# Smartphone cities 2016 Annex

## Mobile broadband performance in London

Research Annex

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# About this document

This document outlines the results of Ofcom's research into the performance of the retail networks of the UK's four national mobile network operators: EE, O2, Three and Vodafone in central London over five days in March 2016. This is a supplementary case study to Ofcom's *Smartphone Cities* report published in March 2016[1].

The purpose of the testing was to compare the mobile broadband performance on each network on Category 4 and Category 6 (newer) type handsets. This is because it is possible that the technological updates featured on newer handsets (Category 6 and above), as well as the capability to pick up carrier aggregation technology[2], can contribute to an enhanced mobile broadband performance experienced by consumers.

This report presents results for: download speeds, web browsing times, upload speeds, YouTube streaming resolution and network response times. The results presented here are not directly comparable to those in previous reports due to the evolution in our testing methodology[3].

It is important to note that the results presented below are a case-study limited to a snapshot of performance in central London over the five days of testing in March 2016 and do not reflect UK-wide performance of each MNO.

This report is part of a wider programme of work by Ofcom into mobile quality of service, which includes our interactive coverage maps.

[1] http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/broadband-speeds/smartphone-cities/

[2] More information on handset technological updates and carrier aggregation technology can be found in on page 2

[3] More information on how the testing reported here differs from that conducted in previous reports can be found on page 14

# Contents

Section 1

# Introduction

In March 2016, Ofcom published its *Smartphone Cities* report, which detailed the results of testing of mobile broadband and voice performance in five UK cities. This document is published as a supplementary annex to this report and details the results derived from testing which was conducted in London over five days in March 2016. These tests measured the mobile broadband performance on each network of the UK's four national mobile network operators ("MNOs"): EE, O2, Three and Vodafone on Category 4 ("Cat-4") and Category 6 handsets ("Cat-6")[4].

The main reason for this testing on Cat-4 and Cat-6 handsets was to understand more about the potential performance benefits available to consumers who upgrade to the latest devices and on each network. Newer handsets contain technological upgrades and advances that can contribute to an improved broadband performance. Newer handsets (Cat-6 and above) are able to make use of one of the key developments in mobile networks recently; the deployment of carrier aggregation ("CA") technology. CA technology can be utilised to enhance the mobile broadband performance experienced by consumers (more information on how CA technology works can be found on page 2).

The Cat-6 device which we used for our test is able to make use of CA technology, while the Cat-4 device is unable to. EE and Vodafone have begun to deploy CA in the UK, with rollout at an early stage, in areas including London, at the time of writing this report.

The results presented in this annex are not directly comparable to those in our previous reports, including *Smartphone Cities*, due to the evolution in our testing methodology and geographical area tested in (more information can be found in on page 14).

***It is important to note that the results presented below are a case-study limited to a snapshot of performance in central London[5] over the five days of testing in March 2016 and do not reflect UK-wide performance of each MNO.***

As with *Smartphone Cities*, this report focuses on two key metrics relevant to the consumer experience of mobile broadband – namely, download speed and web browsing performance – before examining performance relating to other internet activities.

However, it is important to bear in mind that network performance is only one of the factors that a consumer is likely to take into account when choosing a mobile phone service.

[4] We used a Samsung Galaxy S5 (model SM-GF00F) and Samsung Galaxy S6 (model SM-G928F) for the purpose of this testing and they therefore represent proxies of Category 4 and Category 6 handsets.
[5] More information on the testing methodology and testing area can be found 14.

Section 2

# Methodology used for testing

## 2.1 Developments in mobile networks

One of the key developments in mobile networks recently has been the deployment of CA technology[6]. CA can be thought of as the combination of two different channels to deliver traffic to the same location (CA-enabled devices). More channels result in an increased capacity to handle heavy traffic so that video and other data uses can continue moving smoothly. CA can be deployed for multiple reasons, from increasing the speed at which data can be served by the network to a CA-enabled smartphone, to allowing networks to cope better with traffic during congested time periods and to provide lower over-the-air latency. As such, having a handset that can benefit from CA technology should generally enhance the mobile broadband performance experience by consumers.

EE and Vodafone have deployed CA technology in the UK, but rollout is currently at an early stage[7]. It is currently available on the downlink (base to mobile) path. To take advantage of CA technology, consumers have to have a Cat-6 or above handset and be in coverage of a network that has deployed it. Consumers using EE's network to access CA technology have to have a EE Extra or EE Complete plan, while the ability to access CA on Vodafone's network is built into their 4G service offering.

The Samsung Galaxy S5 handset we tested with for these results is a Cat-4 device, which means it is unable to make use of this technology while the Samsung Galaxy S6 is a Cat-9 capable device[8], meaning it can benefit from this deployment.

## 2.2 Developments with the latest handsets

Many of the most popular smartphone manufacturers now tend to release new handsets on an annual basis and each new model tends to contain a series of technological upgrades and advances that contribute to the consumer's experience of their smartphone, such as sharper screen resolutions, a greater amount of memory and advanced camera capabilities. The future use of smart multiple antennas in handsets are likely to increase throughput and also lead to a better experience for consumers because of the increase in transmission robustness.

There are also less visible upgrades that will likely benefit the consumer's quality of experience with their Smartphone, in particular their mobile broadband performance. Fundamental to any improvement in mobile broadband performance and the general device capability is the availability of greater computational power in the handsets, which underpins the adoption of new technology.

For our testing, we used Cat-4 and Cat-6 handsets in order to understand the potential performance benefits related to an upgraded smartphone model. The specific handset models we used were the Galaxy S5 (Cat-4 enabled) and the Galaxy S6 (which is a Cat-9 device but is Cat-6 enabled). These handsets were used to represent the broader

[6] Carrier aggregation is also known as LTE-Advanced and 4G+, and is a 4G technology which allows different bands to be simultaneously used by the base station-device pair to exchange user traffic.
[7] The most up to date information about CA deployment by EE can be found in their coverage checker: http://ee.co.uk/why-ee/network/4gplus. Please note EE refer to CA as '4G+'
[8] While the Samsung Galaxy S6 is a Cat-9 device, it operates as a Cat-6 in the UK, so it is referred to as Cat-6 throughout this annex

performance that can be experienced through handsets in each of the categories. Figure 1 shows a sample list of selected smartphones which are both CA-enabled and will contain the technological upgrades and advances as detailed here (i.e. these handsets are all Cat-6 or above).

