Ofcom
making communications work
for everyone

UK Home Broadband Performance

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

Fairness for customers

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Annex

1. Overview

Reliable, high-speed broadband connectivity is an essential part of life for many people in the UK. Four in five households[1] have a fixed broadband connection, and increasing use of data-hungry activities such as video streaming services (which are used in more than 12 million UK homes)[2] mean that the need for fast, reliable home broadband has never been greater.

To gain insight into the overall performance delivered by UK residential broadband providers, Ofcom has commissioned technical partner SamKnows to set up a panel of consumers who have a monitoring unit connected to their router.[3] This enables us to make a robust assessment of the performance delivered by different services and how they vary by a number of factors including technology, service provider, package, geography and time of day.

Our Home Broadband Performance reports are based on tests run in November of each year. We measure the performance that the internet service provider (ISP) delivers to the consumer's router. The actual performance delivered to consumers' devices varies as it is affected by several factors including wi-fi performance, in-house contention (i.e. when more than one device is connected to the wi-fi), device limitations and the performance of servers delivering content consumed over the connection. The technical methodology is available as Annex 1 and the statistical methodology as Annex 2.

The availability of higher-speed home broadband services continues to improve. In our Connected Nations update: Spring 2019 report, 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 around 95% of UK homes and offices by January 2019, while fibre-to-the-premises (FTTP) full-fibre services were available to 7% of premises.

[1] https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2018/interactive
[2] BARB Establishment Survey: Q4 2018
[3] In 2018, this panel consisted of 4,918 volunteers (including 2,182 panellists on SamKnows' independent global platform, SamKnows One).

What we have found, in brief

The average actual home broadband download speed in 2018 was over 50 Mbit/s for the first time

Average home broadband connection speeds continued to improve in 2018, with average download speeds increasing by 18% to 54.2 Mbit/s and average upload speeds by 15% to 7.2 Mbit/s. This was largely due to the growing availability and take-up of superfast and ultrafast fibre and cable broadband services,[4] which our research shows accounted for just under two-thirds of home broadband connections in November 2018.

There are significant differences in performance between urban and rural areas

Overall, 58% of lines had an average 8-10pm peak-time speed of 30 Mbit/s or above in 2018. The proportion of lines receiving an average peak-time download speed greater than 30 Mbit/s was lower in rural areas of the UK (44%) than in urban areas (61%), and while 13% of urban lines had a peak-time speed of under 10 Mbit/s, the proportion was 33% in rural areas.

Cable and full-fibre services recorded the highest average upload and download speeds

Virgin Media's 362 Mbit/s cable service provided the fastest average download speed of the packages included in the report, both over the whole day (365.0 Mbit/s) and in the peak 8-10pm period (360.2 Mbit/s). BT's 300 Mbit/s full-fibre service ranked second for download speeds, with 24-hour and peak-time average speeds of 302.3 Mbit/s and 300.6 Mbit/s respectively, and top for upload speeds, with a 48.8 Mbit/s average over 24 hours and during the 8-10pm peak-time period.

BT's 67 Mbit/s full-fibre service outperformed its fibre-to-the-cabinet equivalent

The inclusion of full-fibre services in the research for the first time has enabled us to compare the performance of BT's 67 Mbit/s FTTP full-fibre service to the equivalent BT fibre-to-the-cabinet (FTTC) service. We found that for all but one of the metrics for which comparable figures were available (the average number of daily disconnections), full-fibre outperformed FTTC.[5] Full-fibre is also able to provide connection speeds far above those available over FTTC.

Performance varies by service and technology, but not among services relying on the same wholesale input

Our research finds that consumers can often receive better performance by switching to a different technology or by upgrading to a service with a higher advertised speed. However, the services provided by many internet service providers (ISPs), including BT, EE, Plusnet, Sky and TalkTalk, use the same wholesale inputs provided by Openreach, and we find few differences between providers using the same underlying Openreach service. This means it is unlikely that users will experience a significant improvement in performance by switching from one FTTC or asymmetric digital subscriber line (ADSL) package to another with the same, or a similar, advertised speed.

