Ofcom
making communications work for everyone

UK Home Broadband Performance

The performance of fixed-line broadband delivered to UK residential customers

TECHNICAL REPORT:

Publication date: 13 May 2020

Contents

Section

1. Overview

Reliable, good-quality broadband connectivity is an essential part of life for most people in the UK

Growing use of data-hungry activities such as video streaming, and increased levels of home working and learning during the Covid-19 lockdown, mean the need for fast and reliable broadband has never been greater.

Ofcom's Communications Market Report 2019 shows that 80% of UK households have a home broadband connection. To understand how well these services perform, Ofcom commissioned technical partner SamKnows to set up a panel of people who connected a hardware monitoring unit to their broadband router. This enables us to measure the performance delivered by different services and assess how they vary by factors including technology, provider, package, where people live and when they use their service.

Covid-19 lockdown measurements

In addition to the analysis of home broadband performance during November 2019, this report includes measurements taken in March 2020 to assess the effect of shifting broadband use following the Covid-19 lockdown on the performance of home broadband connections. With more homeworking, children using online learning resources and greater use of streaming services, there has been a significant increase in demand on broadband networks during this period.

Broadband providers have prioritised keeping people connected during the Covid-19 lockdown, while also managing reduced staff levels, and our analysis shows that broadband performance has largely withstood the increase in demand.

Our Stay Connected campaign provides advice to help broadband and mobile users get the most from their connections as millions of families work and learn at home.

Wi-Fi performance

We have also carried out testing of router Wi-Fi performance, and the high-level findings from this testing, along with information regarding how Wi-Fi performance can be improved, can be found later in this report.

What we have found – in brief

The performance delivered by broadband providers is holding up well during the Covid-19 lockdown period. Comparing performance during the first and last weeks of March 2020 (pre-and post-lockdown) we find that average download and upload speeds fell by 2% and 1% respectively, while delay (latency) was 2% higher (worse). We did observe differences in performance across providers, with some networks suffering the effects of increased use more than others.

Connectivity to Facebook, Facebook Messenger, WhatsApp and Twitter's servers was also affected. Delay to these services' retrieval and upload servers increased between the first and last weeks in March 2020, although none of the measured differences was greater than 3%.

Average home broadband download speeds continued to increase in 2019. The average speed of UK home broadband connections increased by 18% to 64.0 Mbit/s in 2019. This was largely due to the growing availability and take-up of superfast and ultrafast full-fibre and cable services.

Take-up of faster broadband packages continues to increase. Around 75% of home broadband connections are now superfast packages with advertised download speeds of 30 Mbit/s or higher, while 2% of UK lines are ultrafast packages with advertised download speeds of 300 Mbit/s or more.

Upload speeds have increased significantly due to people migrating onto superfast and ultrafast services. Average (mean) upload speeds increased by 90% to 14.0 Mbit/s in 2019, while median speeds saw a more moderate (55%) increase. The rapid increase in upload speeds is due to growing take-up of higher-tier fibre-to-the-cabinet (FTTC) lines, upgrades to cable upload speeds and growth in take-up of full-fibre services offering very high upload speeds.

Increasing rural superfast take-up has contributed to a narrowing in the gap between urban and rural broadband performance. But although the proportion of rural lines receiving an 8-10pm peak-time speed of less than 10Mbit/s (22%) is falling, and the proportion receiving an 8-10pm speed of 30Mbit/s or higher (56%) is increasing, the average urban peak-time speed (74.6Mbit/s) was still almost double the rural average (38.5Mbit/s) in 2019.

Cable and full-fibre services recorded the highest average upload and download speeds of the services under test. Virgin Media's 362 Mbit/s cable service and BT's 300 Mbit/s full-fibre service provided the fastest average 8-10pm peak time period download speeds (344.0 Mbit/s and 298.7 Mbit/s respectively) and upload speeds (35.7 Mbit/s and 49.5 Mbit/s) of the packages included in the report.

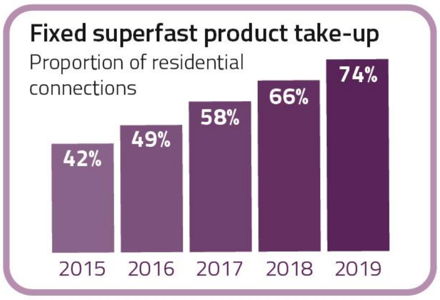
Performance varies by service and technology, but few differences exist between services that use the same wholesale input. Our research finds that people can often receive better performance by switching to a different technology or a service with a higher advertised speed. However, many broadband providers, including BT, EE, Plusnet, Sky and TalkTalk, use the same Openreach wholesale inputs, and we find few differences between services provided using the same underlying service.

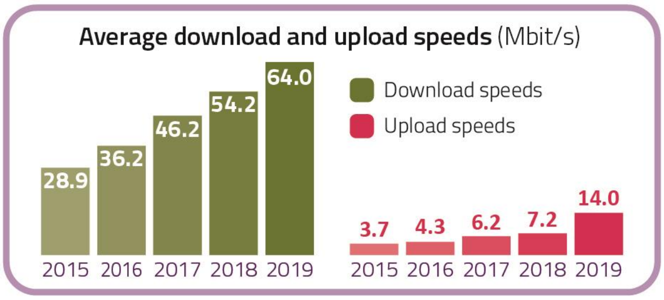
Many customers may be able to increase their Wi-Fi performance by upgrading to a new router. Our limited Wi-Fi testing shows that current routers tend to outperform older ones, so customers may be able to improve their Wi-Fi experience by upgrading to their broadband provider's latest model which, in some cases, they will be able to do free of charge.

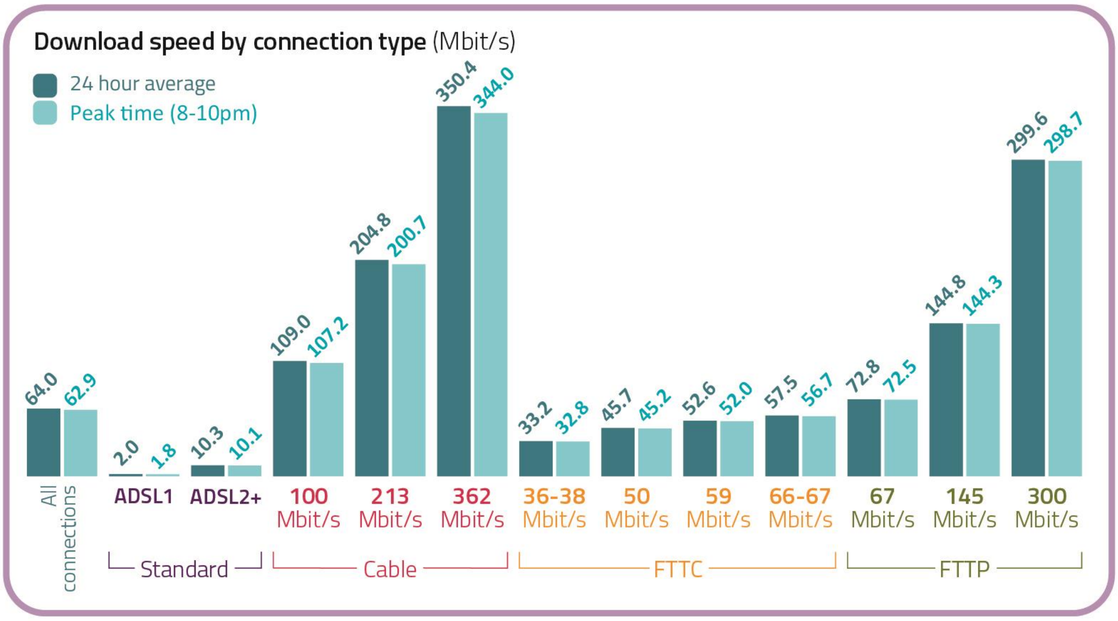
We measure the performance delivered to the customer's router. The performance delivered to connected devices varies as it is affected by several factors including Wi-Fi performance, in-house wiring, in-house contention (i.e. when more than one device is using the broadband connection), device limitations and the performance of servers delivering content over the connection.

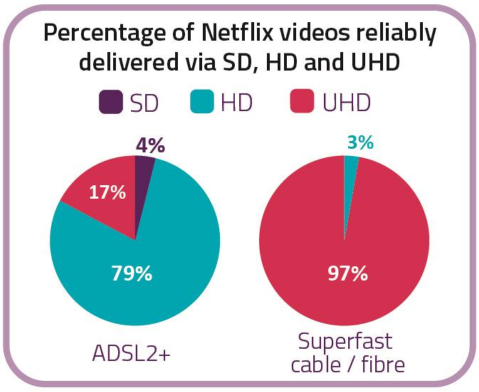
The availability of higher-speed home broadband services continues to improve. In our *Connected Nations update: Spring 2020* where we look at the availability and use of broadband services, we reported that superfast broadband services offering predicted download speeds of at least 30 Mbit/s were available to 95% of UK homes and offices by January 2020, while full-fibre services were available to 12% of premises. Analysis of the results of our testing during the November 2019 measurement period, including broadband provider package comparisons, can also be found in the interactive dashboard that accompanies this report.

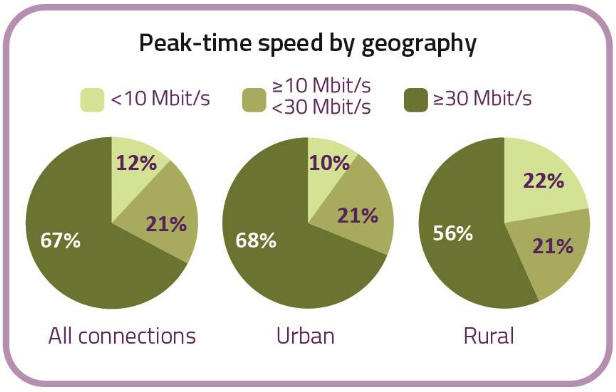
2. Dashboard


Fixed superfast product take-up
Proportion of residential connections
42%
49%
58%
66%
74%
2015
2016
2017
2018
2019


Average download and upload speeds (Mbit/s)
Download speeds
Upload speeds
28.9
36.2
46.2
54.2
64.0
2015 2016 2017 2018 2019
3.7
4.3
6.2
7.2
14.0
2015 2016 2017 2018 2019


Download speed by connection type (Mbit/s)
24 hour average
Peak time (8-10pm)
64.0
62.9
2.0
1.8
10.3
10.1
109.0
107.2
204.8
200.7
350.4
344.0
33.2
32.8
45.7
45.2
52.6
52.0
57.5
56.7
72.8
72.5
144.8
144.3
299.6
298.7
All connections
ADSL1
ADSL2+
100 Mbit/s
213 Mbit/s
362 Mbit/s
36-38 Mbit/s
50 Mbit/s
59 Mbit/s
66-67 Mbit/s
67 Mbit/s
145 Mbit/s
300 Mbit/s
Standard
Cable
FTTC
FTTP


Percentage of Netflix videos reliably delivered via SD, HD and UHD
SD
HD
UHD
4%
17%
79%
ADSL2+
3%
97%
Superfast cable / fibre


Peak-time speed by geography
<10 Mbit/s
≥10 Mbit/s <30 Mbit/s
≥30 Mbit/s
12%
21%
67%
All connections
10%
21%
68%
Urban
22%
21%
56%
Rural

3. Background

Introduction

Ofcom's principal duty under the Communications Act 2003 (the Act) is to further the interests of UK citizens and consumers, where appropriate by promoting competition. In doing so, we are required to secure several things, including the availability of a wide range of electronic communications services, including fixed broadband services.

We must also have regard to the availability and use of high-speed data services throughout the UK, the interests of consumers in respect of choice, price, quality of service and value for money and the desirability of encouraging investment and innovation in relevant markets.

The Act also requires us to make arrangements to find out about consumers' experience in their use of, and access to, electronic communications services, which we do by carrying out research. Subject to certain exceptions, we have a duty to publish the results of our research and to take account of it in carrying out our functions.

To understand the performance of UK fixed-line residential broadband connections, we commission research to measure and report on consumers' experience of using these services. Ofcom has undertaken this research since 2008, using data collected by our research partner SamKnows Limited (SamKnows) from a volunteer panel of UK residential broadband users. We believe that our methodology (see Annex 1), combined with the scale of data collection and the sophistication of the statistical analysis (see Annex 2), ensures that the research presents a robust presentation of UK fixed-line broadband performance.

However, there are other ways in which broadband performance can be measured. For example, our *Connected Nations* reports include analysis of broadband speeds based on information on the 'sync speed' or 'configured speed' of each active line, which is provided to Ofcom by broadband providers. This approach gives a measure of the maximum connection speed achieved between the broadband provider's access network and the customer's premises, which is not affected by contention and is usually slightly higher than the 'end-to-end' line speed measurements we present here.

Embedded panel tests

One of the limitations of our hardware-based measurement methodology is that we can only include packages in the research when we can recruit enough volunteer panellists for them, and this can make it difficult to include packages that do not have widespread take-up.

BT and Virgin Media have SamKnows test firmware embedded into some of their customers' routers and have agreed to allow Ofcom access to some of these test results (on an anonymised basis). We have used test results relating to BT's 67 Mbit/s, 145 Mbit/s and 300 Mbit/s fibre-to-the-premises (FTTP) service, and its 36Mbit/s FTTC package in this report, but have not used any of Virgin Media's data.

The embedded tests run on the BT routers are identical to those run on the main Ofcom panel's measurement units, with the exception of the video streaming and web page loading tests.

SamKnows has confirmed that if the tests are run on a broadband provider's router rather than on one of its 'whitebox' measurement units, this would have no discernible effect on the measured results. In addition, where the broadband providers have provided embedded test result data, we used only a subset of the data provided, in order to minimise the risk of any systematic biases arising from oversampling in certain geographic areas.

4. The effect of the Covid-19 lockdown on broadband performance in March 2020

The effect of remote working during the Covid-19 pandemic on broadband network and online service performance

On 16 March 2020, the Prime Minister delivered a statement asking UK residents to stop all unnecessary travel and start working from home where they possibly could to help slow the spread of Covid-19. This was followed by a nationwide lockdown which started on Monday 23 March 2020 and introduced stringent social distancing measures, including the closure of schools.

With the shift to home working there was a significant increase in data traffic as people turned to online voice and video calling, and the closure of schools led to growth in content streaming, online gaming, etc, as children learn and are entertained at home. These have resulted in increasing data use, particularly during the daytime. The Covid-19 lockdown made the resilience of the UK's internet infrastructure even more critical.

While most of this report looks at home broadband performance during November 2019, this section focuses on broadband performance and connectivity to a number of popular online services in March 2020, to see the effect of rapidly-changing patterns of use. By comparing measurements taken at the beginning and the end of March, we can see the effect of increased use on broadband networks, with any change in the latter half of the month likely to be due to the effects of the lockdown.

While our analysis does not include any information on average data use, this is unlikely to have constrained many people's home broadband use as a majority of services include 'unlimited' data, and a number of broadband providers with customers on capped services removed their caps temporarily in response to the Covid-19 lockdown.

Our Stay Connected campaign provides advice to help broadband and mobile users get the most from their connections as millions of families work and learn at home.

Analysis methodology

The data in this section of the report are taken from the SamKnows UK broadband measurement panel in March 2020.

The analysis includes data for eight of the UK's largest broadband providers. The results are at a provider level (and do not take speed tier into account) and each broadband provider's performance is only compared to itself.

All of the analysis uses a consistent set of 'whiteboxes' across the entire time range in the chart: if a 'whitebox' is included in the analysis, it generated results for every day in the time range and has been included throughout. Our analysis excludes panellists who had a change of 50% or more in either their upload or download speed between 1 March and 31 March (to avoid any distortions in the results caused by people who changed their broadband package as a result of the Covid-19 lockdown) and those who switched broadband provider during the month.

Summary of results

As the Covid-19 lockdown started, there were early concerns about the ability of the UK's broadband infrastructure to cope with changes in network load, as usage increased. Our analysis shows that while there was some degradation in broadband performance in the second half of March 2020, the observed differences tended to be limited.

We consider this is likely to be because broadband providers scale their networks so that they can handle capacity requirements at peak times, and while the Covid-19 lockdown resulted in significant growth in daytime data consumption, this usage was still below the level of pre-lockdown evening peak demand. For example, on 20 March 2020 BT issued a news release which said that while there had been a 35-60% increase in weekday broadband traffic on its network since the Prime Minister's 16 March 2020 statement (up from 5 Tbit/s to a peak of 7.5 Tbit/s), daytime traffic volumes were still much lower than the highest ever recorded volume on its network (17.5 Tbit/s).

The impact of network congestion on the performance of cable services is greater than the impact on other superfast broadband technologies, as is reflected elsewhere in this report. This is due to cable network topologies, which mean that network congestion occurs closer to the customer, making it more difficult to add the additional capacity required to alleviate the effects of congestion.

As such, Virgin Media's (predominantly cable) network generally suffered a greater decline in performance during the second half of the month than other broadband providers' networks. However, the peak-time download speeds provided by most of Virgin Media's cable services are still higher than those offered over FTTC, which is used by most UK home broadband connections.