**Figure 1: Cat-6 and above smartphones examples**

| Manufacturer | Handset |
|---|---|
| Apple | iPhone6S, iPhone 6S Plus |
| Blackberry | Passport, Priv |
| HTC | HTC 10, One (M9, A9) |
| Huawei | Mate 8, Ascend Mate 7, E5786, Honor 6 |
| LG | G4, G5, LG G Flex 2, Nexus 5X |
| Motorola | Moto X Style |
| Nokia | Lumia 950 |
| Samsung | Galaxy S6 |
| Sony | Xperia X, Xperia Z3+/4, Xperia Z5 |

## 2.3 Measuring performance

Both the speed of mobile broadband services and their consistency are important as measures of performance. While consumers can feel frustration with slow download speeds and long waits for web pages to load, connection failures and failed calls are also a source of irritation.

An average speed metric will indicate how fast a service is on average, but it does not reveal how frequently that service fails. In order to gauge the consistency of a mobile network's performance, it is necessary to look at the distribution of results.

It should also be noted handset choice is only one of the factors that consumers should take into account when making decisions about their smartphone. Price, quality of customer service, coverage, contract terms and network performance are also relevant and will play a part in consumers' quality of experience.

The rest of this annex will detail the results of each of the tests that we conducted in order to show the performance benefits related to upgraded handsets.

Section 3

# London case study results

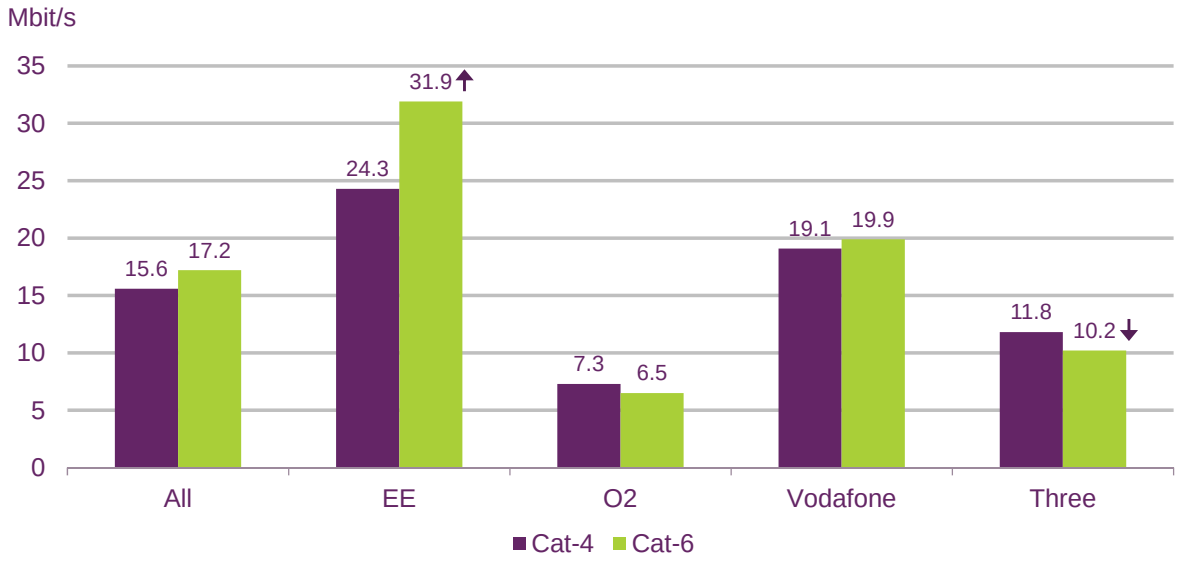
It is important to note that the results presented below are a case-study limited to a snapshot of performance in central London over the five days of testing in March 2016 and do not reflect UK-wide performance of each MNO. The results were gathered where CA technology is available on certain tariffs across EE and Vodafone. Consumers using EE's network to access CA technology have to have a EE Extra or EE Complete plan, while the ability to access CA on Vodafone's network is built into their 4G service offering. Deployment of CA technology is still at an early stage across the UK, meaning the results below are not reflective of performance across the UK as a whole.

## 3.2 Download speed

Download speed refers to the speed at which information is transferred from the internet to a device. In effect, it determines how quickly a file can be downloaded from a remote source to a smartphone. Typically, this involves downloading a file from a website e.g. music, films, pictures, applications and e-books.

Overall, for all download tests carried out, there was no significant difference between Cat-4 and Cat-6 handsets. EE was the only operator which experienced a significant increase for download tests carried out on their network on Cat-4 compared to Cat-6 handsets.