[4] We define superfast connections as those delivering actual download speeds ≥30Mbit/s and ultrafast connections as those delivering actual download speeds ≥300Mbit/s.
[5] To a level of 95% statistical significance.

There was greater variation in the speeds delivered to panellists using copper-based services than to those with cable or full-fibre

The performance of copper-based ADSL and FTTC services degrades over the length of the copper line, while all connection types are affected by congestion during busy periods. Not all customers are affected equally – the performance of copper-based broadband varies from customer-to-customer based on the length and quality of the copper line to their home and, for all technologies, congestion can be localised.

To examine this, we conducted analysis to calculate the coefficient of variation (a measure the variation in set of values relative to their mean) of download speeds for different technologies. This found that ADSL connections had the greatest variation in performance, followed by FTTC services, with much less variation in the performance of cable and full-fibre services. This indicates the importance to consumers of getting an estimate for the speed of their line (which signatories to the voluntary Code of Practice on Broadband Speeds are required to provide) before purchasing an ADSL or FTTC service, rather than relying on advertised speeds alone.

In most cases, superfast products can stream Netflix videos in ultra-high definition (UHD)

The streaming of video content is one of the most data-hungry activities that people use their home broadband users use their connection for, and we ran tests to investigate the capability of delivering Netflix video content. We found that all but one of the superfast cable and fibre products included in the report could reliably deliver over 90% of single Netflix videos in ultra-high definition (UHD) resolution during peak-time periods.[6] For second-generation ADSL (ADSL2+) services, 12% of peak-time streams could be delivered in ultra-high definition (UHD), and over three-quarters (85%) in high-definition (HD).

Ofcom is committed to improving the availability and quality of fixed broadband services

Ofcom has introduced a package of measures to encourage investment in full-fibre, following a range of commitments by broadband companies. Under these rules, Openreach has a duty to make its telegraph poles and underground ducts open to rival providers, making it easier for them to deploy full-fibre. In addition, Openreach must repair faulty infrastructure and provide a 'digital map' of its duct and pole network, so other providers can plan where to lay fibre.

The UK's largest ISPs are signatories to the Voluntary Code on Broadband Speeds, which requires that speed estimates are provided ahead of sale, and gives consumers the right to exit their contract penalty-free if speeds are below a guaranteed minimum level. A new version of the code came into effect in March 2019, including more realistic speed estimates reflecting peak-time speeds, providing a minimum guaranteed download speed at the point of sale, improving the 'right to exit' process and widening its scope to cover all fixed broadband technologies.