As well as the Covid-19 lockdown, there were two other notable events which affected broadband data consumption in March 2020. The first was the release of a 50GB+ update to the videogame *Call of Duty: Modern Warfare* on 10 March 2020, and the second was Netflix reducing the bitrates of its video streaming service across Europe from 23 March 2020 in order to reduce the pressure on broadband networks during a near Europe-wide lockdown.

Our findings are summarised below.

Average download speeds fell in the latter half of March as the UK entered lockdown

4.1 The average download speed across the broadband providers included in the analysis declined during March 2020. We consider this is likely to be the result of contention due to increased network use as the UK entered lockdown.

4.2 On average, download speeds during the last week of the month (23 to 29 March 2020) were 2% lower than those in the first week (2 to 8 March 2020).

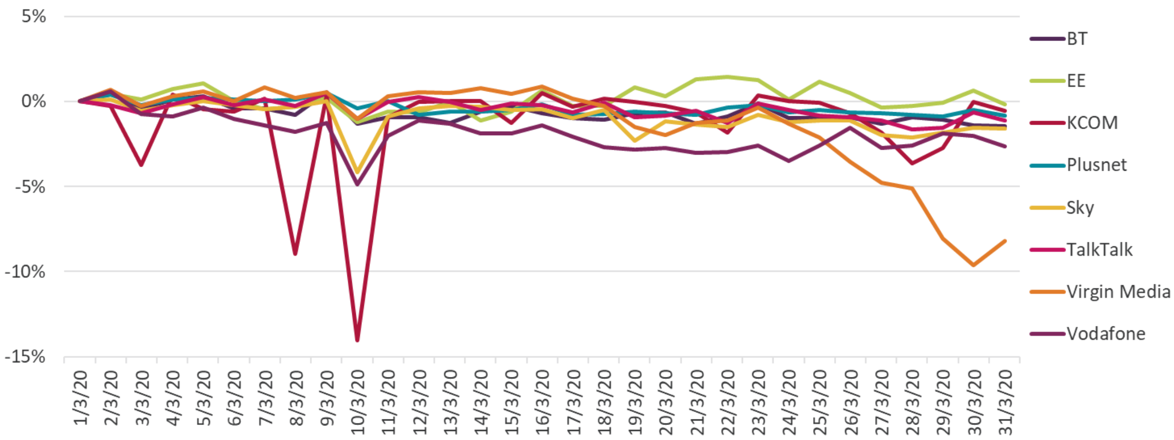
4.3 There were marked differences in the effect of lockdown on network performance across broadband providers, with Virgin Media's average download speeds dropping by almost 10% compared to 1 March 2020 at one point during the month (although the higher speeds delivered by its services make it unlikely that many customers' user-experience would be impacted).

4.4 Conversely, BT-owned EE's average download speeds showing some increases compared to 1 March 2020 as the month progressed.

4.5 KCOM experienced issues with network slowdown on several days in the first half of the month, the largest of which (a 14% fall) coincided with the release of the *Call of Duty: Modern Warfare* update on 10 March 2020. Sky and TalkTalk also suffered from a notable slowing of average download speeds on this date.

4.6 Almost all broadband providers saw a fall in the rate at which download speeds were declining on 23 March 2020, when Netflix started to reduce the streaming quality of its video content, a move that was aimed at reducing the pressure on broadband networks.

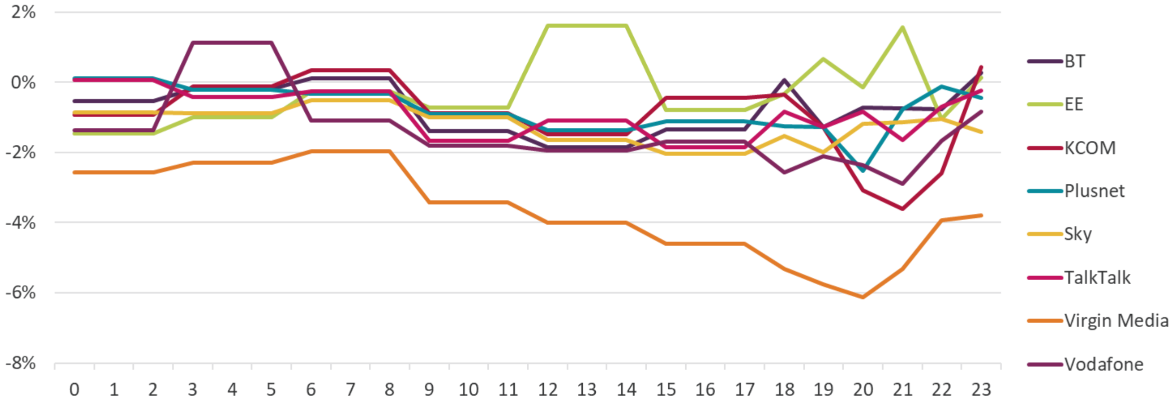
Figure 1: Change in broadband providers' average download speeds in March 2020 (higher is better)



Source: Ofcom, using data provided by SamKnows

Notes: Graph shows the percentage change since 1 March 2020; higher values are better; results are derived from tests to SamKnows' off-net London servers using 3 parallel TCP sessions for 10 seconds; results cover all hours of the day (and not just peak times).

Figure 2: Change in broadband providers' average hourly download speeds in March 2020 (higher is better)



Source: Ofcom, using data provided by SamKnows
Notes: Graph shows the percentage change between w/c 2 March 2020 and w/c 23 March 2020; higher values are better; results are derived from tests to SamKnows' off-net London servers using 3 parallel TCP sessions for 10 seconds.

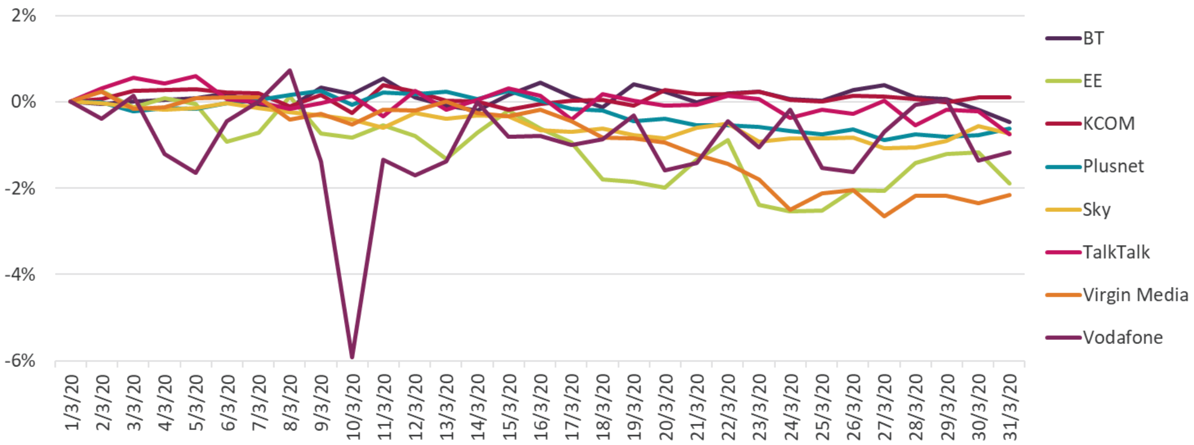
Average upload speeds fell in the latter half of March

4.7 Similar to download speeds, average upload speeds across the broadband providers included in the analysis fell slightly over the course of March 2020, although the decline was less noticeable. On average, upload speeds during the last week of March 2020 were 1% lower than those in the first week of the month.

4.8 Differences in performance between providers were also less marked than for download speeds, with only EE and Virgin Media's average upload speeds falling by more than 2% compared to 1 March 2020 at any point during the second half of the month. Vodafone experienced a fall in upload speeds on 10 March 2020, the date of the *Call of Duty* update.

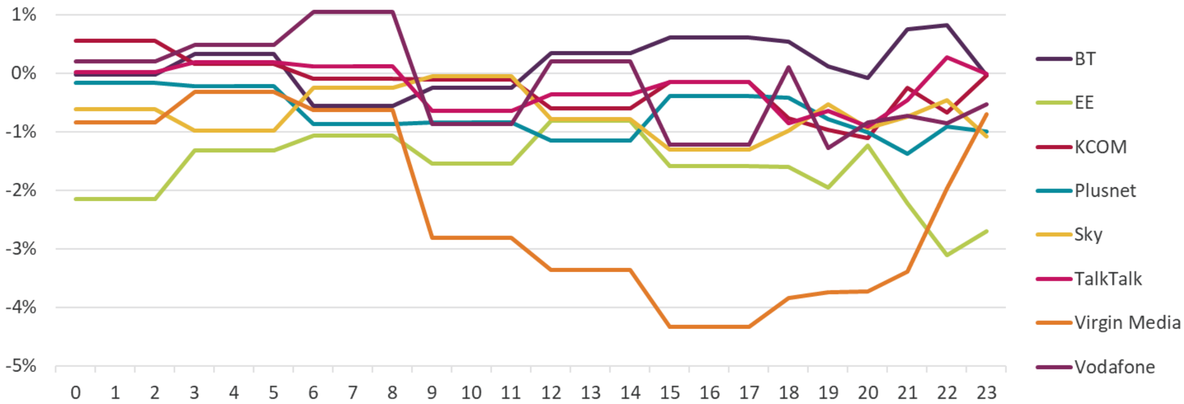
4.9 Given the latency levels shown elsewhere in the report, the observed increases are unlikely to have been noticeable to most home broadband users.

Figure 3: Change in broadband providers' average upload speeds in March 2020 (higher is better)



Source: Ofcom, using data provided by SamKnows
Notes: Graph shows the percentage change since 1 March 2020; higher values are better; results are derived from tests to SamKnows' off-net London servers using 3 parallel TCP sessions for 10 seconds; results cover all hours of the day (and not just peak times).

Figure 4: Change in broadband providers' average hourly upload speeds in March 2020 (higher is better)



Source: Ofcom, using data provided by SamKnows
Notes: Graph shows the percentage change between w/c 2 March 2020 and w/c 23 March 2020; higher values are better; results are derived from tests to SamKnows' off-net London servers using 3 parallel TCP sessions for 10 seconds.

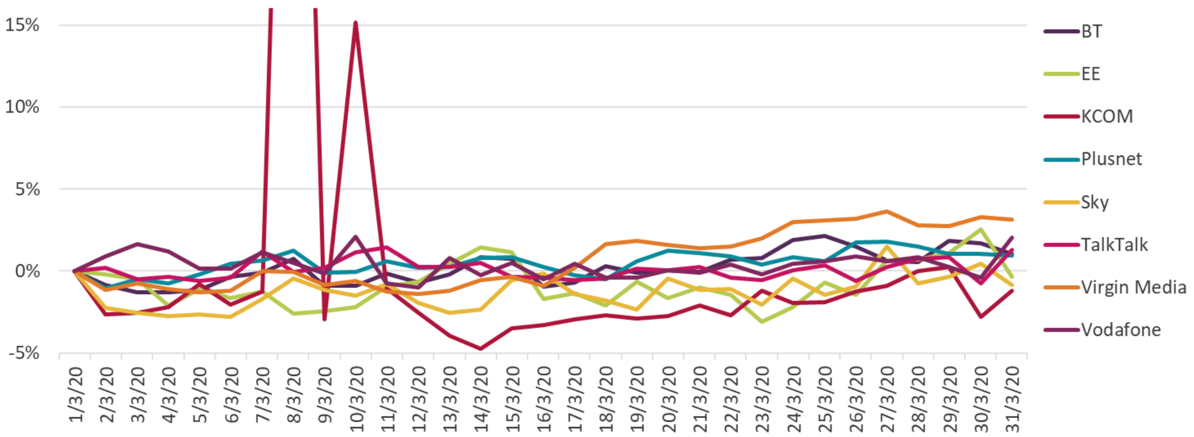
Most broadband providers saw an increase (degradation) in network latency during March 2020

4.10 A connection with low latency will feel more responsive for simple tasks like web browsing, and certain applications perform far better with lower latency.

4.11 Average latency across the broadband providers included in the analysis increased by 2% between the first and last weeks of March 2020, indicating a decline in performance. All but two broadband providers (Vodafone and EE) saw their latency increase during this period, with these increases ranging from less than 0.1% for EE to 3.8% for Virgin Media.

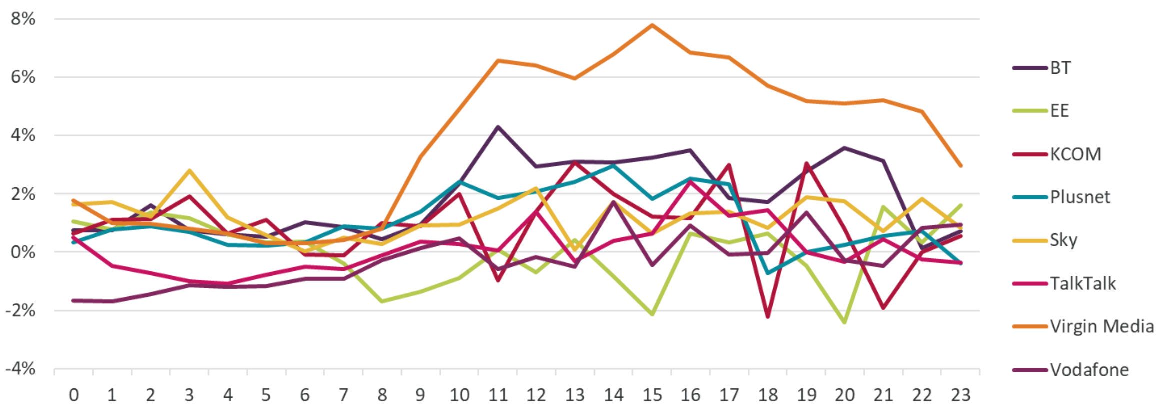
4.12 This is in line with what we would expect to see, given the greater pressure that broadband providers' networks were under following the introduction of lockdown measures in the latter half of the month.

Figure 5: Change in broadband providers' average latency in March 2020 (lower is better)



Source: Ofcom, using data provided by SamKnows
Notes: Graph shows the percentage change since 1 March 2020; lower values are better; results are derived from tests to SamKnows' off-net London servers using the hourly UDP latency test; results cover all hours of the day (and not just peak times).

Figure 6: Change in broadband providers' average hourly latency in March 2020 (lower is better)



Source: Ofcom, using data provided by SamKnows
Notes: Graph shows the percentage change between w/c 2 March 2020 and w/c 23 March 2020; lower values are better; results are derived from tests to SamKnows' off-net London servers using the hourly UDP latency test.

Netflix download speeds decreased for most of the broadband providers included in our analysis during March

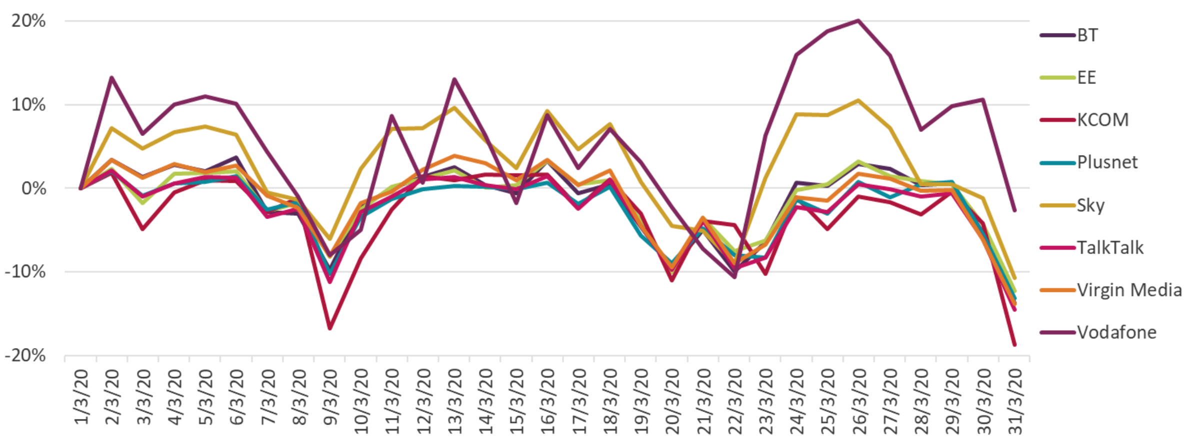
4.13 On average, Netflix download speeds were 3% lower in the last week of March 2020 than in the first week; however, while Netflix download speeds were an average of 4% lower between midnight and 6pm in week 4 than in week 1, average speeds between 6pm and 12am were 1% higher.

4.14 This can be explained by two factors: Netflix reducing video streaming bitrates in Europe from 23 March 2020 to help cope with increased network demand; and the closure of schools.

4.15 The Netflix streaming bitrate reduction had the effect of reducing the volume of data used by Netflix streaming. During the evening (typically the peak time for Netflix use) download speeds improved because any increase in use due to the Covid-19 lockdown only partially offset the impact of the bitrate reduction.

4.16 The schools closure meant that the increase in use between week 1 and week 4 was much greater during the daytime than the evening, and daytime performance declined because the impact of the bitrate reduction on download speeds was not sufficient to offset the effect of this increase during this period.