**Figure 2: Average 4G download speed**

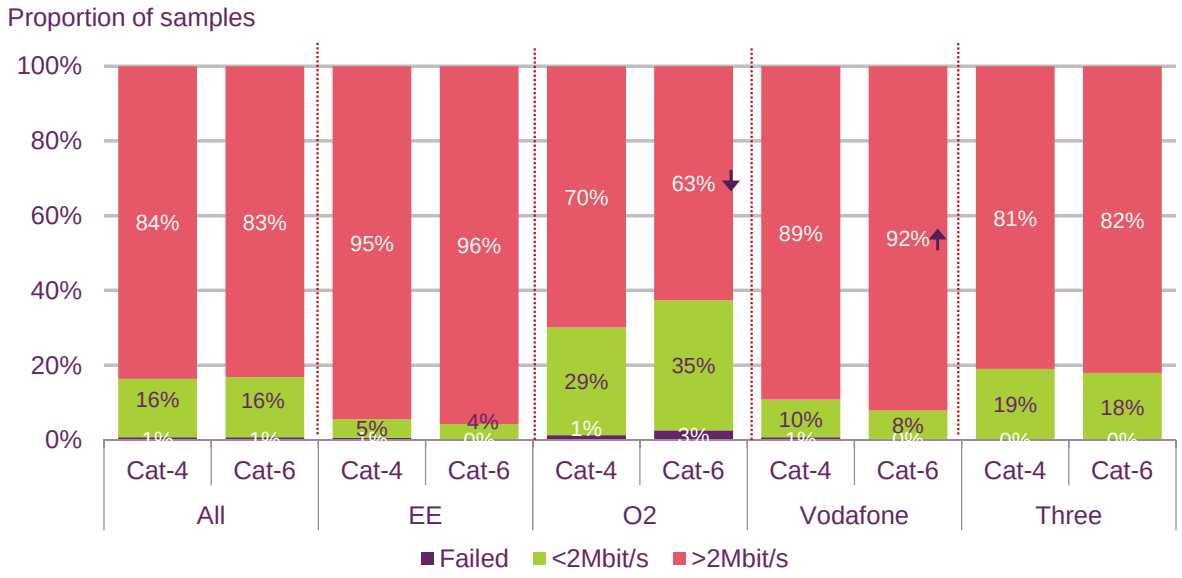



*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average (mean) of all tests gathered with 4G as the best bearer.*
*Significance testing shows any difference between Cat-4 and Cat-6 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

For download speed, we also considered the proportion of tests that produced a speed greater than 2Mbit/s in addition to the overall averages; as such speeds are likely to be sufficient to support high-capacity video services. Looking at distribution gives a better idea of consistency of performance and how the networks respond under stressed conditions.

Across all tests, there was no significant difference, between Cat-4 and Cat-6 handsets, in the proportion of tests that produced a speed greater than 2Mbit/s. Vodafone was the only operator which saw a significant increase in the proportion of tests with a speed greater than 2Mbit/s on Cat-6 compared to Cat-4 (89% vs. 92%).

**Figure 4: Distribution of 4G download results**




*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Significance testing shows any difference between Cat-4 and Cat-6 for >2Mbit/s and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

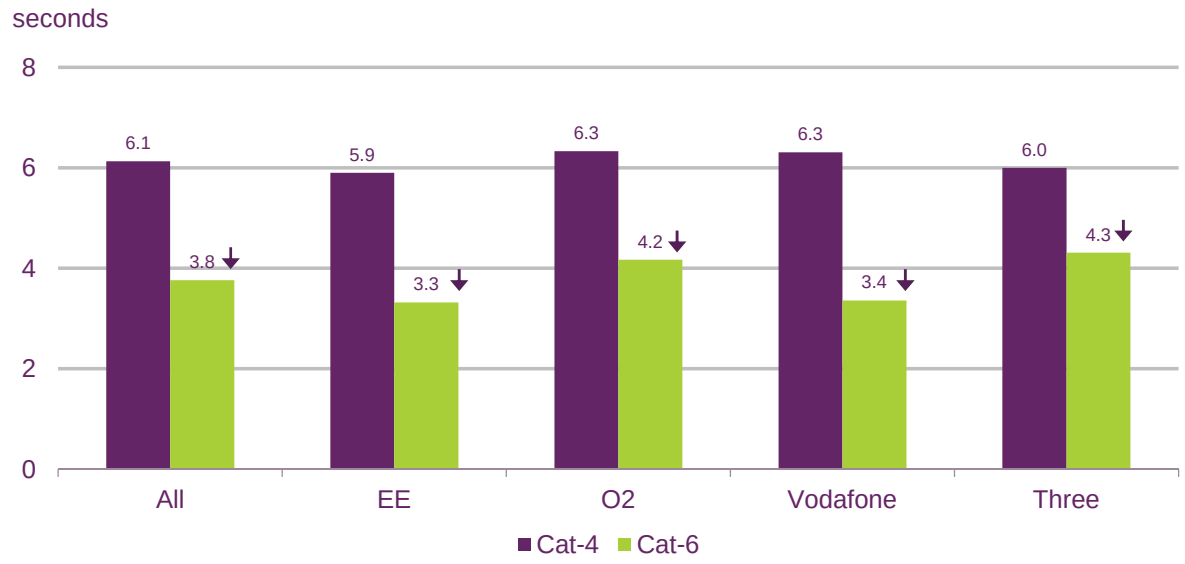
## 3.3 BBC web browsing

Web browsing refers to an activity that allows consumer to access content through an internet browser. Many activities – from using a search engine to loading a news website – require web browsing functionality.

For the web browsing test, we analyse the percentage of occasions when the BBC homepage successfully downloaded within 15 seconds, as well as the average time it took for all information on the homepage to reach the user's handset. This is the time taken for the website to load all content contained on the homepage, rather than the time until a consumer can interact with the page.

Overall, the average time taken to load the BBC homepage on Cat-6 devices was four seconds, which is significantly less than the time taken for Cat-4 devices (six seconds). All networks saw a decrease in the time taken to load the BBC homepage.

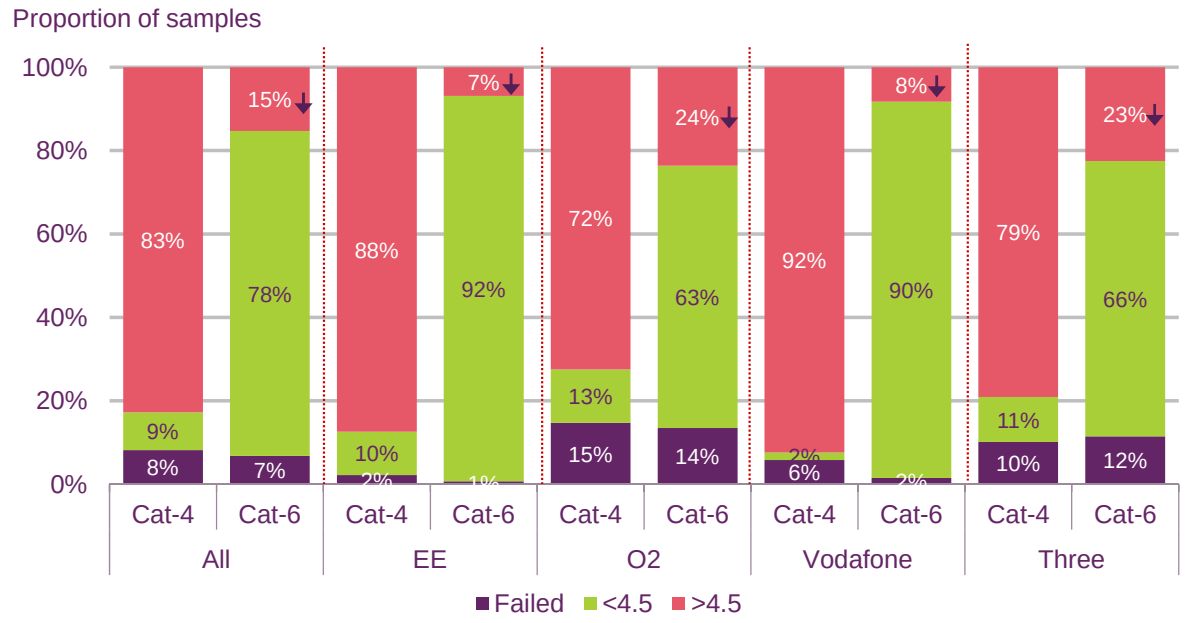
### Figure 5: Average 4G BBC homepage load time