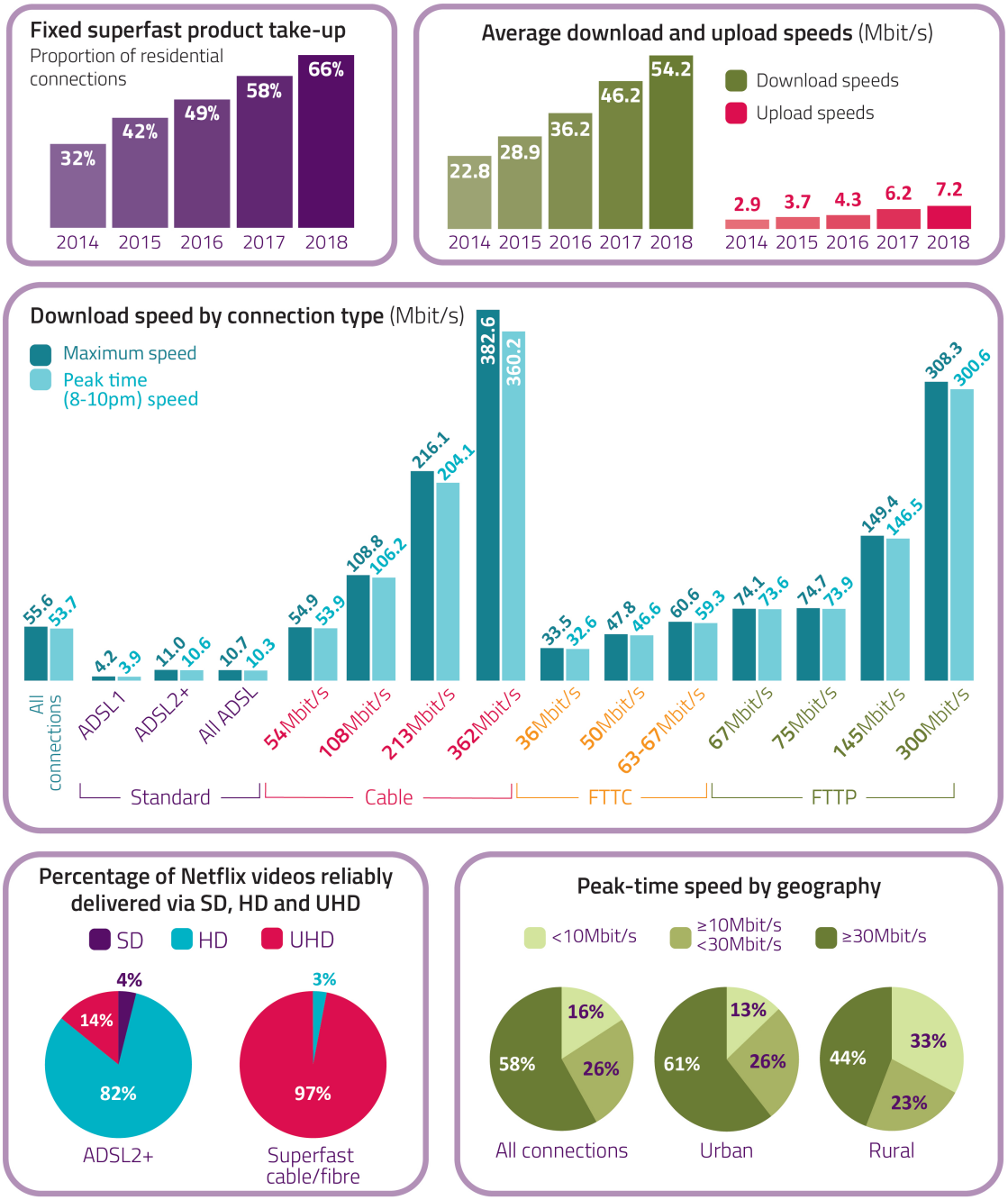
Our Boost Your Broadband campaign highlights that millions of broadband customers could get a faster service or a cheaper package than the one they currently have. We are encouraging

[6] It is important to bear in mind that the streaming quality that can be reliably achieved may drop when multiple users are simultaneously using the same connection.

consumers to see if they can get more from their broadband by checking what services are available in their area and by giving them the information they need to speak to their provider about the deals that are available to them.

Ofcom is in the process of implementing the broadband universal service obligation (USO) which will give people in the UK the right to request a decent broadband connection, defined by Government as a service that can provide a download speed of 10 Mbit/s and an upload speed of 1 Mbit/s upload (with other technical features to ensure service quality).

2. Dashboard


Fixed superfast product take-up
Proportion of residential connections
32%
42%
49%
58%
66%
2014 2015 2016 2017 2018
Average download and upload speeds (Mbit/s)
Download speeds
Upload speeds
22.8
28.9
36.2
46.2
54.2
2.9
3.7
4.3
6.2
7.2
2014 2015 2016 2017 2018
Download speed by connection type (Mbit/s)
Maximum speed
Peak time (8-10pm) speed
55.6 53.7
4.2 3.9
11.0 10.6
10.7 10.3
54.9 53.9
108.8 106.2
216.1 204.1
382.6 360.2
33.5 32.6
47.8 46.6
60.6 59.3
74.1 73.6
74.7 73.9
149.4 146.5
308.3 300.6
All connections
ADSL1
ADSL2+
All ADSL
54Mbit/s
108Mbit/s
213Mbit/s
362Mbit/s
36Mbit/s
50Mbit/s
63-67Mbit/s
67Mbit/s
75Mbit/s
145Mbit/s
300Mbit/s
Standard
Cable
FTTC
FTTP
Percentage of Netflix videos reliably delivered via SD, HD and UHD
SD
HD
UHD
4%
14%
82%
3%
97%
ADSL2+
Superfast cable/fibre
Peak-time speed by geography
<10Mbit/s
≥10Mbit/s <30Mbit/s
≥30Mbit/s
16%
58%
26%
13%
61%
26%
33%
44%
23%
All connections
Urban
Rural