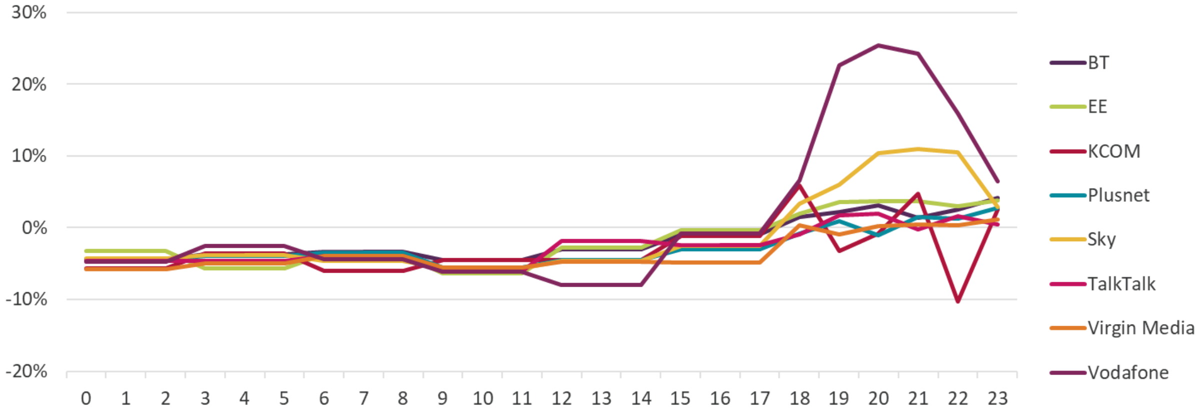
Figure 7: Change in broadband providers' average Netflix download speeds in March 2020 (higher is better)



Source: Ofcom, using data provided by SamKnows

Notes: Graph shows the percentage change since 1 March 2020; higher values are better; results are derived from the Netflix video streaming tests; results cover all hours of the day (and not just peak times).

Figure 8: Change in broadband providers' average hourly Netflix download speeds in March 2020 (higher is better)



Source: Ofcom, using data provided by SamKnows
Notes: Graph shows the percentage change since 1 March 2020; higher values are better; results are derived from the Netflix video streaming tests.

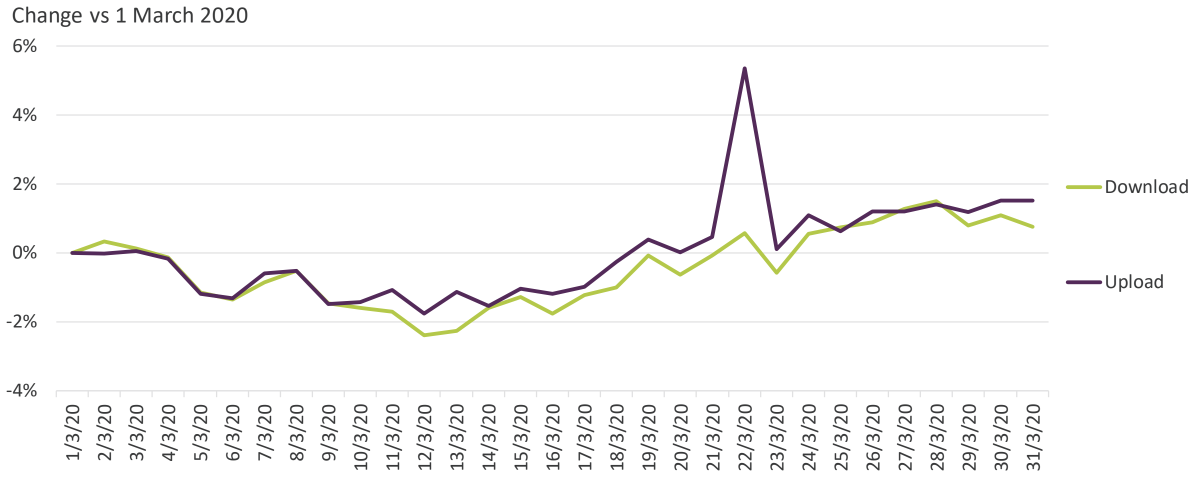
Latency to Facebook's servers

4.17 The quality of service delivered to broadband users is affected by both the performance of the broadband provider providing the internet connection to the home and the performance of the data centres and content delivery networks linked to the content provider.

4.18 To investigate this, we have analysed the latency of Facebook and Twitter content served to three broadband providers' panellists across the month of March 2020. Lower latency represents better performance.

4.19 A spike in latency to Facebook's datacentres was observed on 22 March 2020; this affected connectivity to Facebook, Facebook Messenger and WhatsApp. On average, latency to Facebook's content retrieval servers was 1% higher in the last week of March than the first week, while latency to its content upload servers was 2% higher.

Figure 9: Change in broadband providers' average latency to Facebook in March 2020 (lower is better)



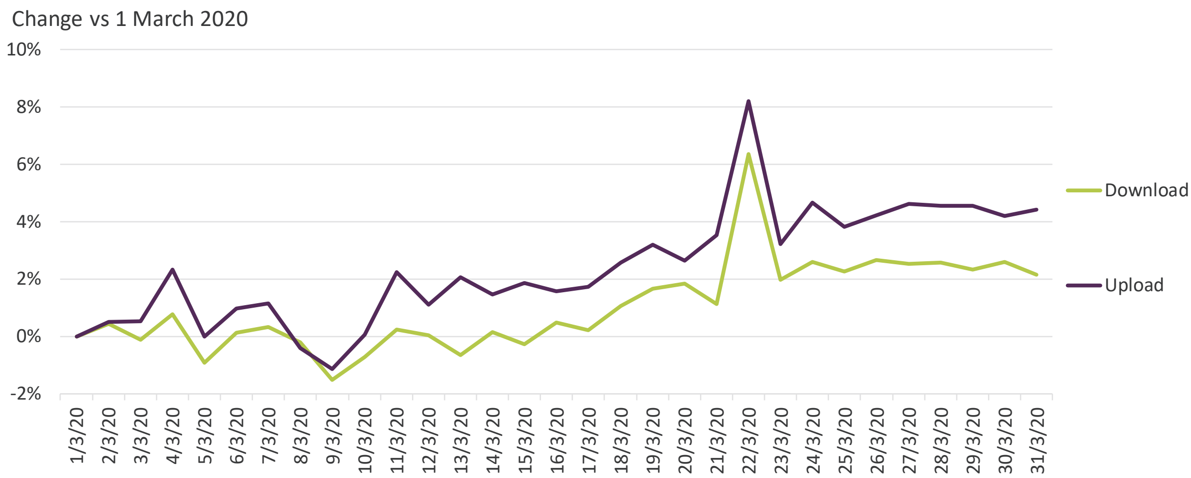
Source: Ofcom, using data provided by SamKnows
Notes: Latency to Facebook's servers; graph shows the percentage change since 1 March 2020; lower values are better; results cover all hours of the day (and not just peak times).

Latency to Facebook Messenger's servers

4.20 There was a spike in latency to Facebook's datacentres on 22 March 2020 which affected connectivity to Facebook, Facebook Messenger and WhatsApp.

4.21 Latency to Facebook Messenger's content retrieval servers was, on average, 2% higher in the last week of March 2020 than in the first week, while latency to its content upload servers was 3% higher.

Figure 10: Change in broadband providers' average latency to Facebook Messenger in March 2020 (lower is better)



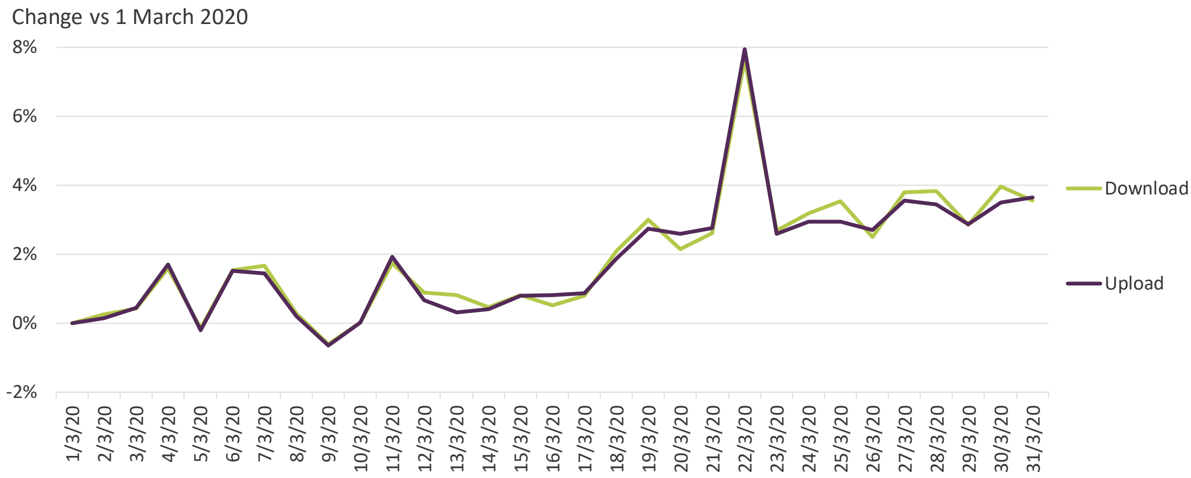
Source: Ofcom, using data provided by SamKnows
Notes: Latency to Facebook Messenger's servers; graph shows the percentage change since 1 March 2020; lower values are better; results cover all hours of the day (not just peak times).

Latency to WhatsApp's servers

4.22 A spike in latency to Facebook's datacentres on 22 March 2020 affected all broadband providers' connectivity to Facebook, Facebook Messenger and WhatsApp.

4.23 Latency to both WhatsApp's content retrieval and upload servers were, on average, 2% higher in the last week of March 2020 than in the first week.

Figure 11: Change in broadband providers' average latency to WhatsApp in March 2020 (lower is better)



Source: Ofcom, using data provided by SamKnows
Notes: Latency to WhatsApp's servers; graph shows the percentage change since 1 March 2020; lower values are better; results cover all hours of the day (and not just peak times).

Latency to Twitter's servers

4.24 On average, latency to both Twitter's content retrieval and upload servers were 1% higher in the last week of March 2020 than in the first week.

Figure 12: Change in broadband providers' average latency to Twitter in March 2020 (lower is better)

Source: Ofcom, using data provided by SamKnows
Notes: Latency to Twitter's servers; graph shows the percentage change since 1 March 2020; lower values are better; results cover all hours of the day (not just peak times).

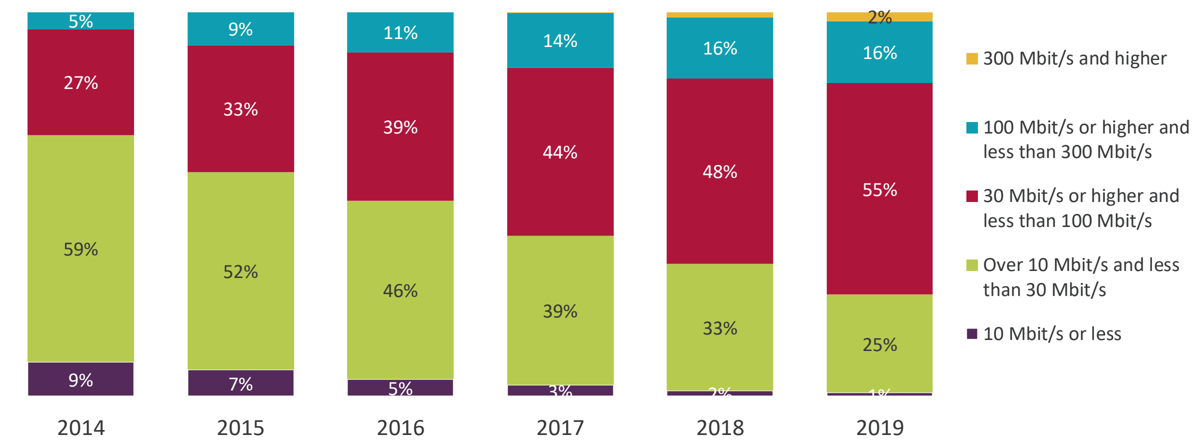
5. November 2019: download speeds

Around three-quarters of home broadband connections were superfast products in November 2019

5.1 Broadband provider data shows that just under three-quarters (74%) of UK home broadband connections were superfast products with an advertised speed of 30 Mbit/s or higher in November 2019.

5.2 Two per cent were ultrafast products with advertised speeds of 300 Mbit/s or higher, up from 1% a year earlier.

Figure 13: UK residential broadband lines, by advertised speed: 2014 to 2019



Source: Ofcom / operators; see note [1] in the Sources section.
Note: The proportion of lines with an advertised speed of 300Mbit/s or higher in 2019 shown here (2.3%) is slightly lower than the proportion receiving average 24-hour speeds of 300Mbit/s in Figure 15 (2.6%) due to the composition of our panel, and this difference is not material.

Average home broadband download speeds were over 60 Mbit/s in 2019

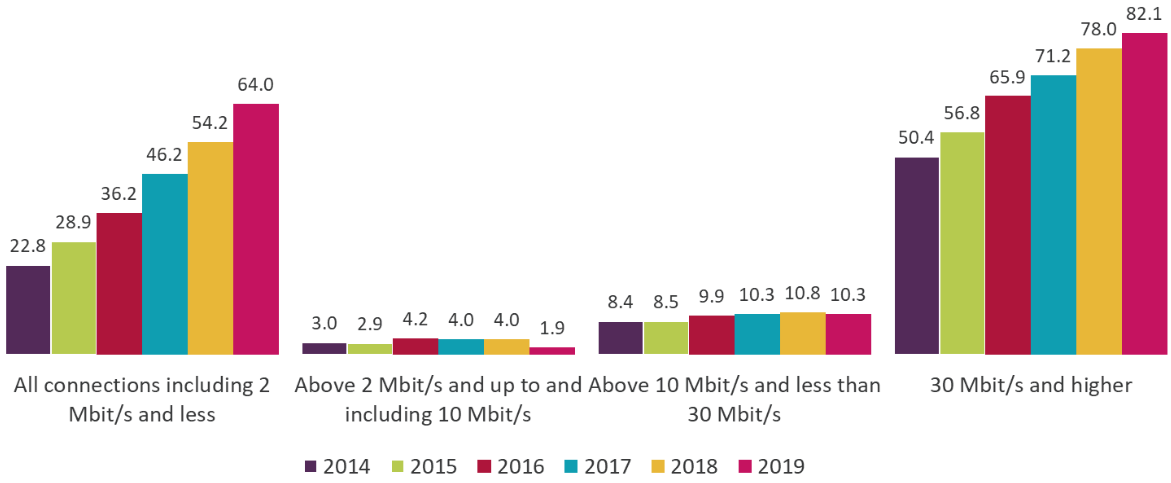
5.3 The average actual speed of UK residential fixed broadband services recorded over the 24-hour period increased by 9.8 Mbit/s to 64.0 Mbit/s in 2019.

5.4 This was higher than the 8.1 Mbit/s (18%) increase recorded in 2018, although the rate of increase was unchanged at 18%.

5.5 The average download speed of connections with an advertised speed of less than 10Mbit/s fell by 2.1 Mbit/s to 1.9 Mbit/s. The proportion of lines that had an advertised speed of less than 10Mbit/s fell to 1% during the year, and we consider it is likely that the deterioration in performance recorded is due to people with better connections upgrading to higher speed packages.

5.6 The rate at which average download speeds for superfast products (those with an advertised speed of 30Mbit/s or higher) is increasing has slowed, which we consider is probably because of limitations in the performance of fibre-to-the-cabinet (FTTC), which makes up most of these connections.

Figure 14: Average actual broadband speeds: 2014 to 2019 (Mbit/s)



Source: Ofcom, using data provided by SamKnows; see note [2] in the Sources section.

Around 70% of residential broadband lines had an average download speed of 30 Mbit/s or higher

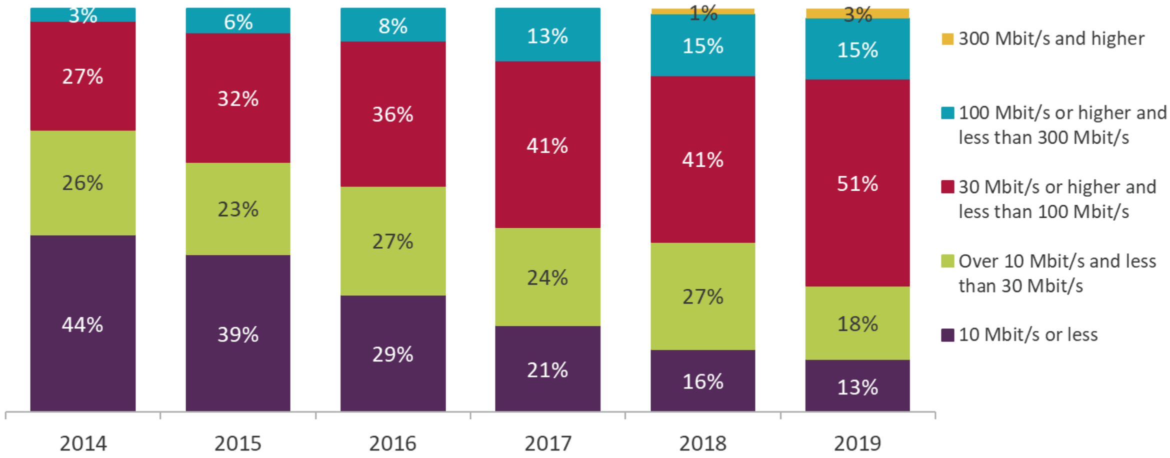
5.7 We define broadband connections as superfast if download speeds are 30Mbit/s or higher. Our research suggests that 69% of residential broadband lines had a 24-hour average download speed of 30 Mbit/s or higher in 2019, up from 58% in 2018.