*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average (mean) of all tests gathered with 4G as the best bearer.*
*Significance testing shows any difference between Cat-4 and Cat-6 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

Overall, the proportion of web browsing speeds under 4.5 seconds for all tests carried out on Cat-6 devices was 78%, compared to 9% on Cat-4 devices.

### Figure 7: Distribution of 4G BBC homepage loading time results




*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Significance testing shows any difference between Cat-4 and Cat-6 for >4.5 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

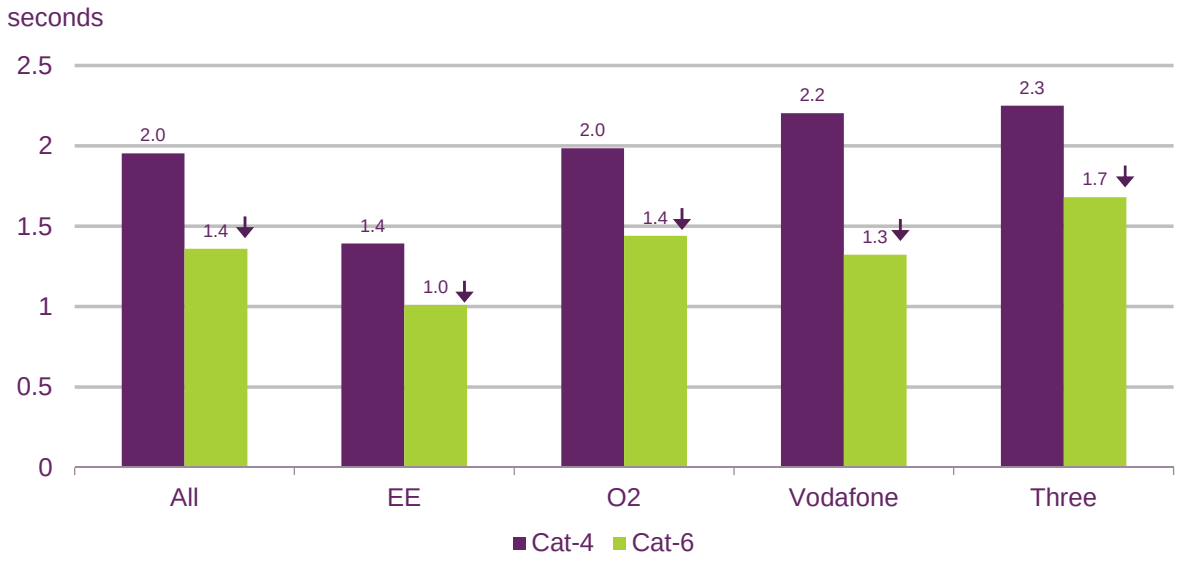
## 3.4 Standard web page loading time

In addition to our BBC homepage web browsing test, we tested web browsing performance on a standard web page containing a small amount of static content.

Standard web page load time refers to how long it took for a basic web page to load on each of the operators' networks, from the time between a consumer sending a request for a web page and the page finishing loading. For this test we used an industry standard-sized web page (based on an ETSI 'mKepler' standard reference page) which is static – its content does not change. Comparisons with these standard web page results and our BBC browser results show how different aspects of mobile networks come into play for different tasks.

Overall, the average time taken to load the standard web page on Cat-6 devices was 1.3 seconds, which is significantly less than the time taken for Cat-4 devices (1.8 seconds). All networks saw a significant decrease in the time taken to load the standard web page on Cat-6 devices compared to Cat-4.

**Figure 8: Average standard web page load time**

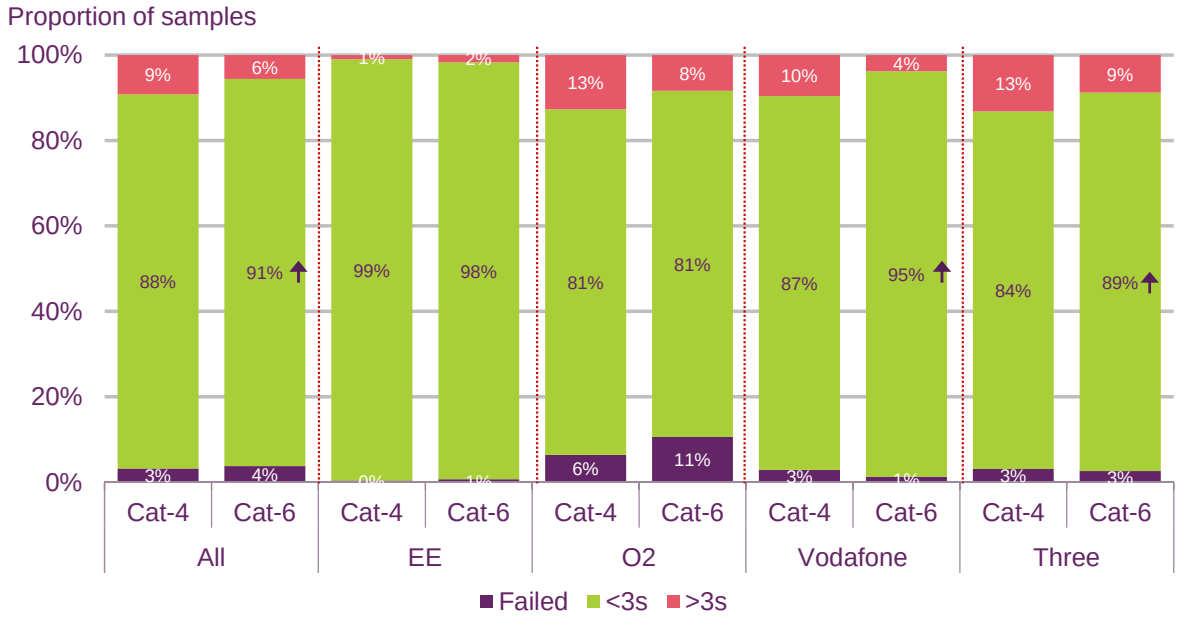



*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average of all tests gathered with 4G as the best bearer.*
*Significance testing shows any difference between Cat-4 and Cat-6 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