3. Background

Introduction

Ofcom's principal duty under the Communications Act 2003 (the Act) in carrying out its functions 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, which includes fixed broadband services. We must also have regard to the desirability of encouraging investment and innovation in relevant markets, the availability and use of high-speed data services throughout the UK, and the interests of consumers in respect of choice, price, quality of service and value for money.

The Act also requires us to make arrangements to find out about consumers' experience in their use of, and access to, electronic communications services, and we do this 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 the consumer 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 2), combined with the scale of data collection and the sophistication of the statistical analysis (see Annex 3), 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 ISPs. This approach gives a measure of the maximum connection speed achieved between the ISP's access network and the consumer's premises, which is not affected by contention and is usually slightly higher than the 'end-to-end' line speed measurements we present here.

There are a number of limitations to the research that we present here. While our research accurately represents the performance delivered to our panellists' routers, it does not capture certain important factors other than broadband network performance that can affect the end user's experience, such as wi-fi router performance. Similarly, there may be steps that consumers can take to improve their user experience, such as replacing in-home wiring and moving their router to a more suitable location.

Embedded panel tests

One of the limitations of our hardware-based measurement methodology is that we are only able to 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 for the first time, they allowed Ofcom to access to some of these test results (on an anonymised basis) to feed into this report. BT gave access to test results relating to its 67 Mbit/s,

145 Mbit/s and 300 Mbit/s fibre-to-the-premises (FTTP) full-fibre services, while Virgin Media allowed Ofcom to use test results relating to its 54 Mbit/s and 362 Mbit/s cable services.

The embedded tests run on the BT and Virgin Media routers are identical to those run on the main Ofcom panel's measurement units, with the exception of the video streaming test, which is not run by BT. SamKnows has confirmed that the tests being run on an ISP's router rather than on one of its Whitebox measurement units would have no discernible effect the measured results. In addition, where the ISPs 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.

Package advertised speeds

On 23 May 2018, new Advertising Standards Authority (ASA) guidelines on the advertising of broadband speeds were introduced.

These require that any speeds used in broadband advertising should reflect actual package performance and should be based on the download speed available to at least 50% of customers at peak times. Previous guidelines required that the advertised speed should be the maximum speed available to at least 10% of customers on a package, meaning that, potentially, up to 90% of customers might never be able to receive it.

Because of the new guidelines, the advertised speeds of most services have changed since last year. Examples of the changes to advertised speeds are shown below.

Figure 1: Comparison of speeds used in home broadband advertising under old and new guidelines

ISP/s	Technology	Old advertised speed	New advertised speed
BT, Plusnet, Sky & TalkTalk	ADSL2+	14-17 Mbit/s	10-11 Mbit/s
BT, EE, Plusnet, Sky & TalkTalk	FTTC	38 Mbit/s	36 Mbit/s
BT	FTTC	52 Mbit/s	50 Mbit/s
BT, EE, Plusnet, Sky & TalkTalk	FTTC	76 Mbit/s	63-67 Mbit/s
Virgin Media	DOCSIS / cable	50 Mbit/s	54 Mbit/s
Virgin Media	DOCSIS / cable	100 Mbit/s	108 Mbit/s
Virgin Media	DOCSIS / cable	200 Mbit/s	213 Mbit/s
Virgin Media	DOCSIS / cable	350 Mbit/s	362 Mbit/s

Source: Ofcom.

BT speed upgrades and FTTC line quality

BT rolled out speed upgrades to some of its lower-tier BT Infinity 1 fibre-to-the-cabinet (FTTC) customers in late 2017. Under the upgrade programme, existing Infinity 1 customers whose lines

could support sync speeds greater than 55 Mbit/s had their upload and download speeds upgraded to those offered by BT's higher-tier Infinity 2 (67 Mbit/s) service, free of charge. More than a million BT customers benefited from this upgrade.