5.8 The proportion of lines receiving an average download speed of 10 Mbit/s or less fell by three percentage points to 13% in 2019

5.9 The proportion of lines receiving an average download speed of 100Mbit/s was slightly higher in 2019 at 17%, a one percent increase since 2018.

5.10 We define broadband connections as ultrafast if download speeds are 300Mbit/s or higher. Three per cent of lines had an average 24-hour download speed of 300 Mbit/s or higher, up from 2% a year earlier.

Figure 15: Distribution of average 24-hour download speeds: 2014 to 2019 (Mbit/s)



Source: Ofcom, using data provided by SamKnows; see note [2] in the Sources section.
Note: The proportion of lines with an advertised speed of 300Mbit/s or higher in 2019 shown in Figure 13 (2.3%) is slightly lower than the proportion receiving average 24-hour speeds of 300Mbit/s shown here (2.6%) due to the composition of our panel, and this difference is not material.

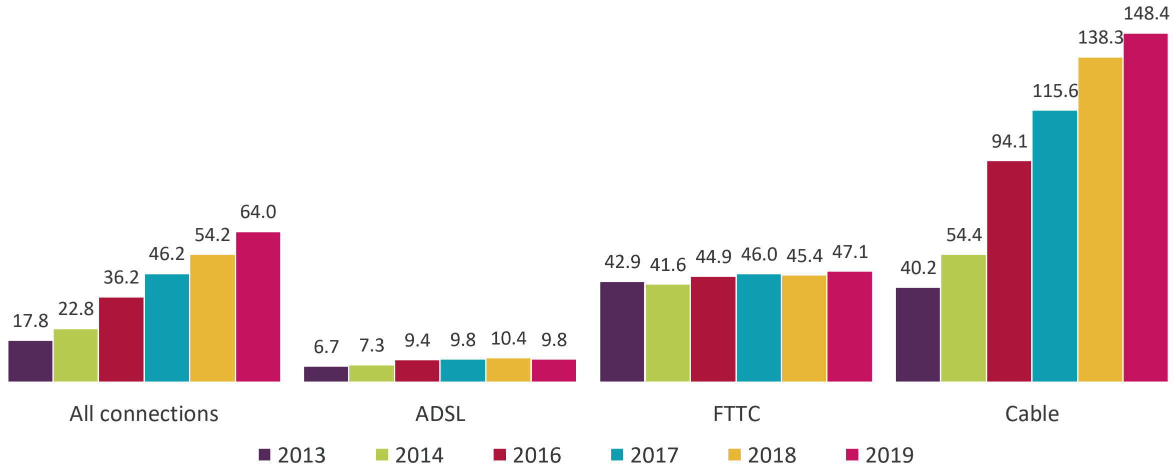
Full fibre and cable connections continue to have the fastest average speeds

5.11 Our analysis indicates a slight increase in the average download speed of cable connections in 2019, up by 10.1 Mbit/s (7%) to 148.4 Mbit/s.

5.12 There was also a small increase in the average download speed delivered by FTTC connections, up by 1.7Mbit/s (4%) to 47.1 Mbit/s. This is largely due to a migration to higher speed packages in 2019.

5.13 Download speeds for standard broadband connections delivered over asymmetric digital subscriber line (ADSL) decreased from 10.4Mbit/s to 9.8Mbit/s. We consider this is likely to be related to people with better quality lines upgrading to superfast services.

Figure 16: Average download speeds for fixed broadband connections, all connections including 2 Mbit/s and lower, by technology (Mbit/s)



Source: Ofcom, using data provided by SamKnows; see note [3] in the Sources section.

Longer line lengths in rural areas result in lower average speeds for both ADSL and FTTC connections

5.14 A characteristic of the copper technologies used to deliver ADSL and FTTC broadband is that speeds slow down due to attenuation over the length of the copper over which data travels.

5.15 With ADSL, data travels over copper all the way from the local exchange to the end-user's premises, whereas with FTTC copper is only used from the street cabinet to the end-user.

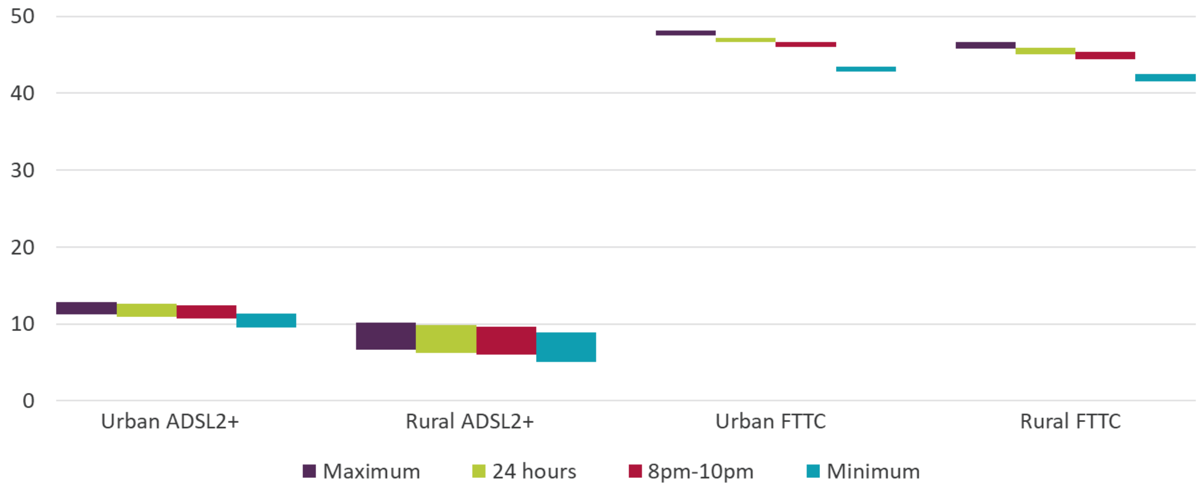
5.16 As ADSL and FTTC copper lines tend to be shorter in urban areas than in rural ones (where population density is lower), urban lines tend to perform better than those in rural areas.

5.17 For second-generation ADSL (ADSL2+) connections, this resulted in the average 24-hour download speed in urban areas (11.7 Mbit/s) being 36% higher than the average in rural areas (8.1 Mbit/s).

5.18 There is less variation in the length of copper line from the street cabinet to the user's premises and therefore less variance in performance. We found a smaller (3%) difference in FTTC download speeds in rural areas (45.5 Mbit/s) compared to those in urban areas (46.9 Mbit/s).

5.19 Average FTTC download speeds were over five times faster than ADSL average download speeds in rural areas in 2019, and most rural ADSL customers who upgrade to FTTC will experience a significant increase in performance.

Figure 17: Average ADSL and FTTC download speeds, by rurality: 2019 (Mbit/s)



Source: Ofcom, using data provided by SamKnows; see note [4] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all customers (i.e. not just the customer panellists within our sample) falls within the ranges shown; it is not possible to make direct comparisons between this data and figures published in previous reports due to panel composition differences and a change in the weighting methodology used for this analysis.

The gap between urban and rural broadband performance is narrowing

5.20 Ofcom's *Connected Nations update: Spring 2020* shows that superfast broadband services were available to 98% of urban premises in January 2020, compared to 80% in rural areas.

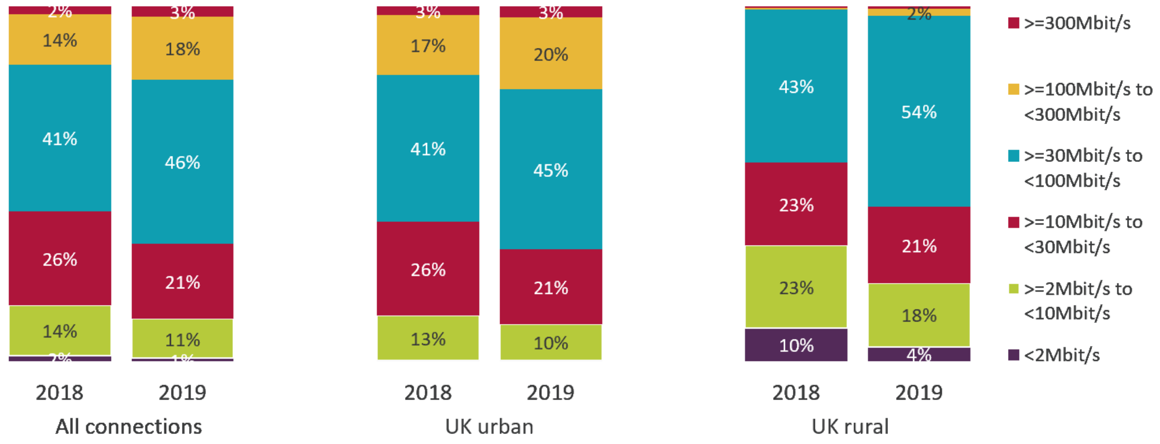
5.21 As the availability and take-up of superfast services are increasing in rural areas, the gap between average urban and rural home broadband performance is narrowing.

5.22 Our research shows that there was an 11 percentage point (pp) difference between the proportion of urban (11%) and rural (22%) broadband lines with an average 8-10pm peak-time actual download speed of less than 10 Mbit/s in 2019, down from 20pp in 2018.

5.23 Similarly the 12pp difference between the proportion of urban (68%) and rural (56%) lines with an average evening peak-time speed of 30Mbit/s or higher was lower than the 16pp figure for 2018.

5.24 However, while our research shows that the difference between average urban and rural peak-time download speeds is getting smaller, average peak-time download speeds in urban areas (74.6 Mbit/s) were almost double those in rural areas (38.5Mbit/s) in 2019.

Figure 18: Distribution of average peak-time, 8-10pm, fixed broadband download speeds, by rurality: 2019 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [5] in the Sources section.

Around one-fifth of rural broadband lines receive download speeds of 10 Mbit/s or less

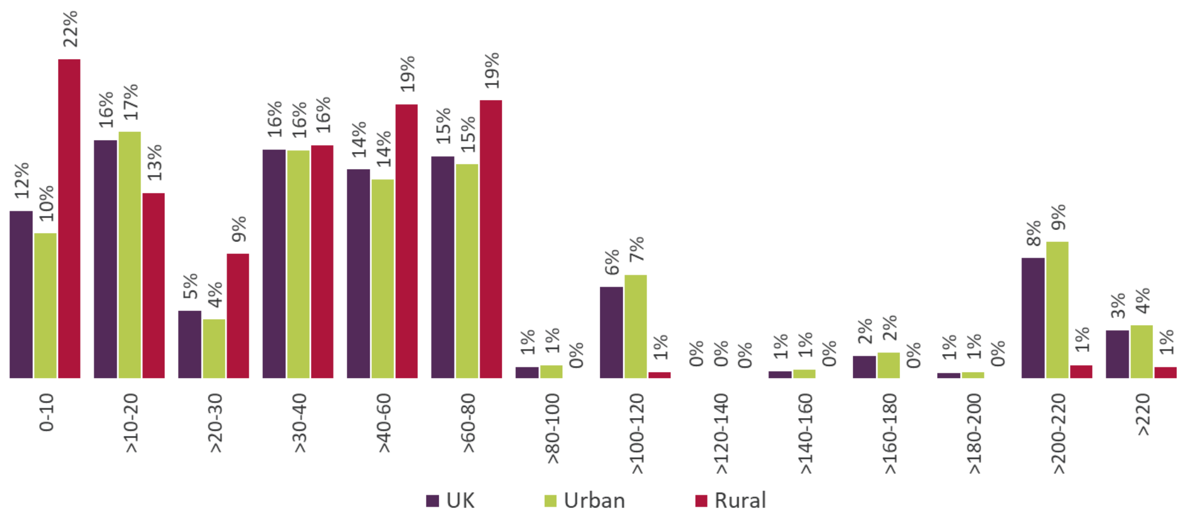
5.25 We consider the actual download speed that is necessary for a decent broadband service (i.e. one which enables full participation in a digital society) to be 10 Mbit/s.

5.26 Our research shows that in November 2019 over one-fifth (22%) of panellists in rural areas of the UK received an average 24-hour download speed of less than this.

5.27 This proportion was higher than for the UK as a whole (12%) and the proportion in urban areas (10%).

5.28 However, many rural and urban customers may be able to achieve higher speeds by switching to fibre or cable services.

Figure 19: Distribution of average peak-time, 8-10pm, fixed broadband download speeds, by rurality: 2019 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [5] in the Sources section.
Note: It is not possible to make direct comparisons between this data and figures published in previous reports due to panel composition differences and a change in the weighting methodology used for this analysis.

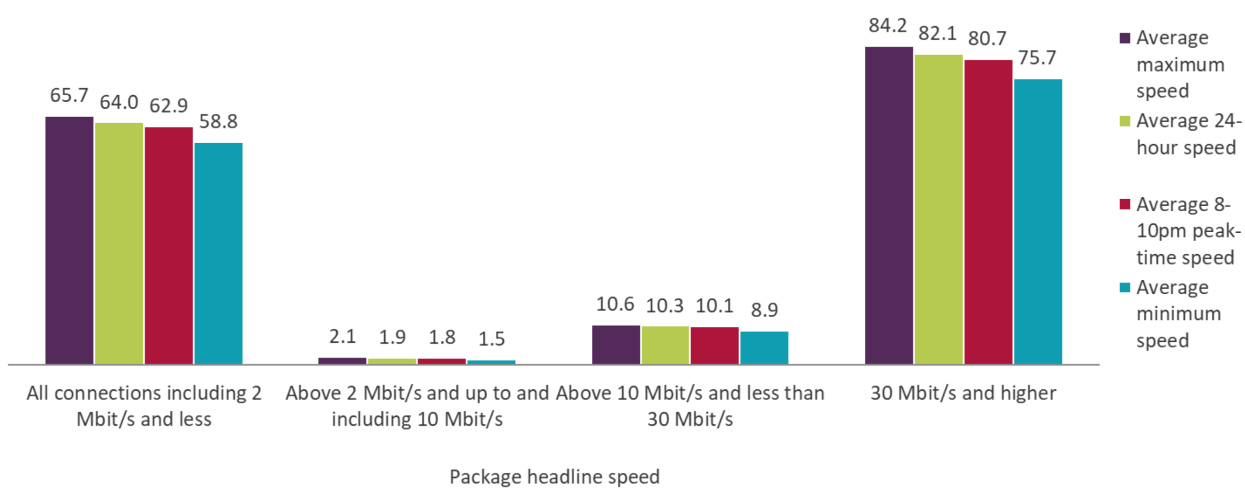
Download speeds vary slightly throughout the day

5.29 The performance of broadband services varies by time of day, with speeds slowing down during busy periods when network traffic volumes are highest.

5.30 Across all connections the average daily minimum speed (58.8 Mbit/s) was 90% of the average maximum speed (65.7 Mbit/s).

5.31 The average download speed recorded during the 8-10pm peak time period was 62.9 Mbit/s, 96% of the average maximum speed.

Figure 20: Average UK broadband speeds, by time of day: 2019 (Mbit/s)



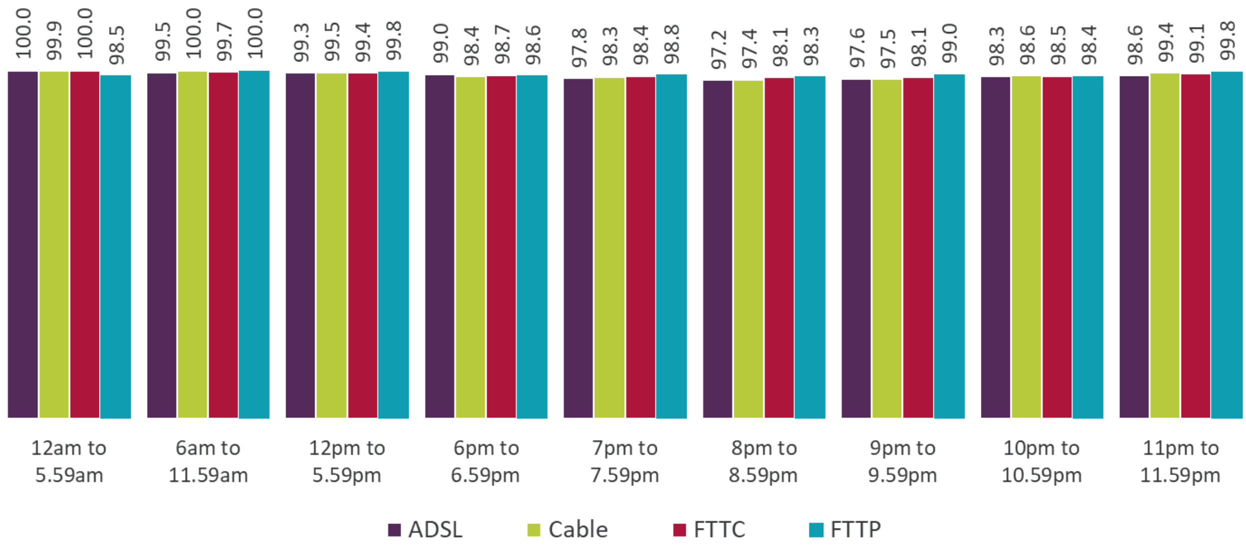
Source: Ofcom, using data provided by SamKnows; see note [2] in the Sources section.