Overall, the proportion of web browsing speeds under three seconds for all tests carried out on Cat-6 devices was 91%, which is an increase of three percentage points compared to all tests carried out on Cat-4 devices.

Tests carried out on Cat-6 devices on Vodafone and Three's networks both saw an increase in the proportion of tests achieving speeds less than three seconds compared to tests on Cat-4 devices, while the distribution of standard web page loading times were similar across all handsets for tests on EE and O2's networks.

**Figure 10: Distribution of 4G standard web page loading time results**



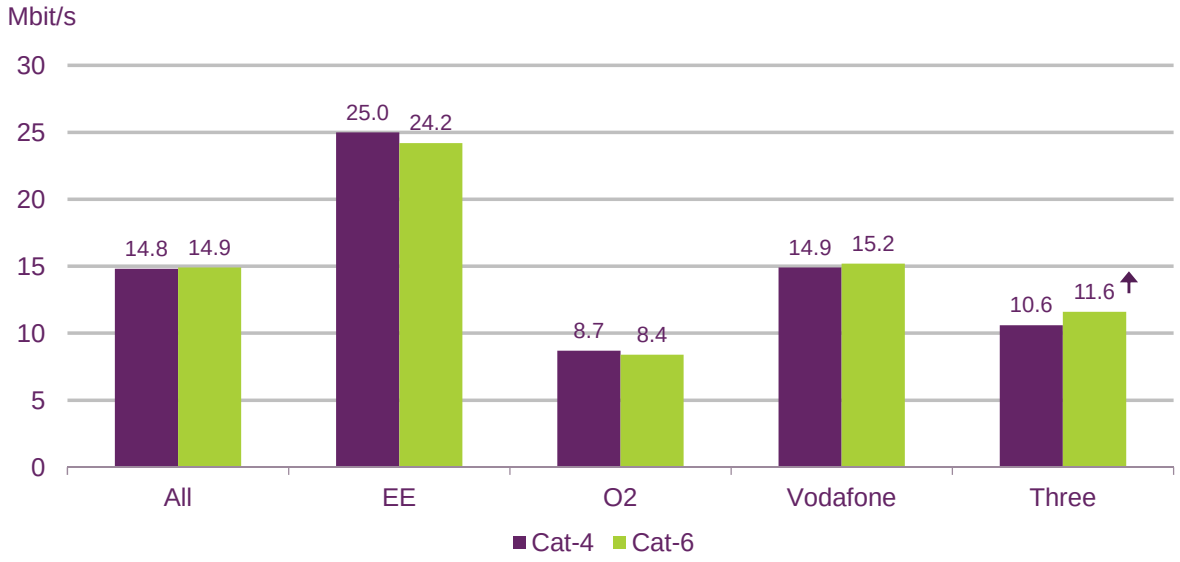

*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Significance testing shows any difference between Cat-4 and Cat-6 for <3s and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

## 3.5 Upload speed

Upload speed refers to the speed at which information is transferred from a device to the internet. For example, to post a photo taken on a smartphone to Facebook, a consumer will upload the photo to Facebook from their device.

Across all tests carried out on all networks, the average upload speed was similar for Cat-4 and Cat-6 devices, except an increase on Three's network. A point to note here is that CA is not currently applied to the uplink (mobile to base) path.

**Figure 11: Average 4G upload speed**



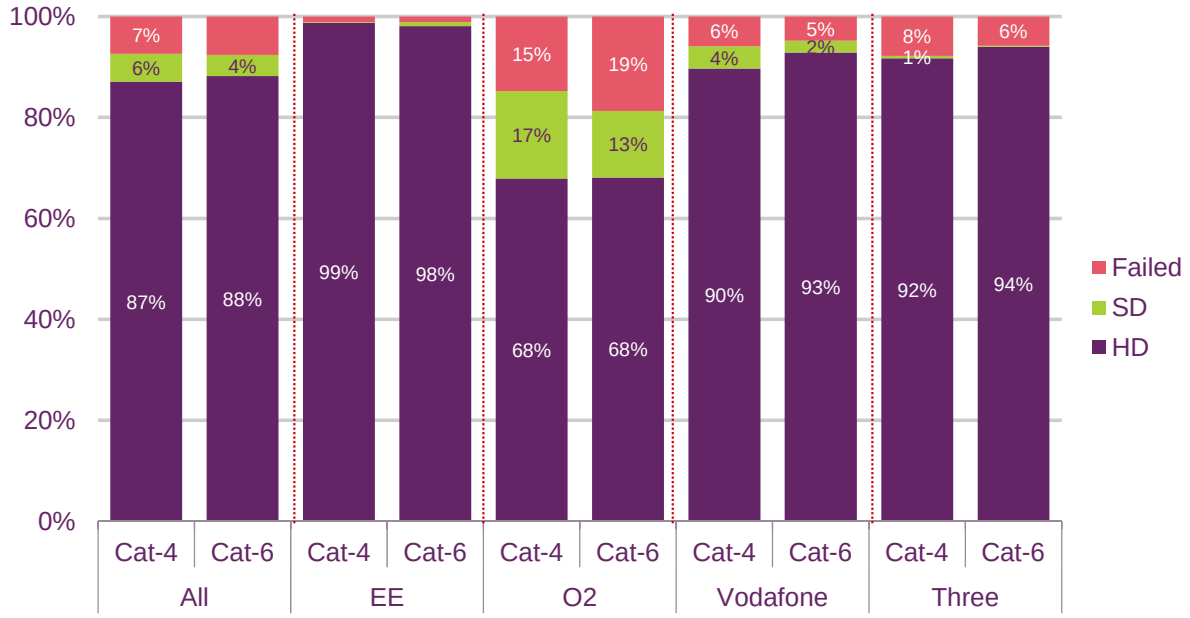

*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average (mean) of all tests gathered with 4G as the best bearer.*
*Significance testing shows any difference between Cat-4 and Cat-6 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

## 3.6 YouTube streaming

YouTube streaming is a process in which short-form video content is viewed in real time. This metric indicates the proportion of videos streamed on each network that were in standard definition, high definition, and what proportion failed to play. We used the trailer for the latest Bond film, *Spectre*, in our YouTube streaming test.