In our analysis, BT Infinity 1 36 Mbit/s panellists whose speeds were upgraded under the programme are included in the 'BT 67 Mbit/s FTTC' category. While the upgrades were beneficial to those who received them, they are likely to have several effects on the data collected in 2018:

- As BT Infinity 1 panellists with higher-quality lines are likely to have been upgraded to its 67 Mbit/s service, the remaining panellists on these packages are likely to have lower-than-average-quality lines. As a result, the data in this report are likely to slightly understate the performance that we would expect new customers signing up to BT's 36 Mbit/s and 50 Mbit/s FTTC services to receive.
- The upgrades also mean that BT 67 Mbit/s FTTC panellists are likely to have higher-than-average-quality lines, resulting in an overstatement of the performance that we would expect new customers buying this service to receive.

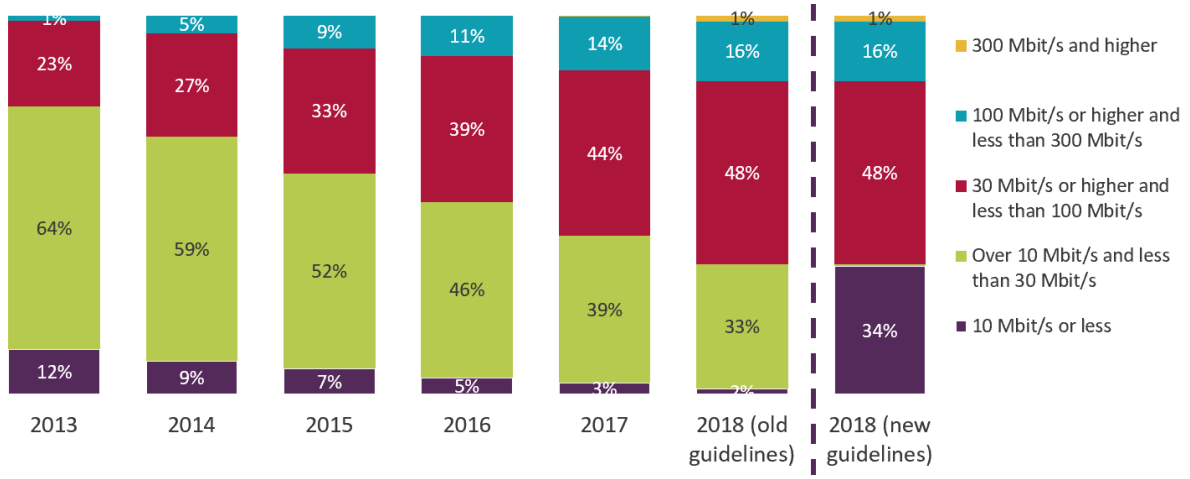
We are unable to conclude whether any differences in the performance of BT's FTTC services and those of other ISPs services are due to the upgrades or any other service provision factors.

4. Download speeds

Around two-thirds of UK home broadband connections were superfast products in November 2018

- In 2018, around two-thirds (66%) of UK home broadband connections were superfast products with an advertised speed of 30 Mbit/s or higher.
- Similarly, 1% were ultrafast products with an advertised speed of 300 Mbit/s or higher.
- New broadband advertising guidelines mean that the proportion of customers on packages with an advertised average speed of up to 10 Mbit/s increased in 2018.
- This is due to changes in the way in which ADSL-based standard broadband services are advertised.