Broadband speeds are likely to be lowest at 7-10pm

5.32 Our research shows that all technologies recorded their lowest average speeds between 7pm and 9.59pm.

5.33 FTTP packages had the least slowdown at busy times; the average download speed between 8pm and 8.59pm was 98.3% of the highest speed recorded between 12am and 5.59am.

Figure 21: Proportion of maximum speed delivered through the day: 2019 (%)



Source: Ofcom, using data provided by SamKnows; see note [6] in the Sources section.
Note: FTTP figures are weighted averages based on figures for BT's 67Mbit/s, 145Mbit/s and 300Mbit/s FTTP services and KCOM's 75Mbit/s service.

FTTP connections have the least variation in performance

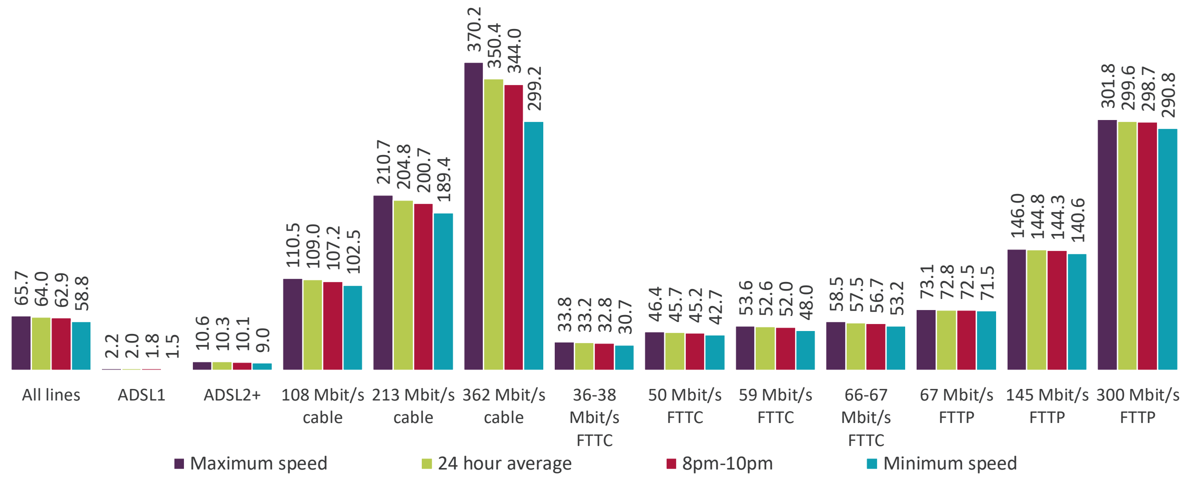
5.34 Our research shows that 24-hour, peak-time and minimum download speeds were lower than average maximum speeds for all connection types in 2019.

5.35 There are two main reasons why home broadband connections do not always provide their headline (advertised) speed throughout the day:

- For copper-based technologies such as ADSL and FTTC, the maximum speed that a line can support is dependent on the length and quality of the line from the end-user's home to the local exchange (for ADSL) or street cabinet (for FTTC) – lines to some premises will never support the service's advertised speed (although under the Voluntary Code of Practice for broadband speeds, broadband providers must provide an estimate of the speed that the line can support, before purchase).
- The actual speeds of all connection types tend to fall when broadband providers' networks are busy. The variation in speeds at peak times tends to be higher for cable connections, due to network congestion occurring nearer to the customer,

making it harder to add the additional capacity required to reduce the effects of congestion.

Figure 22: Variations in download speeds, by time of day: November 2019 (Mbit/s)



Source: Ofcom, using data provided by SamKnows; see note [7] in the Sources section.

Contention varies by network technology

5.36 We measure network slowdown during busy periods (contention) by comparing broadband provider packages' average minimum and maximum speeds, our assumption being that the primary reason for any differences between the two is network congestion.

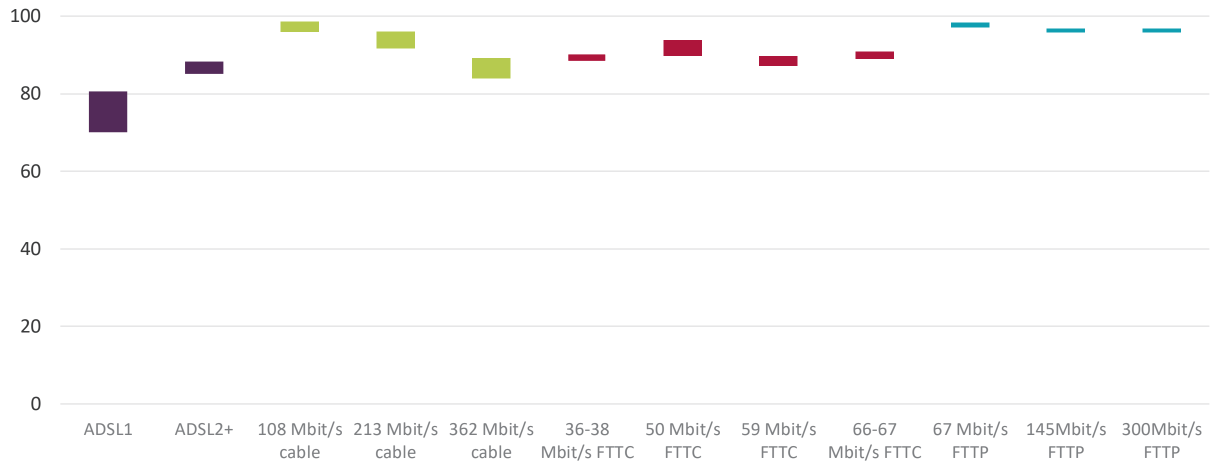
5.37 For 54 Mbit/s, 108 Mbit/s 213 Mbit/s and 362 Mbit/s cable services, minimum download speeds were between 87% and 97% of maximum speeds.

5.38 For 36 Mbit/s, 50 Mbit/s, 59 Mbit/s and 66-67Mbit/s FTTC services, average minimum download speeds were between 88% and 92% of their average maximum download speeds.

5.39 Among the FTTP packages included in the research, minimum speeds were between 96% and 98% of the maximum speeds.

5.40 For ADSL2+ services, minimum download speeds were 87% of maximum speeds, while for ADSL1 the figure was 75%.

Figure 23: Minimum speed as proportion of maximum speed: 2019 (%)



Source: Ofcom, using data provided by SamKnows; see note [8] in the Sources section.
Note: The chart bars show that there is a 95% probability that the actual average speed for all customers (i.e. not just the customer panellists in our sample) falls within the ranges shown.

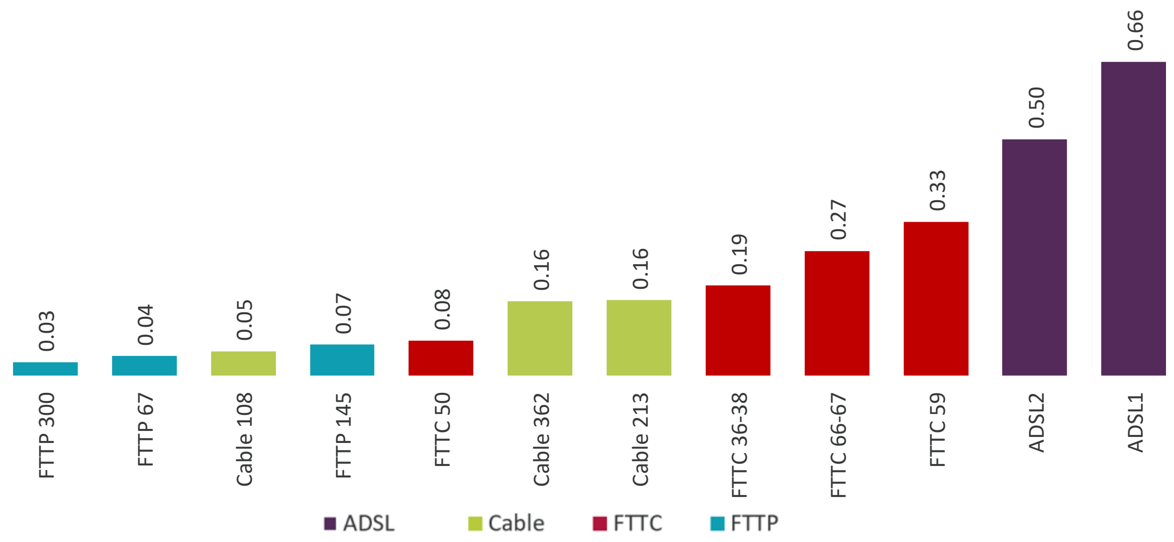
There is a greater variation in the speeds delivered to ADSL standard broadband connections than superfast ones

5.41 To better understand the variations in performance among different services, we calculated the coefficient of variation for the 24-hour download speeds for each package type.

5.42 Coefficient of variation is a measure that is used to quantify the amount of variation or dispersion of a set of data values, relative to the mean of those values. The smaller the coefficient of variation, the more concentrated the data points are around the mean, and the larger the coefficient of variation, the wider the spread of download speeds recorded for a package.

5.43 Our analysis shows that connections provided using ADSL tended to have a higher coefficient of variation (and exhibit more variation in performance) than those provided over full fibre, cable and FTTC.

Figure 24: Coefficient of variation for average 24-hour download speeds



Source: Ofcom, using data provided by SamKnows; see note [9] in the Sources section.

6. November 2019: upload speeds

Average UK upload speeds increased significantly in 2019

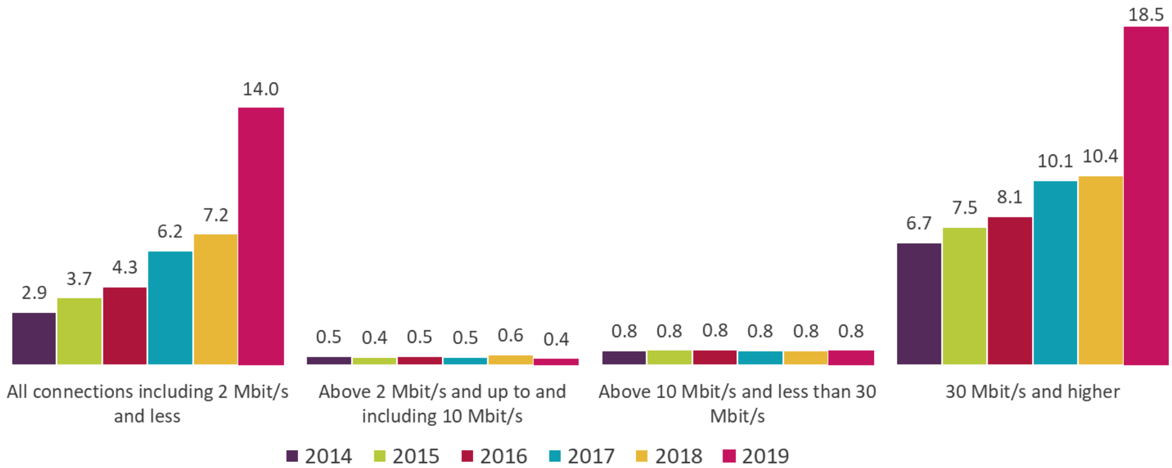
6.1 Upload speeds are important to users who use real-time video communication services, play video games online or who upload or share files.

6.2 Our research suggests that there was a significant increase in the mean average upload speed of UK residential fixed broadband services compared to 2018, up by 90%, from 7.2 Mbit/s in 2019 to 14.0 Mbit/s in 2019.

6.3 The median average speed saw a more modest, but still significant, increase of 3.3 Mbit/s (55%) from 6.0 Mbit/s to 9.3 Mbit/s.

6.4 The main drivers of this increase were the growing take-up of higher-tier FTTC services (which typically offer advertised upload speeds of around 19 Mbit/s), upgrades to upload speeds for over 3.5 million cable customers and growing take-up of full fibre packages with ultra-high upload speeds, some of which provide actual upload speeds as high as 900Mbit/s.

Figure 25: Average UK fixed broadband upload speeds (Mbit/s): 2014 to 2019



Source: Ofcom, using data provided by SamKnows; see note [10] in the Sources section.

7. November 2019: Netflix streaming and disconnections

7.1 The streaming of video content is one of the most capacity-hungry activities required of broadband connections. To understand how well various fixed broadband connections handle the streaming of video content, we measured the streaming performance of broadband connections when accessing content from Netflix.

7.2 The charts below show the proportion of Netflix video streams that were delivered in the most commonly available resolutions: standard definition (SD), high definition (HD) and ultra-high definition (UHD) for each connection type.

7.3 These results represent the case where only one user is streaming on a broadband connection; the streaming quality that can be reliably achieved may drop when multiple users are simultaneously using the same connection. HD and UHD resolutions are only available to those taking higher-tier Netflix plans.

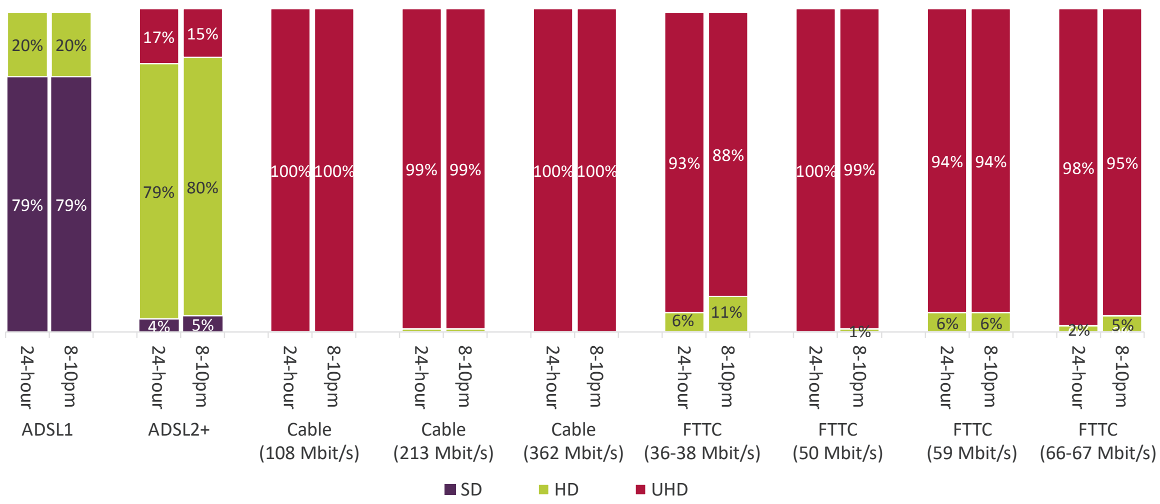
Cable and FTTC products can stream Netflix at UHD resolution

7.4 The majority of Netflix streams delivered over FTTC and cable lines were delivered at UHD resolution during the 8pm-10pm peak-time period.

7.5 For ADSL2+ services, over three-quarters of Netflix videos were streamed at HD resolution, while 17% and 15% of streams were delivered in UHD during the 24-hour and 8-10pm peak-time periods respectively (ADSL1 is not capable of supporting the speeds required for UHD).

7.6 For people who are satisfied with HD rather than UHD quality, ADSL2+ may therefore currently be enough to meet the current broadband requirements of some smaller households, as video streaming is one of the most data-hungry uses of a home broadband connection.

Figure 26: Proportion of Netflix videos reliably delivered at the given video quality, over 24 hours and at peak times, by technology



Source: Ofcom, using data provided by SamKnows; see note [11] in the Sources section.

Fibre and cable connections recorded the fewest average disconnections

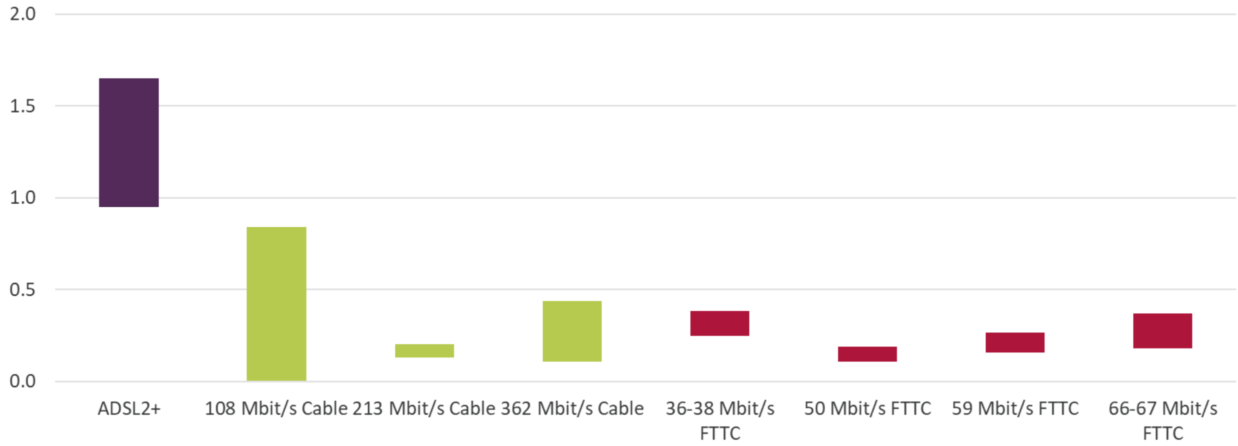
7.7 The average daily disconnections metric measures the frequency of broadband service disconnections lasting longer than 30 seconds.