Across all networks, the distribution of video streaming resolution was similar for Cat-4 and Cat-6 handsets.

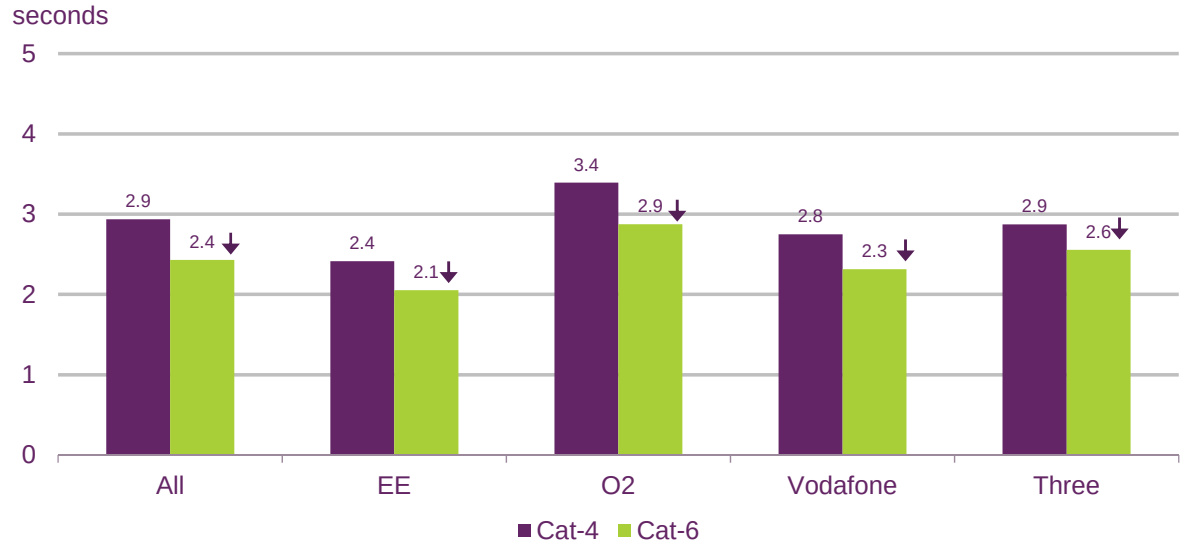
## Figure 13: Video streaming resolution on 4G




*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Proportion of all tests gathered with 4G as the best bearer. HD videos here have a resolution of 720p and SD videos have a resolution of 360p. Any differences between operators are not necessarily significantly different.*

The average time it took for the YouTube video to load across all networks on Cat-6 handsets was 2.4 seconds, which is significantly less than the time it took on Cat-4 handsets. All networks saw a decrease in the time it took for the YouTube video to load.

## Figure 14: Average time to first picture on 4G

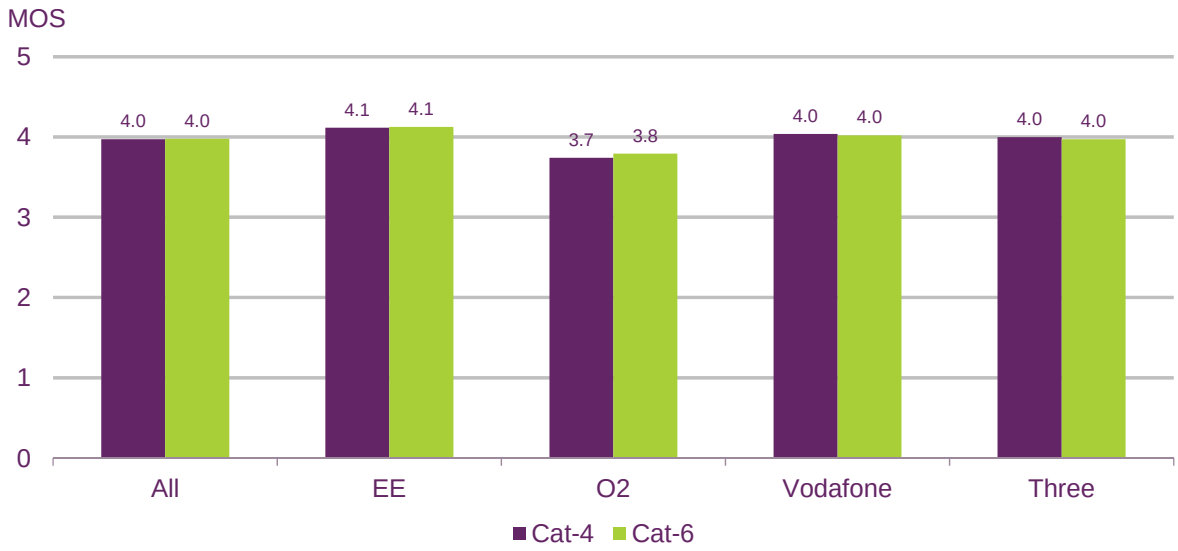



*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average (mean) of all tests gathered with 4G as the best bearer.*
*Significance testing shows any difference between Cat-4 and Cat-6 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

For the YouTube streaming test, we also calculated the video quality score called a mean opinion score ("MOS")[9] for each network on both Cat-4 and Cat-6 devices. This score aggregates the results of a range of test results for YouTube streaming and presents an overall quality score on a scale of one (bad) to five (good).

The average MOS across all networks on both handsets was 4.