Figure 2: UK residential broadband lines, by advertised speed: 2013 to 2018

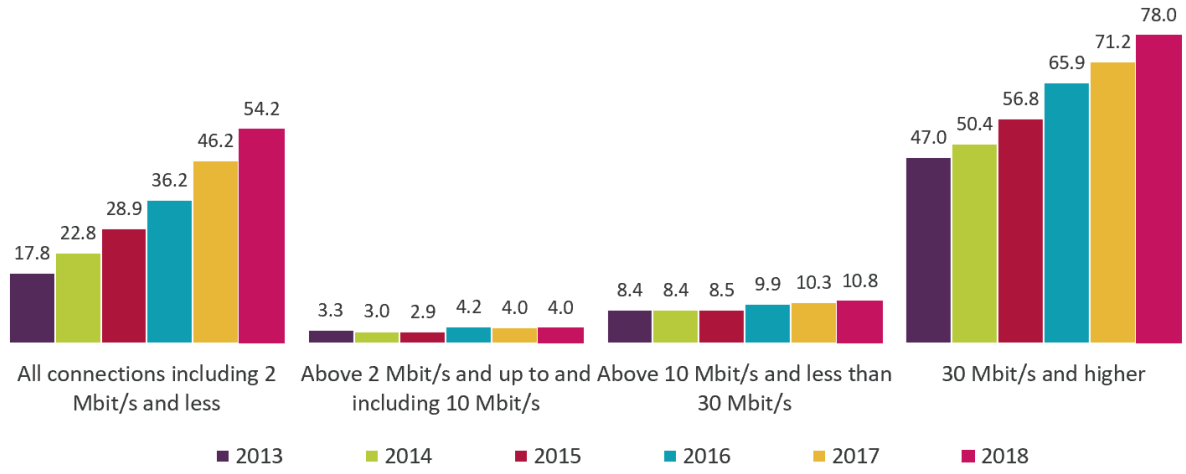


Source: Ofcom / operators; see note [2] in the Sources section.

The average actual residential download speed was over 50 Mbit/s for the first time in 2018

- The average actual speed of UK residential fixed broadband services recorded over the 24-hour period increased by 8.1Mbit/s (18%) to 54.2 Mbit/s in 2018.
- This was a slower rate of increase than the 10.0 Mbit/s (28%) increase recorded in 2017.

Figure 3: Average actual broadband speeds: 2013 to 2018 (Mbit/s)

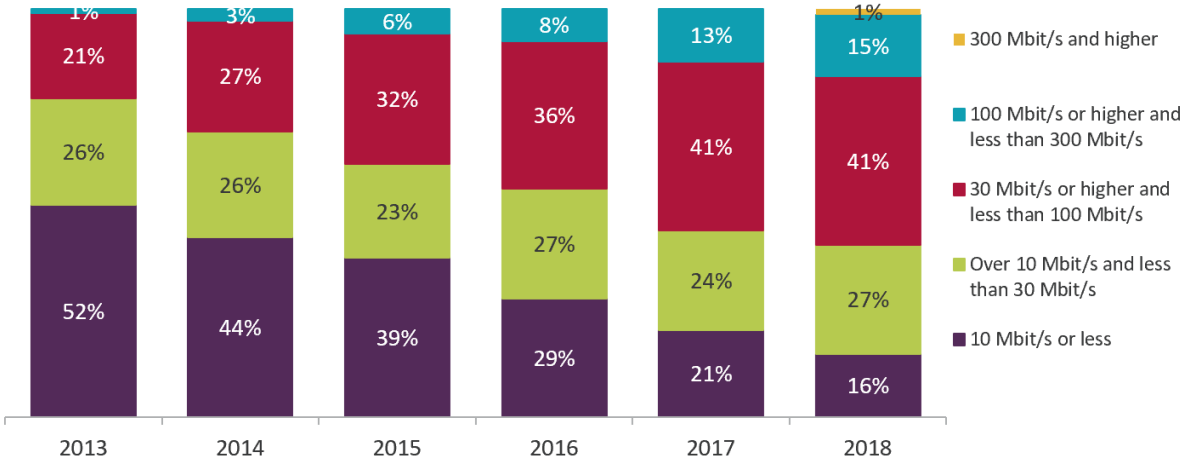


Source: Ofcom, using data provided by SamKnows; see note [1] in the Sources section.

Sixty per cent of residential broadband lines had an average speed of 30 Mbit/s or higher in 2018

- Our research shows that 58% of residential broadband lines had a 24-hour average download speed of 30 Mbit/s or higher in 2018, up from 54% in 2017.
- One per cent of lines had an average 24-hour download speed of 300 Mbit/s or higher.
- The proportion of lines receiving an average download speed of 10 Mbit/s or less fell in 2018, down six percentage points to 16%.