7.8 Users cannot undertake any online activities when their service loses internet connectivity, and interruptions to the fixed broadband service can be inconvenient and frustrating.

7.9 It should be noted that not all disconnections are due to network performance: for example, a panellist rebooting their router would be classified as a disconnection event by our test.

7.10 ADSL2+ was statistically worse than all other packages. There was little statistical variation between other broadband technologies.

Figure 27: Average daily disconnections of 30 seconds or longer (lower values indicate better performance): 2019 (actuals)



Source: Ofcom, using data provided by SamKnows; see note [12] in the Sources section.
Note: The chart bars show that there is a 95% probability that the actual average speed for all customers (i.e. not just the customer panellists in our sample) falls within the ranges shown; in some cases testing may record scheduled maintenance as being a disconnection event.

8. Wi-Fi performance

Benchmarking router Wi-Fi performance

Our Home Broadband Performance research covers broadband performance to the router, as this is where the broadband provider has the greatest influence.

However, most homes connect to their home broadband service wirelessly using Wi-Fi. As broadband connection speeds increase, Wi-Fi can become a performance bottleneck and the router a determining factor of the user experience.

In order to better understand Wi-Fi performance, Ofcom ran a programme of Wi-Fi performance testing based on Broadband Forum's TR-398: Wi-Fi In-Premises Performance Testing standard. The performance of a number of current and legacy broadband provider routers, along with two third-party routers, were tested under lab-based conditions in a semi-anechoic chamber.[1]

Our Stay Connected campaign provides advice to help broadband and mobile users get the most from their connections, including improving their Wi-Fi signal, as millions of families work and learn at home.

Summary of results

8.1 Our limited testing shows that the maximum download speeds recorded over Wi-Fi were greater than those of the home broadband services with which they were provided for all but one of the routers under test.

8.2 Details of the methodology used, its limitations and anonymised results by router can be found in the accompanying *Wi-Fi performance testing of home broadband routers* technical report.

8.3 Figures 28 and 29 below show the anonymised results of our 'range versus rate' download speed testing. The range versus rate test measures the upload and download throughput rates for varying distances between the client device and router.

8.4 As the distance between the router and device is increased, the signal strength of the Wi-Fi signal is reduced and the recorded throughput speeds declines. Distance was simulated by the addition of the attenuation (measured in dB) between the router and client device.

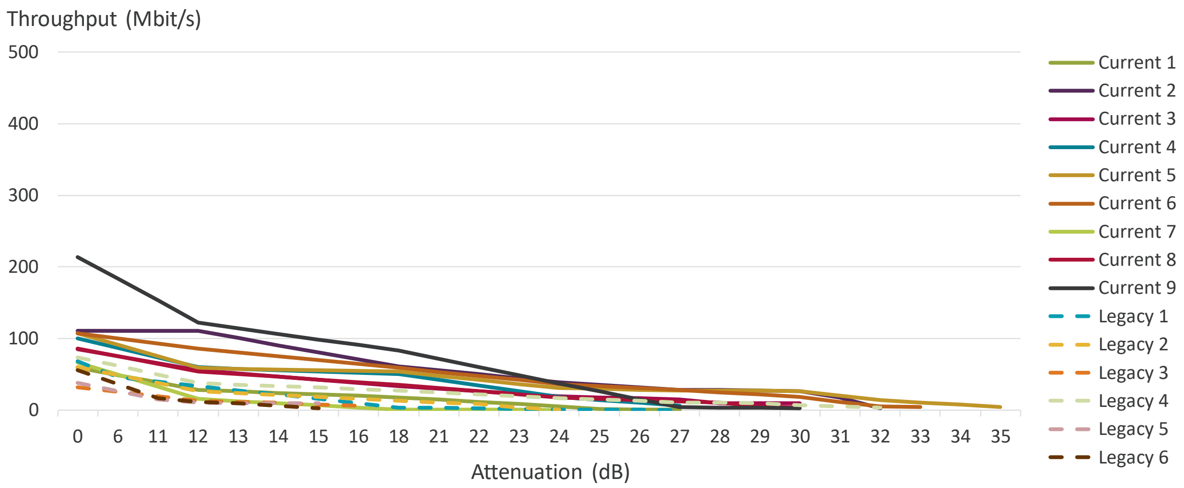
8.5 We found that differences in Wi-Fi performance tended to be most pronounced between current and older routers than across current models, with newer routers generally offering better performance than older ones.

8.6 This suggests that many people may be able to improve their Wi-Fi experience by updating their router to the latest model offered by their broadband provider. In some cases, they

[1] A semi-anechoic chamber is a radio frequency (RF) shielded enclosure where the walls are lined with a material that absorbs radio waves. This isolates the chamber from outside RF signals, creating a 'clean' RF environment.

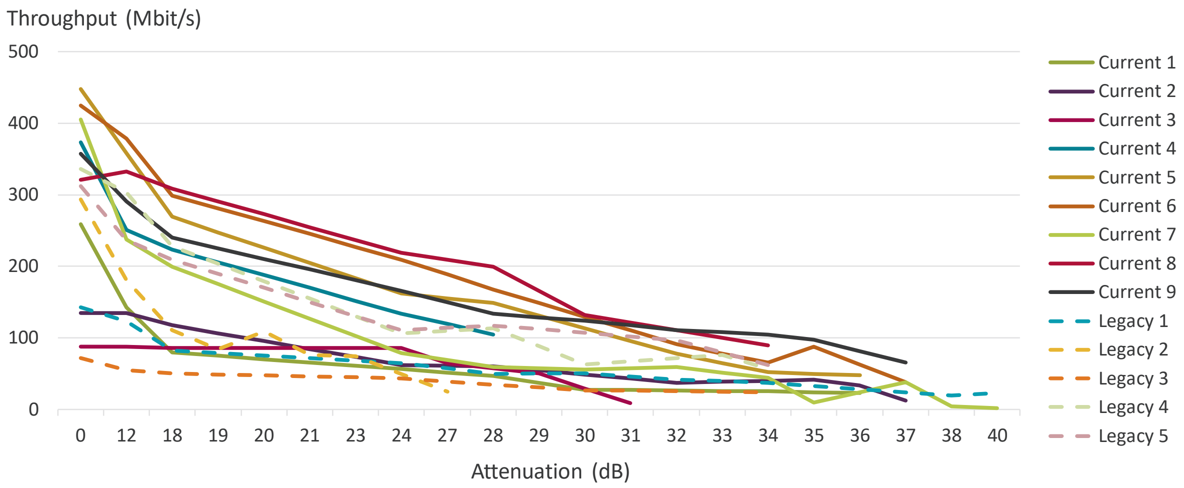
may be able to do this free-of-charge. We also found that Wi-Fi performance tended to be better over the 5GHz band than the 2.4GHz band.

Figure 28: Wi-Fi testing: 2.4 GHz range vs rate download speed results



Source: Ofcom

Figure 29: Wi-Fi testing: 5 GHz range vs rate download speed results



Source: Ofcom

Note: one legacy router did not support the 5GHz band and was excluded from the results for that test.

8.7 The table below can be used to convert the attenuation values shown in Figures 28 and 29 into distances under ideal conditions.

Figure 30: Conversion of attenuation to distance under ideal conditions

Attenuation (dB)	Equivalent distance (m)
0	1
10	3.16
20	10
30	31.6
40	100

Source: Ofcom

8.8 In a real home, the Wi-Fi signal is also reduced by obstacles such as doors and walls. The following table gives some examples of how different construction materials attenuate the signal, which has the effect of reducing range within the home.

Figure 31: Attenuation values of construction materials

Material	Attenuation (dB)	
	2.4GHz	5GHz
Interior drywall	3-4	3-5
Wooden door (hollow – solid)	3-4	6-7
Brick / concrete wall	6-18	10-30
Glass / window	2-3	6-8
Double-pane coated glass	13	20

Source: Ofcom

Ways of improving Wi-Fi performance

8.9 There are several ways to improve Wi-Fi performance within the home. Below we outline how Wi-Fi signal strength and coverage can be improved to get the best possible home broadband experience.

Router network selection

8.10 Most Wi-Fi routers broadcast their signal on one of two separate frequencies: 2.4GHz and 5GHz.[2] This is why '2G' or '5G' is sometimes included in the Wi-Fi network's name (SSID). Both frequencies have their advantages and drawbacks. As shown above, Wi-Fi broadcast on the 2.4GHz frequency offers slower data speeds but can travel further and cover a larger area than 5GHz Wi-Fi signals. Conversely, the 5GHz frequency offers faster internet speeds at the cost of signal range.

8.11 The frequency a router broadcasts on (or which devices use) can be changed if either an increase in the coverage of home Wi-Fi signal or an increased speed of wireless connection

[2] Some newer (Wi-Fi 6) routers also use the 5.8GHz band.

is preferred. Otherwise, most modern routers will intelligently connect using whichever frequency is likely to provide the best connectivity. The device in use will determine the Wi-Fi user-experience, and an older device with a basic Wi-Fi chipset will not be able to take advantage of the improved performance offered by newer Wi-Fi connection types, even if the router supports this functionality.

Router placement

8.12 The location of the Wi-Fi router within the home can greatly affect Wi-Fi performance. As Wi-Fi passes through different materials the signal degrades, with some materials reducing the signal more than others.

8.13 For example, it is likely to be more difficult to get a strong Wi-Fi signal throughout an old house with internal brick walls than a newer one with stud walls, although the foil-backed insulation used in modern homes can also make it difficult to receive a strong Wi-Fi signal. This is because metal has a high attenuation, meaning that it blocks more of the Wi-Fi signal. Water also has a high attenuation, so it is better to place a router away from objects like radiators and fish tanks.

8.14 Some electrical devices can interfere with the router's signal, such as microwave ovens which operate on the same 2.4GHz band as some routers. Other electrical devices known to impact Wi-Fi signals include baby monitors, cordless telephones, lamps and even Christmas tree fairy lights, so it is best to place the router as far from any other electrical equipment as possible.

8.15 The placement of the router can also impact on the quality of the Wi-Fi signal. Routers are designed to broadcast signals in all directions, including vertically, so placing the router on a raised surface off the ground (such as a shelf) can help improve coverage. Another way to maximise Wi-Fi coverage is to position the router so that it does not send signals outside the home. Placing the router in a central location in the home, as opposed to next to external walls, will avoid wasted signal coverage. If the router has more than one antenna, the signal can be directed by positioning the antennae at 90 degrees to one another, e.g. positioning one horizontally and the other vertically instead of pointing them in the same direction.

Additional ways to boost Wi-Fi performance

There are a number of products on the market that are designed to work with existing routers to improve Wi-Fi signal strength and coverage.

8.16 ***Wi-Fi boosters/extenders/repeaters.*** These tend to work by picking up the signal broadcast by the existing home Wi-Fi router and then amplifying and rebroadcasting it, although some create a new Wi-Fi network. Positioning these products in a part of the home where the existing router's signal is weak can extend home Wi-Fi coverage, though users may find that connection speeds are slowed down and network response time (latency) is increased as a result.

8.17 ***Wi-Fi mesh networks.*** Wi-Fi mesh networks create their own Wi-Fi network by way of a main router which connects to individual "nodes" that can be placed around the home. These nodes then communicate with one another to improve signal strength and coverage and can be easily moved from room to room to allow for a more flexible and integrated home Wi-Fi network. A benefit of mesh networks is that when connected correctly the performance of the connection is not impaired.

8.18 ***Third-party routers.*** Another option is to purchase a third-party router (i.e. one that is not provided by the broadband provider). There may be benefits to using a third-party router, for example, it might provide better Wi-Fi performance than a router provided by the broadband provider and give the user greater freedom to configure its settings, although set-up is likely to require a degree of technical knowledge. A drawback of using a third-party router is that the broadband provider will probably not be able to offer technical support if a problem occurs.

Wired broadband connectivity solutions

Wired solutions offer an alternative to Wi-Fi.

8.19 ***Ethernet cable.*** Wired Ethernet connections offer a more consistent internet connection (including faster internet speeds and lower latency) than Wi-Fi and are not affected by interference and signal loss to the same extent. Those using a device with an Ethernet port, such as a games console or TV set-top box, are likely to find that connecting the device via Ethernet will improve the quality of the connection. It is important to use Ethernet cabling that can provide the data transmission speeds of your broadband connection, otherwise the performance may be limited.

8.20 ***Powerline.*** Powerline extenders work by using the electrical wiring of your home to transmit data around the house. The set-up involves two adapters which are plugged into electrical sockets, one of which is connected to the router via an Ethernet cable and the other to the device/s being used (using Ethernet, or sometimes Wi-Fi). Powerline is relatively inexpensive but will only work in homes where there is one electrical ring (circuit). The performance of a Powerline connection is also dependent on the Powerline devices being used and the quality of the electrical wiring in the home.

A1. Technical Annex

Technical methodology

This report is Ofcom's seventeenth fixed-line residential broadband speeds report and the fourteenth in which we have published broadband provider package-specific data and comparisons between broadband providers. The technical methodology chosen is the same as that used in Ofcom's previous reports and is based on that created by broadband performance company SamKnows Limited, Ofcom's technical partner in this research project.

SamKnows recruited a panel of UK residential broadband users and supplied monitoring units to each panellist. SamKnows also managed the collection and aggregation of the performance data and made a major contribution in assisting Ofcom in the analysis of the data.

All panellists were sent a hardware monitoring unit which they were instructed to connect to their router. The monitoring unit sits between the panellist's router and the rest of their network, thereby allowing the unit to determine when the network is free to run tests (the device operates in a bridging mode, rather than routing).

The measurement units are connected to panellists' routers using an Ethernet cable in order that the test results accurately reflect the performance of their connections. Where people use Wi-Fi (or other technologies such as powerline) to connect devices to their router, it is possible that the actual speeds received will be lower than those delivered over an Ethernet connection because of the limitations of these technologies (although recent mass market Wi-Fi technologies can theoretically support speeds in excess of 300 Mbit/s). The potential for this difference is greater for higher-speed broadband connections, where the speeds delivered may be higher than the maximum bandwidth that the in-home network technology can support.

This report also used broadband provider-provided data where the SamKnows Router SDK had been embedded directly into the customers' CPE. The Router SDK includes all the SamKnows quality of service (QoS) and quality of experience (QoE) tests, as well as cross-traffic detection capabilities. The test methodology used is the same as employed in the 'Whitebox' and as described below.

SamKnows developed a customised OpenWRT firmware image which is installed on the units. At the point of delivery to the panellists, this is all that is present on the device; the physical unit contains no additional software, apart from a single script that checks for the availability of the software component at boot-up. This is beneficial both from a security perspective (everything is destroyed when the power is lost) and from a support perspective (any problems with a unit's configuration can be undone simply by power-cycling it). New versions of the software can be delivered remotely without requiring a reboot.

Software within the unit then performed a range of tests to a set schedule, running over 14,000 separate tests from each panellist over the course of a day. The software was configured to identify other network activity and not to run tests when such activity was detected. This avoided compromising results by running tests at a time when bandwidth was being used by other internet-connected devices in the household (including those using a wireless connection).

The software uses a combination of standard UNIX tools and custom code developed in C and C++.

All monitoring units maintain accurate time using ntp.

We believe that this technical methodology is robust as it does not rely on monitoring solutions that do not account for the impact on speed of PC set-up, or for having more than one computer using a broadband connection.

Speed tests

The project uses speed tests with multiple concurrent TCP connections, to assess the capacity of the user's broadband connection.

Speed tests run for a fixed duration of 10 seconds if the user's broadband connection is not subject to a data cap or has had it lifted for the purposes of this project. Fixed-duration speed tests ensure comparability across broadband connections regardless of their access speed.

On connections slower than 30Mbit/s, units download 3 x 2MB files using separate TCP sessions (in parallel). Connections faster than 30 Mbit/s will transfer an increased amount during the downstream throughput test. This amount is up to 12MB (3 x 4MB files) or 10 seconds (whichever is reached first). Connections of 50 Mbit/s or faster are all without data caps and therefore employ the full 10-second speed test.

The nature of the protocols used on the internet means that during a file download the speed at which data is sent is gradually increased until a stable speed is achieved. To measure this stable speed, our tests exclude the period of the speed ramp-up. The exact way in which the speed ramp-up occurs on different networks may lead to slight variations in the accuracy with which the stable speed can be measured.

An initial lead-in period is used to ensure that TCP window sizes are increased before measurements are made. Multi-thread tests were run nine times per day, once every six hours in off-peak periods and once every hour at peak times. We found that, typically, the download speeds achieved using the multi-thread tests in the early hours of the day determine the maximum speed the line can support.