**Figure 16: Average YouTube streaming quality on 4G**




*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average of all tests gathered with 4G as the best bearer. 'MOS' stands for mean opinion score with scores ranging from 1 (bad) to 5 (excellent). Any differences between operators are not necessarily significantly different.*

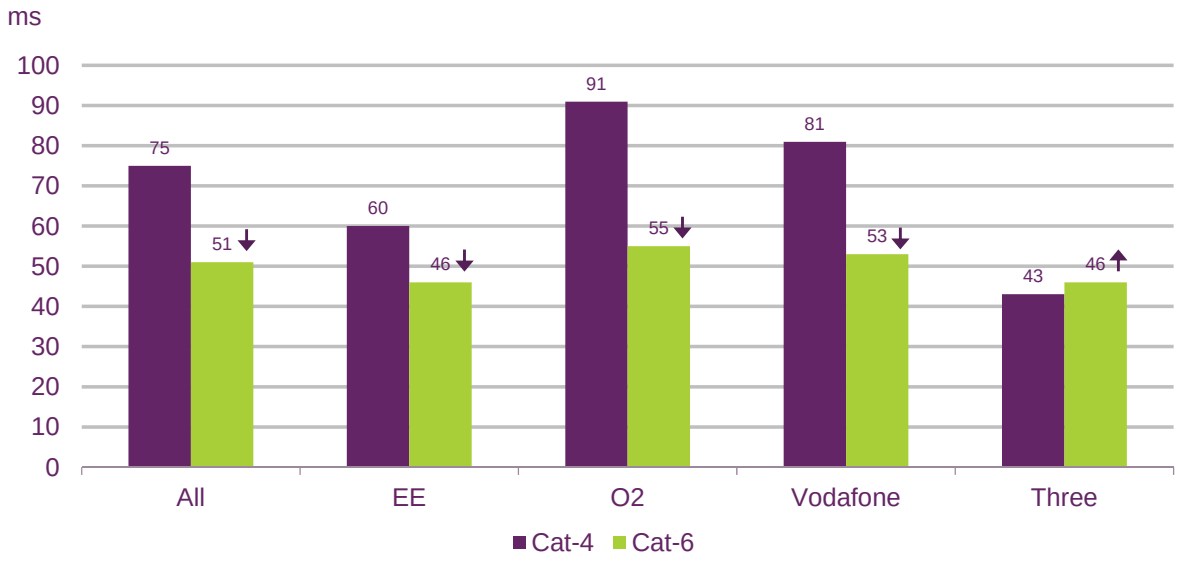
## 3.7 Response time

Response time is the delay between a consumer making a request to their mobile network for information and the network providing this information to the device. A quick response time is important for activities that require information to be delivered with a little delay as possible. In particular, the responsiveness of a network is significant when using Skype or FaceTime.

On average, the response time for all tests carried out on Cat-6 devices was significantly less than those on Cat-4 devices (51ms vs. 75ms). A similar pattern was seen across tests carried out on EE, O2 and Vodafone's networks.

[9] More information on how the MOS is calculated can be found in the technical annex of the Smartphone Cities report, found here: http://stakeholders.ofcom.org.uk/binaries/research/broadband-research/smartphone-cities/technical_annex.pdf

**Figure 18: Average 4G response time**




*Source: Ofcom mobile broadband measurements, fieldwork in London in March 2016.*
*Note: Average (median) of all 32 byte ping tests gathered with 4G as the best bearer.*
*Significance testing shows any difference between Cat-4 and Cat-6 and is indicated by arrows. Any differences between operators are not necessarily significantly different.*

## 3.8 Results summary table

The table below summarises the results across all tests.

It is important to note that the results presented below are a case-study limited to a snapshot of performance in central London over the five days of testing in March 2016 and do not reflect UK-wide performance of each MNO.

## Figure 20: results summary table

| | EE | | O2 | | Three | | Vodafone | |
|---|---|---|---|---|---|---|---|---|
| Metric | Cat-4 | Cat-6 | Cat-4 | Cat-6 | Cat-4 | Cat-6 | Cat-4 | Cat-6 |
| **Download speed** | | | | | | | | |
| Average speed | 24Mbit/s | 32Mbit/s | 7Mbit/s | 7Mbit/s | 12Mbit/s | 10Mbit/s | 19Mbit/s | 20Mbit/s |
| % over 2Mbit/s | 95% | 96% | 70% | 63% | 81% | 82% | 89% | 92% |
| **Web browsing** | | | | | | | | |
| BBC homepage load time: average | 6s | 3s | 6s | 4s | 6s | 4s | 6s | 3s |
| BBC homepage success rate | 98% | 99% | 85% | 87% | 90% | 89% | 94% | 99% |
| Standard webpage load time: average | 1.4s | 1.0s | 1.8s | 1.3s | 2.1s | 1.6s | 2.0s | 1.2s |
| Standard webpage success rate | 100% | 99% | 94% | 89% | 84% | 89% | 97% | 99% |
| **Upload speed:** average | 25Mbit/s | 24Mbit/s | 9Mbit/s | 8Mbit/s | 11Mbit/s | 12Mbit/s | 15Mbit/s | 15Mbit/s |
| **YouTube** | | | | | | | | |
| % of HD streams | 99% | 98% | 68% | 68% | 92% | 94% | 90% | 93% |
| Time to first picture: average | 2.4s | 2.1s | 3.4s | 2.9s | 2.9s | 2.6s | 2.8s | 2.3s |
| Video Quality: average MOS | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Response time:** average | 60 | 46 | 91 | 55 | 43 | 46 | 81 | 53 |

*Source: Ofcom. Note: 's' is seconds and 'ms' is milliseconds. 'MOS' stands for mean opinion score and scores range from 1 (bad) to 5 (excellent).*

Section 4

# Testing methodology

The March results presented in this annex are not directly comparable to the main testing done in November 2015 due to the evolution in our testing methodology and the geographical area tested in. This section is focused on the changes made to the testing methodology compared to the methodology used in November 2015, and thereby reported in *Smartphone Cities*[10].