Figure 4: Distribution of average 24-hour download speeds: 2013 to 2018 (Mbit/s)

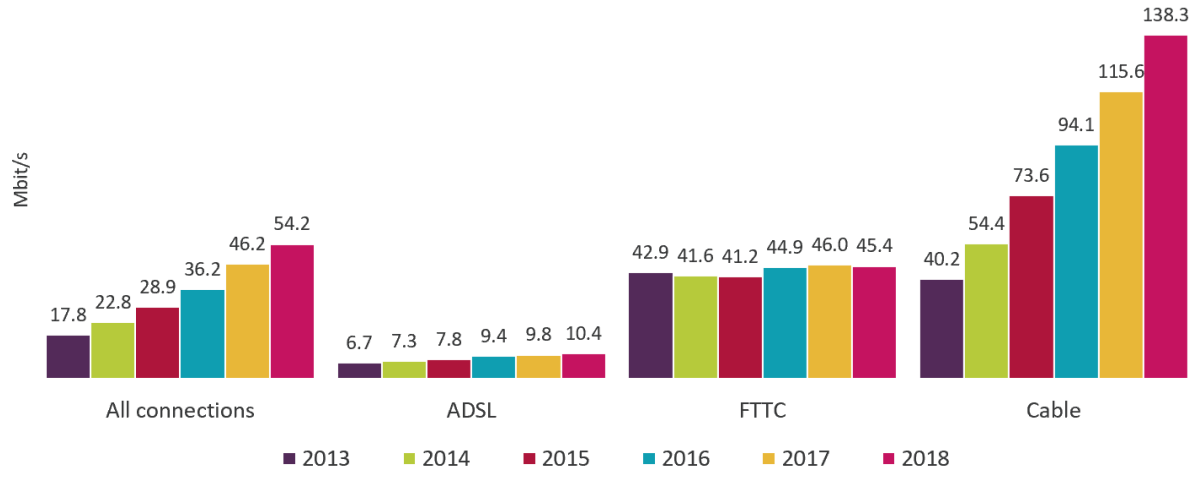


Source: Ofcom, using data provided by SamKnows; see note [1] in the Sources section.

Cable and FTTP connections had the fastest average download speeds in 2018

- Our analysis indicates that the average download speeds of cable connections increased in by 20% to 138.3 Mbit/s in 2018.
- This was partly due to the introduction of a new 362 Mbit/s top-tier service by Virgin Media.
- There was a small decrease in the average download speed delivered by fibre-to-the-cabinet (FTTC) connections, down by 0.6Mbit/s (1%) to 45.4Mbit/s, driven by a fall in the proportion of FTTC lines that were higher-tier 63-67 Mbit/s connections.[7]

Figure 5: Average download speeds for fixed broadband connections, all connections including 2 Mbit/s and less, by technology (Mbit/s)



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

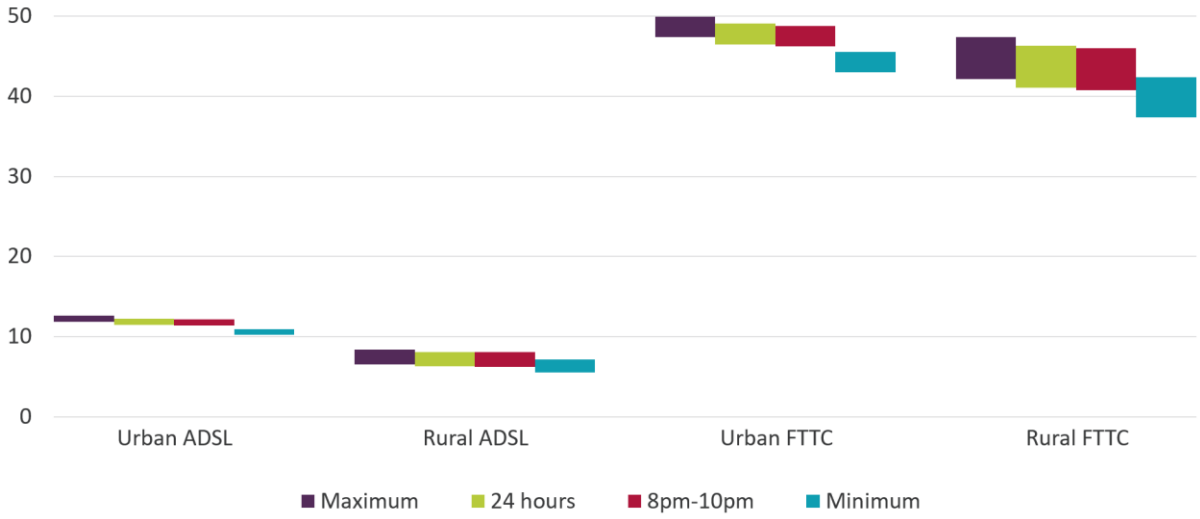
Longer line lengths in rural areas result in lower average speeds for copper-based broadband services