Additionally, it is understood that some broadband providers operate transparent HTTP proxy servers on their networks. To overcome this, the web servers are configured to respond with the following headers, which should disable caching in standards-compliant proxy servers:

Cache-Control: "private, pre-check=0, post-check=0, max-age=0"

Expires: 0

Pragma: no-cache

Upload tests are performed for a fixed duration of 10 seconds for connections without data caps or those with an upload speed of 20 Mbit/s or faster. On connections slower than 30Mbit/s, upload tests were performed using 3 x 1MB files with a similar initial lead-in period to that used for download tests. Connections with upload speeds faster than 10 Mbit/s will transfer an increased amount during the upstream throughput test. This amount is up to 6MB. Four speed-test servers are deployed in a data centres in London to handle the traffic. 40Gbit/s of capacity is shared between these servers. Each server is monitored for excessive network load and for CPU, disk and memory load.

The test results gathered by each server are compared against one another daily, to ensure that there is no significant variation in the speed attainable per server. Units cycle through the speed-test servers in a round-robin fashion when testing.

Testing web page loading times

The test downloaded the HTML and media assets of a simple web page hosted on a SamKnows-managed server. This makes use of up to eight concurrent TCP connections to fetch the assets. Both tests make use of libcurl.

The time in milliseconds to receive the complete response from the web server is recorded, as well as any failed attempts. A failed attempt is deemed to be one where the web server cannot be reached, or where a HTTP status code of something other than 213 is encountered.

Tests were run every hour.

Testing latency, packet loss and jitter

A bespoke application was used to test latency, packet loss and jitter. The application was designed to run continuously to get a statistically robust set of data. The test used UDP rather than ICMP and sent approximately 2000 packets every hour.

The test also records instances of contiguous packet loss events. These are termed ‘disconnections’. The duration of the disconnection event will vary by its cause – a minor routing issue may only cause a few seconds’ disconnection, whereas a modem losing synchronisation with the telephone exchange may result in a 30 second disconnection.

Testing recursive DNS resolver responsiveness and failures

Testing a broadband provider’s recursive DNS resolution can be accomplished using many tools, such as nslookup, dnsip and dig. A custom DNS measurement client is used so that we may support regular UDP-based DNS queries, as well as emerging standards such as DNS-over-HTTPS and DNS-over-TLS.

For regular UDP-based DNS queries, as used in this report, the Whitebox will honour the DNS servers offered by the home router over DHCP. This router may provide the DNS servers of the broadband provider directly, or it may provide its own IP address and then proxy the DNS requests upstream. In all cases, we record the DNS server IP address that the router provided over DHCP.

The tests record the number of milliseconds for a successful result to be returned. A successful result is deemed to be one when an IP address is returned (the validity of the IP address is not checked). A failure is recorded whenever the DNS server could not be reached, or an IP address was not returned. The hostnames of four popular websites were queried every hour.

Testing Netflix video streaming performance

The Netflix test is an application-specific test, supporting the streaming of binary data from Netflix's servers using the same CDN selection logic as their real client uses. The test has been developed in direct cooperation with Netflix.

The test begins by calling a Netflix hosted web-based API. This API examines the client's source IP address and uses the existing proprietary internal Netflix logic to determine from which Netflix server this user's IP address would normally be served content. This logic will consider the broadband provider and geographic location of the requesting IP address. Where the broadband provider participates in Netflix's Open Connect programme, it is likely that one of these servers will be used. The API will return to the client a HTTP 302 redirect to a 25MB binary file hosted on the applicable content server.

The test then establishes a HTTP connection to the returned server and attempts to fetch the 25MB binary file. This runs for a fixed 20 seconds of real time. HTTP pipelining is used to request multiple copies of the 25MB binary, ensuring that if the payload is exhausted before the 10 seconds are complete, we can continue receiving more data. The client downloads data at full rate throughout; there is no client-side throttling taking place.

It is important to note that this 25MB binary content does not contain video or audio; it is just random binary data. However, with knowledge of the bitrates that Netflix streams content at, we can treat the binary as if it were video/audio content operating at a fixed rate. This allows us to determine the amount of data consumed for each frame of video (at a set bitrate) and the duration that it represents. Using this, we can then infer when a stall occurred (by examining when our simulated video stream has fallen behind real-time). The test currently simulates videos at bitrates of 235Kbps, 375Kbps, 560Kbps, 750Kbps, 1,050Kbps, 1,750Kbps, 2,350Kbps, 3,000Kbps, 4,500Kbps, 6,000Kbps and 15,600Kbps.

The test captures the 'bitrate reliably streamed' (the highest quality video that can be streamed without rebuffering events), the download speed from the Netflix Open Connect Appliance and the video start-up delay.

Testing social media platforms

This test measures the round-trip latency and reachability of a selection of major social media services, taking into account different endpoints that the social media service may use for different content types.

A single social media site can use a variety of endpoints for different content types (e.g. audio, video) and different activities (downloading and uploading). For example, Facebook use a different set of servers when allowing users to download videos versus upload videos. This test captures round-trip latency to all of the supported combinations.

Figure A1 summarises the different content types and social media services for which we measure latency.

Lack of support for a particular combination is due to the social media service itself not supporting certain content types. For example, the main Facebook app does not support downloading or uploading audio clips (but the Facebook Messenger app does).

Figure A1: Support for download and upload of various media types by major social media and messaging services

	Download: Text	Download: Image	Download: Video	Download: Audio	Upload: Text	Upload: Image	Upload: Video	Upload: Audio
Facebook App	Yes	Yes	Yes		Yes	Yes	Yes	
Facebook Messenger	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Instagram App		Yes	Yes			Yes	Yes	
Instagram Messenger	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
WhatsApp	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Snapchat	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Twitter	Yes	Yes	Yes		Yes	Yes	Yes	

Source: SamKnows

Note that we have split Instagram into two separate apps, even though they are delivered to the user as a single smartphone app. This is due to the private messaging feature within the Instagram app supporting different functionality to the main part of the app. Moreover, the private messaging feature of the Instagram app uses different endpoints to the main part of the app.

For each social media service we determined the endpoints to test against by performing a traffic analysis of how their Android and iOS apps behaved. All apps, with the exception of Facebook and Instagram, use a static set of endpoints. For example, Twitter uses api.twitter.com for most operations. Of course, this does not prevent Twitter from geographically load balancing api.twitter.com via any cast or DNS based load balancing, but all clients use this single hostname. Facebook and Instagram make use of the Facebook "FNA" caches for retrieval of image and video content. Facebook FNA caches are the on-premises caches that Facebook provides to large broadband providers, much like Google do with GGCs or Netflix does with OCAs. The Facebook FNA cache to be used is determined dynamically by the latency measurement client.

Additionally, the latency measurement mechanism can vary for some social media sites too. All services, with the exception of Snapchat, currently use ICMP to measure round trip latency. For Snapchat we instead use HTTP time-to-first-byte for Snapchat because they front all of their API servers (currently hosted in the US) by Amazon's CloudFront reverse proxy, which are distributed globally. To just measure round trip time to their CloudFront hostname would misrepresent the end-to-end latency that a user really experiences.

The social media test fully supports IPv4 and IPv6. It may optionally be run with DNS resolution performed over DNS-over-HTTPS or DNS-over-TLS, instead of using the default system resolver. For each social media service and endpoint, we measure the following:

- Average round trip latency for 10 packets (by default)
- Minimum, maximum, median and standard deviations for the latency measurements
- The number of sent and received packets
- The number of hops to the endpoint (performed using a traceroute)
- The resolver IP address of the endpoint

Connections with usage caps

Some of the test units were deployed on broadband connections with relatively low usage caps. To avoid using a significant proportion of the available download limit each month, the test schedule for the test units on these connections was reduced.

Research methodology

The performance data in this report are taken from a base of 3,481. This includes data from 3,027 panellists on SamKnows' independent global platform, SamKnows One, who had a broadband monitoring unit connected to their routers in November 2019, and 454 panellists who had the SamKnows SDK embedded into their CPE. Ofcom's definitions of geographic broadband markets use the definitions for the wholesale broadband access (WBA) market review. These were an important consideration in recruiting our panel and applying statistical analysis, because they enabled us to ensure that our panel was representative of the UK residential broadband market overall, and facilitated like-for-like comparison between broadband provider packages:

- Each panellist was assigned to one of the geographic markets, and we weighted the analysis accordingly to ensure that our overall findings were representative of UK residential broadband performance overall (for example, as Market A represents around 1% of UK premises, we ensured that performance data from panellists in Market A contributed 1% towards the overall computation of UK residential broadband performance).
- For comparisons of broadband provider package performance, we used only panellists who live within geographic markets B. This means that all panellists used for the broadband provider package comparisons live in areas served by a local telephone exchange in which at least one operator other than BT is present, i.e. there is at least one local loop unbundling (LLU) operator. This avoids any potential distortions of the data by broadband providers using BT wholesale services (BT Retail, EE and Plusnet), caused by the inclusion of panellists who live in (typically less densely populated) 'Market A' areas, and to whom LLU services are not available.

We have used statistical techniques to adjust our results to ensure that they are representative of the overall UK broadband population. This includes weighting the results from our panel by rural/urban, distance from exchange, geographic market definition and broadband provider. For the provider-specific comparisons we have also 'normalised' the data for ADSL operators by distance from exchange (using the straight-line distance from the panellist's location to the exchange), which we believe is necessary to provide like-for-like comparisons of broadband providers which have different customer profiles.

David Saville of Saville Rossiter-Base has assessed the research methodology and panel and helped ensure its suitability for purpose. Checks were also applied to ensure that straight-line distance was an appropriate metric to carry out normalisation, including comparing this distance with the line attenuation. Details of the statistical methodology used are provided in Annex 2. The methods of analysis for the provider-specific comparison are based on those used in the July 2009 report which had expert review by econometrician Professor Andrew Chesher of University College London.

A2. Statistical Annex

Key statistical concepts used in this report

This report presents the findings from research which has involved the collection and interpretation of 2.79 million data points. It has been a complex process, both technically and statistically.

The glossary in Annex 4 provides definitions 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 collected.

- 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 panellists) and the variation (spread or range of results) between panellists.
- 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 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. In the tables where we present differences which are statistically significant, we present differences which are significant to a 95% level of confidence, but also highlight those which are significantly different to a 99% level of confidence by using an asterisk.
- In order to ensure that the national data we present are representative of UK residential broadband users as a whole, we have weighted the data by ISP package, nation and rural/urban split, market classification, distance from the exchange for ADSL packages and max attainable speed for FTTC packages.
- We have similarly weighted the data where we are comparing the performance of individual ISPs' packages, in order to ensure that the analysis provides a fair comparison of actual performance rather than reflecting random differences in the ISP package customer profiles in the sample.
- To ensure comparisons between the performance of different technologies in urban and rural areas are representative of the urban and rural market, we applied a separate

weight which gave a representative sample by technology, speed tier and urbanity when making these comparisons.

- A difficulty in comparing ADSL and FTTC broadband providers is that with this technology, speed varies by the length and quality of the specific consumer's telephone line. Therefore, providers which have a higher proportion of customers in rural areas, where line lengths are typically longer, may be expected to deliver lower speeds on average than those which focus on towns and cities, simply because they have a different customer profile. For FTTC customers, the critical part of the line is that between the customer's house and the cabinet – this section of the line is copper and subject to line degradation.
- To address this issue, we have taken the following steps:
    - For all ISP comparisons, we have included only consumers who live in an area where the exchange has been 'unbundled' by at least one LLU operator. This means that ISPs using wholesale services (such as BT Wholesale's IP stream or Wholesale Broadband Connect products) can be compared on a like-for-like basis with LLU operators.
    - We have excluded all ADSL customers where the straight-line distance from their home to the local telephone exchange is more than 5km, in order to limit the impact of outliers when weighting, and normalised data to straight-line distance distributions.
    - Straight-line distance weighting was applied only to ADSL operators in this report and not to cable or FTTC services, where performance is less influenced by distance from the exchange.
    - For FTTC customers, we do not have adequate information on distance between cabinet and customer premises. We therefore approximate this distance by normalising data using the maximum attainable speed. The maximum attainable speed is the best speed which a line can carry and is therefore a suitable proxy for measuring quality of the line.
    - No weights are applied to Virgin Media cable packages or FTTP packages, as these circuits are not affected by distance from the exchange or supplier cabinets.

Sample methodology

A panel of UK residential broadband users was drawn from a pool of volunteers following a recruitment campaign by SamKnows. The objective was to obtain a representative panel, in order to monitor the performance of residential fixed-line broadband in the UK over a two-year period of research. In addition to obtaining a panel sufficient for monitoring changes in overall performance, the panel was recruited to enable specific analysis of the performance of the most common ISP packages in the UK, in particular higher-speed packages.

The main purposes of this recruitment have been to:

- replace panellists who leave the panel due to natural attrition, such as moving house or losing interest in participating in the research

- ensure adequate samples for all ISPs and replacing panellists who, although remaining on the panel, have decided to switch their operator and/or package. As the Ofcom panel tends to be comprised of people with an interest in telecoms, there is a strong focus on ensuring coverage of lower speeds packages, and
- enable the ISP-level reporting of new packages such as high-speed fibre and cable as soon as sufficient numbers can be recruited.

Due to shortfalls in some areas, SamKnows provided additional data from its independent global platform, SamKnows One. At the moment, the total active panel is 3,212 – active meaning contributing results to either the ISP, or national analysis. 2,533 of these respondents belong to the Samknows panel and 442 to SamKnows' enabled embedded panel. Their data will be used for this report, but Ofcom seeks to recruit panellists unique to the Ofcom panel to fill these gaps.

The current active panel also excludes customers with packages with headline speeds of 2Mbit/s and less, because of the current low share of these connections (less than 0.1% of the total in November 2013). In our first round of research, conducted between October 2008 and April 2009, we found that the speeds delivered by 2Mbit/s and less packages were consistent over time and between providers. In this report we have excluded data from 2Mbit/s and less packages, due to their low market share.

Prior to dispatch of the monitoring units, volunteers were screened and preliminary speed measurements and checks on IP addresses were undertaken, in order to reduce the impact of respondent misconceptions regarding which package they were using on the sampling.

Definition of valid panellists and test volumes

All measurement data were collated and stored for analysis purposes as a monthly trimmed average of the measurements obtained for each respondent for the relevant time interval (e.g. 24 hours, 8 to 10pm weekday, 9am to 5pm Monday to Friday). Only panellists who provided a minimum of five valid measurements across all the download speeds, upload, latency, DNS and webpage tests for the narrow 8 to 10pm peak measurement period, and a good spread of tests throughout the day, were included in the monthly analysis. A trimmed mean was used because, for a small proportion of respondents, the occasional test result was far in excess of what was achievable on the line. The top and bottom 1% of results per respondents did not count towards the average.

The average number of measurements per respondent for the 24-hour multi-thread download speed tests between 1 November 2019 and 30 November 2019 was 302, from a theoretical maximum of 360 per respondent on the SamKnows panel, and a theoretical maximum of 720 per respondent on the embedded panel (i.e. if all panellists had their monitoring unit connected on 1 November and all scheduled tests were run - tests were not run when the monitoring unit detected concurrent use of the bandwidth).

Average download speeds are generally very accurately measured, so the main factors limiting the accuracy of the analysis reported here are the number of panellists and the average number of measurements.

Quotas and weightings

Quotas were set before the exact package market shares for operators were available, but results were weighted to be representative at national level. To recruit ISP packages to match the specific quota criteria above, and to achieve 100-150 panellists per package, only those ISP packages with more than 250,000 subscribers in total were targeted, although we do include ISP packages with fewer than 250,000 subscribers where we can recruit sufficient panellists, and where we believe a package is important enough to the future development of the market to warrant inclusion in the report.

The results and analysis of the 3,212 panellists' measurement results were divided into two separate datasets, each weighted to targets.

- National panel (over 2Mbit/s packages): 1,950 panellists. All with at least five valid test measurements across all download tests, with a validated IP address, single measurement speed check, and distance and geographic market classification data.
- ISP package panel: 2,975 panellists. Respondents for this panel consist of panellists from geographic markets 2 and 3 only. There was a target of 100 valid panellists for each ISP package, but the criterion for inclusion in the reporting was an effective sample minimum of c.50 valid panellists (those with a base of fewer than 75 should be treated with caution). Additional validation for the ISP package panel included a review of measured speed against straight-line distance from the exchange to the panellist's premises, and a review of outliers. Any package reassignment identified was made to both the ISP package panel and the national panel datasets.
- Rurality panel: 1,950 panellists. All with at least five valid test measurements across all download tests, with a validated IP address, single measurement speed check, and distance and geographic market classification data. The sample composition of this panel is the same as the national panel.

Sample weighting

National panel:

- Weighting by ISP market and package shares by LLU/ non-LLU connections supplied by ISPs as at November 2019, urban/rural, geographic market classification, ADSL distance to exchange (fitted to UK representative exchange line distribution provided by Openreach Limited) and max attainable normalisation for FTTC lines.

ISP package panel:

- Weighting to distance from exchange (those panellists with an unrecorded or straight-line distance to the exchange of more than 5km were excluded);
- ADSL2+ packages were normalised by distance from exchange, to the aggregated distribution of straight-line distance between premises and exchanges of all panellists on those headline packages
- FTTC packages were normalised to the appropriate max attainable speed curve that matched the headline package speed (36Mbit/s, 50Mbit/s or 63-67Mbit/s).