## 4.2 Devices

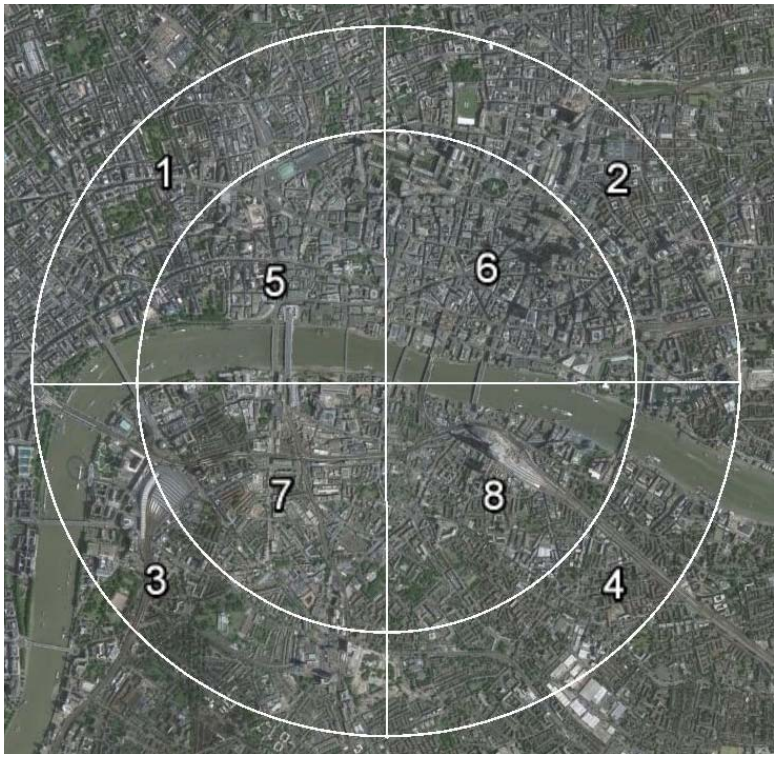
Our testing for this annex was carried out using Samsung Galaxy S5 (Model G900F) Cat-4) handsets and CA services was carried out using Samsung Galaxy S6 Edge+ (model SM-G928F) handsets (Cat-6).

## 4.3 Measurement locations

This phase of additional testing was carried out in London over a five day period in March 2016. The initial 4km radius used in the main testing was replaced with a smaller 2km radius in central London. The centre was also moved from Charing Cross station to Ofcom's head office in Riverside House for logistical reasons. This 2K radius circle was entirely within the initial 4K radius used in the main testing. The inner circle radius is 1.41 km to keep the area under each segment the same.

[10] For more information, see Smartphone Cities Technical annex: http://stakeholders.ofcom.org.uk/binaries/research/broadband-research/smartphone-cities/technical_annex.pdf

**Figure 21: London testing area**




The testing was carried out in the schedule shown in Figure 22. Overall the testing ran from 7am to 8pm. This schedule was designed to avoid the both sets of equipment hitting the same base stations at the same time, so both sets were in different segments. However, to make the data comparable, the testing was repeated in the same segment using the other set at around same time of the day but on a different date. For example Sector 7 was measured using Cat-4 devices between 7am to 11am on Day 1 and measured with Cat-6 devices between 7am to 11am on Day 3. The same route was covered as much as possible during the walk and drive tests.

**Figure 22: Testing schedule**

| Day | Team 1 | Team 2 |
|---|---|---|
| 1 | CAT 4<br>7am-11am Sector 7<br>11am-3pm Sector 3 | CAT 6<br>11am-3pm Sector 6<br>3pm-8pm Sector 2 |
| 2 | CAT 4<br>11am-3pm Sector 8<br>3pm-8pm Sector 4 | CAT 6<br>7am-11am Sector 5<br>11am-3pm Sector 1 |

| | | |
|---|---|---|
| **3** | CAT 6<br>7am-11am Sector 7<br>11am-3pm Sector 3 | CAT 4<br>11am-3pm Sector 6<br>3pm-8pm Sector 2 |
| **4** | CAT 6<br>11am-3pm Sector 8<br>3pm-8pm Sector 4 | CAT 4<br>7am-11am Sector 5<br>11am-3pm Sector 1 |
| **5** | CAT 6 Driving<br>4-3-1-2-6-8-7-5 | CAT 4 Driving<br>5-6-8-7-3-1-2-4 |

## 4.4 Testing in a fair and consistent manner

Our test methodology was designed to ensure consistency and fairness for all operators.

- Each network was tested concurrently to ensure that environmental conditions were the same for each operator
- Identical handsets were used for each network: the Samsung Galaxy S5 handsets for one team and Samsung Galaxy S6 Edge+ handsets for the other
- The handset position was rotated in the measurement equipment daily to evenly distribute the physical location of the handsets in the measurement backpacks
- The SIM cards were rotated between devices once in the middle of the week to eliminate any bias that might occur from variations in individual handset performance
- The measurement period was between 7am and 8pm each day from Monday to Thursday and the morning of Friday using the schedule in Figure 22.

## 4.5 Test schedule

The measurement schedule was set up in the order shown in the table below. The test shown in bold fonts were used for internal testing purposes and were not used included in our metrics. The difference from the main testing in November/December is that the voice call testing and Voice quality testing were removed. This may have a slight impact on the data performance as there is going to be no Circuit Switch Fall Back resulting due to shifting from Voice to Data test sessions.

| | |
|---|---|
| HTTP Download (30s) | Max test duration 30s |

| | |
|---|---|
| | Max setup time 30s |
| Ping 32 bytes (5 pings) | 100ms Interval |
| | Timeout 1s |
| | Max test duration 5s |
| **Ping 1300 bytes (5 pings)** | **100ms Interval** |
| | **Timeout 1s** |
| | **Max test duration 5s** |
| PAUSE 15s | |
| HTTP Upload (15s) | Max test duration 15s |
| | Max setup time 30s |
| PAUSE 15s | |
| HTTP Browser mKepler | Max test duration 15s |
| PAUSE 15s | |
| **HTTP Browser 'small'** | **Max test duration 15s** |
| PAUSE 15s | |
| HTTP Browser BBC | Max test duration 15s |
| PAUSE 15s | |
| YouTube | Display Duration 20s |
| | Max Duration 30s |
| | Connection timeout 25s |
| | Stream loss timeout 20s |
| PAUSE 15s | |

The 1300 byte test and the HTTP browser ‘small’ test were included for additional analysis but not published in our final report.