take part. This was achieved via a special screening survey, which confirmed the details of the dongle they used, and informed them of the nature and reward available for the study if they participated. YouGov also sent out a separate screening to its panel members it had yet to ask about usage of mobile broadband, thus ensuring as many people as possible with mobile broadband were invited to the Ofcom study.

Once panel members with mobile broadband agreed to take part in the study, YouGov sent them to an Epitiro hosted website where they entered their details and downloaded the Broadband Test Application for installation.

Confidence intervals for means

Charts in this report may have confidence intervals for means presented. These confidence intervals may be shown for some measures and for each MNO and/or period of the day. Significance was calculated at a 95% confidence level.

Confidence intervals for the mean is useful when estimating a population mean from the sample mean. The size of the interval gives the indication about the precision of estimation – narrow intervals suggest better precision.

Confidence intervals are associated with certain levels of confidence (reported as percentages). For example: with 95% confidence we can say that the confidence interval contains a population mean. When changing the confidence to a higher level (e.g. from 90% to 95%) the confidence intervals will become wider as this is a trade-off between confidence and precision.

The size of intervals depends also on the sample size as well as the standard deviation. With a larger sample the intervals become narrower. Standard deviation values have the opposite affect and when these get larger the confidence intervals become wider and the estimation will be less precise.

The formula to estimate confidence intervals with a 95% confidence level is as follows:

1.96 **x** Standard error of the mean **+/-** Sample mean

Where:

Standard error of the mean is equal to standard deviation of the sample mean divided by the square root of the sample size. Standard deviation measures how much the numbers vary around the average (mean).

The 1.96 value is associated with 95% confidence level. If the sample means are normally distributed then about 95% of the sample means should be placed within 1.96 standard deviations of the mean.

Confidence levels

The confidence level is the probability that the confidence interval contains a population mean. The most commonly reported confidence level is 95%, but other levels often used are 90% and 99%.

The confidence levels and associated constants are based on assumption that the mean of the sample is normally distributed. If the population distribution is not normal but a sample size is large enough, the mean of a sample will be approximately normally distributed and we can compute confidence intervals for the estimation.

We applied 95% confidence level for significance tests. The same level was used to compute confidence intervals for a mean.

Testing of significant differences

To test if the mean of a performance measure of one MNO differs significantly from another MNOs mean score, we used a comparison of column means (t-tests). The p-level is equal to 0.05.

p-level is the probability of an error of accepting that there are significant differences between categories, while in reality there are no such differences. In other words p-level tells us about the probability that our results (difference between means) occur by chance. With p-value equal to 0.05 we have a 5% chance that the results are not showing significant differences but rather random occurrence of the difference between means.

This test relies on a *central limit theorem* approximation to the normal distribution. This means that a large sample (generally at least 30 cases) is required if the data is not distributed normally. In our report each filtered sample is large enough to meet the central limit theorem requirements. Generally we have excluded any samples where they have fewer than 50 cases.

Significant differences can be visualised on charts by showing confidence intervals for each group. If the intervals don't overlap, that indicates that the means are significantly different.