- Sky's 59Mbit/s package was weighted to the distribution of max attainable speed lines serving this package
- Cable or FTTP packages are not weighted, as speed of services is not directly related to distance from the exchange

Rurality panel:

- Weighting by package speed tier take-up within technology and within rurality. The weighting structure was formulated using May 2019 data provided to Ofcom by internet service providers.

- As mentioned previously, our measurement approach does not take account of respondent-specific issues, such as wiring, which may influence the speed of connection. Such variations have most impact on high-speed services where a respondent has a short line length. We assessed several methods of accommodating this issue and asked Saville Rossiter-Base for guidance.
- The conclusion was that allowing for variance across the sample based on line length would not necessarily lead to the widening of confidence intervals to build in this element of respondent variability. This is because the calculation of confidence intervals requires a constant mean and standard error across the sample or sub-sample under review. If we allow variance to differ by band, we would also need to allow the mean to differ by distance band. Leaving aside the increased complexity of the calculation, allowing the mean to differ by distance band to reflect respondent difference would reduce the variance in each band and reduce the confidence intervals for pooled estimate of the mean across the whole sample. The following calculation, based on all non-cable 20Mbit/s packages in May 2012, shows this to be the case.

Figure 2.1: Variation of mean and variance, by distance band

Distance Band	Sample	Mean	Variance	Standard Deviation
1	62	12.91482	13.95910	3.73619
2	68	11.60854	9.42604	3.07019
3	74	8.73505	10.31055	3.21101
4	78	5.87748	9.55572	3.09123
5	67	2.90284	5.73256	2.39428

Source: Ofcom

The average variance across the five cells is 9.8, giving a standard deviation of 3.1, giving a confidence interval of 8.48 +/- 0.3Mbit/s. But the overall standard deviation, if mean is held constant, is 4.7, which would give a confidence interval of 8.48 +/- 0.5Mbit/s. The current methodology therefore overestimates the variance in the sample and hence the confidence intervals.

Assigning panellists to ISP and broadband package

The following process was applied, to select panellists and assign them to the correct ISP package:

- Volunteer panellists were required to provide their ISP, package name, headline speed and download limit from drop-down menus and/or text boxes provided in an online form. This was used as initial categorisation of potential candidates against the target quotas.
  - The stated package name and headline speed (where they allowed identification of the correct ISP package) were used to assign panellists to an ISP package.
- Volunteers who matched the sample criteria were screened by ISP package, and an average speed reading estimate was obtained to screen actual versus stated package. Those who were successfully screened were sent monitoring units.
  - The stated ISP allocation was validated against IP address. When an IP address and stated ISP were inconsistent or missing, the volunteer was rejected. When an average speed measurement was outside the feasible range, the volunteer was flagged, and a monitoring unit box dispatched if there was still sample required for the assessed package.
- Once the volunteer correctly connected the monitoring unit and test measurements were received, straight-line distance from home to exchange and geographic market classification were added to the measurement data.
- A further stage of ensuring that respondents were assigned to the correct ISP package took place before the analysis stage. The following steps were undertaken:
  - The initial assumption was that the package assignment, recorded in the panel data file, was correct. However, the ISPs were asked to verify that respondents were on the correct package.
  - However, those participants whose stated and measured package assignments or ISP were not consistent, and could not be definitively reconciled, were excluded from the comparison data. Only those panellists with an ADSL connection, who were connected to an ADSL2+ enabled exchange, were considered for an ADSL2+ package allocation. The above modification (upload speed assignment) was necessary to identify those customers using ADSLMax on an ADSL2+ exchange.

Weighting to distance from exchange

As performance of ADSL broadband is significantly affected by the length of the line between a consumer's premises and the local exchange, any comparison between ISPs or technology could be affected by the distribution of distance among the sample.

It was therefore necessary to weight the data by distance from exchange in order to provide like-for-like comparison between the previously published data, to ensure that any differences identified were due to differing performance and not due to a differing distribution of line lengths. Openreach Limited provided three curves which indicate the national distance profile of ADSL1, ADSL2+ and all

ADSL lines for all lines in the UK. Each relevant ADSL2+ ISP package in the ISP panel is adjusted to match this national profile. ADSL packages in the national panel are adjusted to match the profile of all ADSL lines as provided by Openreach Limited.

Distance from premises to local exchange was captured as the straight-line ('as the crow flies') distance, measured from the full postcodes of premises to the local exchange.

Weighting fibre packages

Although fibre technologies show little speed degradation between the local exchange and the final point where fibre is present, most respondents with fibre have FTTC only. This means that the length of the co-axial cable between the cabinet and the consumer premises can have a significant impact on speed. As the FTTC network is being rolled out into more rural areas, the distribution of distance from the cabinet becomes important, as rural lines tend to be longer than urban.

In a similar manner as weighting to distance from exchange for ADSL, Ofcom has decided to normalise for distance from cabinet for FTTC products, to ensure a like-for-like comparison. An identical model to ADSL, based on straight-line distances from the cabinet, is not possible, as the relevant cabinet for many premises will be in the same postcode. Therefore, a proxy for distance from cabinet was used – this is maximum attainable speed. This is a network metric which assesses the line and determines the maximum speed it can carry. Openreach Limited provided the maximum attainable speed for each panellist, and also the profile of fibre lines in the UK. Each ISP's respondent profile is adjusted to match the national profile and weighted accordingly to ensure like-for-like comparisons.

Ofcom uses a single curve for each speed, which does not discriminate between respondents with self and engineer installed lines.

Weighting efficiency

Overall, against the entire weighting framework, the national panel achieved a weighting efficiency of 36%. Since there are five factors making up the national weights, the weighting efficiency is often lower than the broadband provider and rurality panel weighting. It is also affected by the composition of our panel and can therefore vary year on year. The under-0.5s are primarily driven by the over-representation (against current market shares) both of some FTTC packages, and panellists in rural areas, and Scotland and Wales. The over-2s are driven by market shortfall for some packages and for under-sampling in market A.

Figure 2.2: National panel range of weights

Weights	Count	Percentage
Less than 0.5	882	45.2%
0.5 to 1	426	21.8%
1 to 1.5	200	10.3%
1.5 to 2	213	10.9%

More than 2	229	11.7%

Source: Ofcom

Overall, against the entire weight frame, the ISP package panel achieved a weighting efficiency of 89%. This is because Virgin Media cable and FTTP packages are not weighted, as distance from exchange does not impair download speeds.

Figure 2.3: ISP package range of weights

Weights	Count	Percentage
Less than 0.5	175	5.9%
0.5 to 1	2034	68.4%
1 to 1.5	518	17.4%
1.5 to 2	211	7.1%
More than 2	37	1.2%

Source: Ofcom

Figure 2.4: Weighting efficiency, by ISP package

ISP Package	Weighting Efficiency	ISP Package	Weighting Efficiency
BT ADSL2+	89.5%	EE 76 Mbit/s	93.6%
Plusnet ADSL2+	88.1%	Plusnet 76 Mbit/s	88.9%
Sky ADSL2+	88.2%	TalkTalk 76 Mbit/s	91.3%
TalkTalk ADSL2+	93.8%	BT 76 Mbit/s FTTP	100%
BT 36 Mbit/s	74.1%	BT 160 Mbit/s FTTP	100%
EE 36 Mbit/s	83.4%	BT 330Mbit/s FTTP	100%
Plusnet 36 Mbit/s	82.1%	Virgin Media 100 Mbit/s	100%
TalkTalk 26 Mbit/s	91.5%	Virgin Media 200 Mbit/s	100%
BT 52 Mbit/s	62.5%	Virgin Media 350 Mbit/s	100%
Sky 59 Mbit/s	63.5%	Virgin Media 500 Mbit/s	100%
BT 76 Mbit/s	98.0%		

Source: Ofcom

Overall, the rurality panel achieved a weighting efficiency of 75%. The sub-samples for both urban and rural ADSL1, and for rural FTTC 50 and FTTC 63-67 packages were boosted to ensure these panellists did not need to be over-weighted too much.

Figure 2.5: Rurality panel range of weights

Weights	Count	Percentage

Less than 0.5	186	9.5%
0.5 to 1	1,136	58.3%
1 to 1.5	394	20.2%
1.5 to 2	67	3.4%
More than 2	167	8.6%

Source: Ofcom

Comparison of urban and rural speeds

Using Bluewave Geographic's Locale dataset, it is possible to segment all UK postcodes into one of seven urban-rural groupings. This dataset, widely used in market research design and sampling, allocates postcodes to a category based on their population density and how close the settlement they live within is to a larger one. The seven groupings range from A (large cities such as London and Birmingham), to G (isolated rural areas such as the Western Isles and Dartmoor).

To simplify the analysis, the groupings have been banded together into two broad groups: urban and rural (population less than 2,500 and in open countryside). This grouping enables us to compare rural and urban areas over time.

A3. Sources

Sources

[1] Source: Ofcom, based on data provided by the UK's largest ISPs by retail market share (representing over 90% of the total market), data as at November of each year. Notes: (1) The up to 10Mbit/s category includes ADSL2+ connections which are not marketed using a connection speed.

[2] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: 1950 (Above 2 Mbit/s and including 10Mbit/s – 112; Above 10Mbit/s and less than 30Mbit/s – 222; Above 30Mbit/s – 1616) Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests; (3) The above 10 Mbit/s and less than 30 Mbit/s includes ADSL2+ connections which are not marketed using a connection speed.

[3] Source: SamKnows measurement data for all national panel with a connection in November 2019. Panel members with a connection in November 2019. Panel base: 1950 (ADSL – 329; FTTC – 1069 and cable – 401) Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK overall; (2) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable; (3) Data are collected from multi-thread download speed tests.

[4] Source: SamKnows measurement data for all rurality panel members with a connection in November 2019. Panel base: urban ADSL – 167; rural ADSL – 162; urban FTTC – 813 and rural FTTC – 256) Notes: (1) Data have been weighted by take-up rates by speed tier and technology within rurality to ensure urban and rural sub-samples are representative of the market by rurality and of the UK overall; (2) Data are collected from multi-thread download speed tests; (3) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[5] Source: SamKnows measurement data for all rurality panel members with a connection in November 2019. Panel base: 1950 (urban – 1501; rural – 449) Notes: (1) Data have been weighted by take-up rates by speed tier and technology within rurality to ensure urban and rural sub-samples are representative of the market by rurality and of the UK overall; (2) Data are collected from multi-thread download speed tests.

[6] Source: SamKnows measurement data for all national panel with a connection in November 2019. Panel members with a connection in November 2019. Panel base: 1950 (ADSL – 329; FTTC – 1069, FTTP – 151 and cable – 401) Notes: (1) All connections, ADSL and FTTC data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK overall; (3) Data are collected from multi-thread download speed tests.

[7] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: 1950 (ADSL1 – 39; ADSL2+ – 290; FTTC 36-38 – 371; FTTC 50 – 67; FTTC 59 – 236; FTTC 66-67 – 395; cable108 – 112, cable213 – 167, cable362 – 136, FTTP63-67 – 137, FTTP145 – 110 and FTTP300 – 112) Notes: (1) All connections, ADSL and FTTC data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests; (3) Due to the low

representation of high-speed cable packages in the UK, ISP panel results are used for cable 108 Mbit/s, cable 213 Mbit/s, cable 362Mbit/s, FTTP 63-67 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s.

[8] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: 1950 (ADSL1 – 39; ADSL2+ – 290; FTTC 36-38 – 371; FTTC 50 – 67; FTTC 59 – 236; FTTC 66-67 – 395; cable108 – 112, cable213 – 167, cable362 – 136, FTTP63-67 – 137, FTTP145 – 110 and FTTP300 – 112) Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests; (3) Maximum speed is calculated as the average of the daily maximum speeds achieved throughout the month; (4) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 108 Mbit/s, cable 213 Mbit/s, cable 362Mbit/s, FTTP 63-67 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s. (5) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[9] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: ADSL1 – 39; ADSL2+ – 290; FTTC 36-38 – 371; FTTC 50 – 67; FTTC 59 – 236; FTTC 66-67 – 395; cable108 – 112, cable213 – 167, cable362 – 136, FTTP63-67 – 137, FTTP145 – 110 and FTTP300 – 112. Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests; (3) Coefficient of variation is calculated by dividing the standard deviation by the mean across panel members for the average 24-hour download speed; (4) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 108 Mbit/s, cable 213 Mbit/s, cable 362 Mbit/s, FTTP 75 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s.

[10] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: 1950 (Above 2 Mbit/s and including 10Mbit/s – 112; Above 10Mbit/s and less than 30Mbit/s – 222; Above 30Mbit/s – 1616) Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) The above 10 Mbit/s and less than 30 Mbit/s includes ADSL2+ connections which are not marketed using a connection speed.

[11] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: 1950 (ADSL1 – 39; ADSL2+ – 290; FTTC 36-38 – 371; FTTC 50 – 67; FTTC 59 – 236; FTTC 66-67 – 395; cable108 – 112, cable213 – 167, cable362 – 136) Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 108 Mbit/s, cable 213 Mbit/s and cable 362 Mbit/s

[12] Source: SamKnows measurement data for all national panel members with a connection in November 2019. Panel base: ADSL1 – 39; ADSL2+ – 290; FTTC 36-38 – 371; FTTC 50 – 67; FTTC 59 – 236; FTTC 66-67 – 395; cable108 – 112, cable213 – 167, cable362 – 136, FTTP63-67 – 137, FTTP145 – 110 and FTTP300 – 112. Notes: (1) Data have been weighted by ISP package market share, nation and geographic market classification, max attainable speed (FTTC) and distance from exchange (ADSL) to ensure that they are representative of the UK as a whole; (2) Due to the low representation of high-speed packages in the UK, ISP panel results are used for cable 108 Mbit/s, cable 213 Mbit/s, cable 362 Mbit/s, FTTP 67 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s (3) The bars indicate that

there is a 95% probability that the actual number of disconnections for all corresponding consumers fall within the given range.

A4. Glossary of terms

ADSL Asymmetric digital subscriber line. A digital technology that allows the use of a standard telephone line to provide high speed data communications. Allows higher speeds in one direction (towards the customer) than the other.

ADSL1 The first generation of ADSL, capable of theoretical data speeds of up to 8Mbit/s towards the customer and up to 640kbit/s from the customer.

ADSL2+ An improved version of ADSL, offering high speeds, especially on shorter telephone lines. In the case of ADSL2+, theoretical speeds of up to 24Mbit/s can be delivered towards the customer.

Advertised speed The speed at which broadband services are typically marketed, usually expressed as x Mbit/s (megabits per second).

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

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

Broadband provider. A company that provides broadband internet access.

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

Cable Sometimes referred to as Hybrid Fibre Coaxial (HFC) networks, cable networks combine optical fibre and coaxial cable (a cable made up of a conductor and a tubular insulating layer) to carry TV and broadband signals to end users. DOCSIS (Data Over Cable Service Interface Specification) is the technology standard used to deliver high speed broadband over HFC networks.

Contention A slowdown in performance caused when multiple users share the same bandwidth within a network and the bandwidth available is less than the aggregate demand.

Download speed Also downlink or downstream speed. 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) provides a crucial role in the internet. This protocol translates domain names (such as google.com) into the IP addresses that are used to route traffic (e.g. 80.77.246.42). Every broadband provider maintains its own DNS servers through which customers' computers issue queries to translate names into IP addresses. When these servers fail or operate slowly, web browsing and other online activities suffer.

Exchange The local telephone exchange is the building where all customers' copper telephone lines are connected to enable telephone calls to be switched, and where network equipment is installed which enables customers' data traffic to be routed via an operator's core network to its destination.

FTTC (fibre-to-the-cabinet) An access network consisting of optical fibre extending from the access node to the street cabinet. The street cabinet is usually located only a few hundred metres from the subscriber premises. The remaining segment of the access network from the cabinet to the customer is usually a copper pair, but another technology such as wireless could be used.

Headline speed See ‘advertised speed’.

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

Latency The time it takes a single packet of data to travel from a user’s PC to a third-party server and back again. The figure is most commonly measured in milliseconds, and a connection with low latency will feel more responsive for simple tasks like web browsing.

LLU (local loop unbundling) LLU is the process whereby incumbent operators (in the UK these are BT and Kingston Communications) make their local network (the lines that run from customer’s premises to the telephone exchange) available to other communications providers. The process requires the competitor to deploy its own equipment in the incumbent’s local exchange and to establish a backhaul connection between this equipment and its core network.

Local loop The access network connection between the customer's premises and the local telephone exchange, usually a loop comprising two copper wires.

Mbit/s Megabits per second. A unit measuring the bit-rate.1 Mbit/s is the equivalent of 1,000 kbit/s.

Multi-thread test A test involving the download of two or more data files simultaneously – in the case of our research, three files (see Technical Methodology – Annex 1). Multi-thread tests typically record faster speeds than single-thread tests, in particular for higher-speed connections.

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

Streaming content Audio or video files sent in compressed form over the internet and consumed by the user as they arrive. Streaming is different to downloading, where content is saved on the user’s hard disk before the user accesses it.

Sync speed (modem synchronisation speed) The maximum download speed that a line can support according to the way the line is configured by a customer’s broadband provider.

Upload speed Also uplink or upstream speed. Rate of data transmission from a customer’s connection to a network operator’s access node, typically measured in Megabits per second (Mbit/s).