- 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.
- 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.
- As ADSL 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.
- For ADSL connections, the average 24-hour download speed in urban areas (11.9 Mbit/s) was 65% higher than the 7.2 Mbit/s average in rural areas.
- There is less variation in the length of copper line from the street cabinet to the user's premises, and we found that average FTTC download speeds in rural areas (43.8 Mbit/s) were in line with those in urban areas (47.8 Mbit/s).

[7] Top tier FTTC services had an advertised speed of 'up to' 76Mbit/s under the old broadband speeds advertising guidance.

- Most rural ADSL customers who upgrade to FTTC will experience a significant increase in performance, and average FTTC download speeds were around six times faster than ADSL average download speeds in rural areas in 2018.

Figure 6: Average ADSL and FTTC download speeds, by rurality: 2018 (Mbit/s)

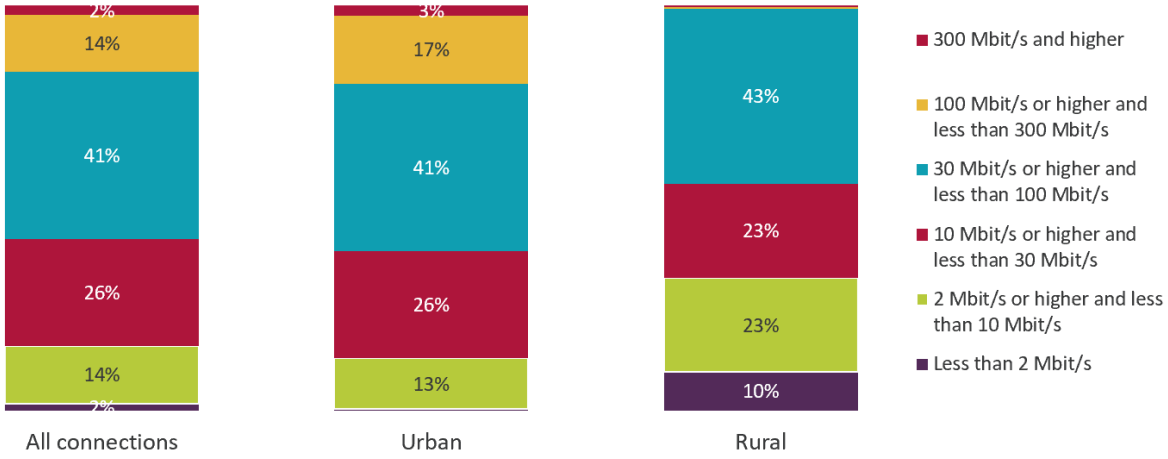


Source: Ofcom, using data provided by SamKnows; see note [4] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists within our sample) falls within the ranges shown; it is not possible to 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

…which combined with lower superfast availability results in lower actual speeds in rural areas

- In addition to ADSL download speeds tending to be lower in rural areas, the availability and take-up of superfast broadband tends to be lower.
- Ofcom's Connected Nations update: Spring 2019 shows that superfast broadband services were available to 98% of urban premises in January 2019, compared to 76% in rural areas.
- Our research shows that 58% of UK home broadband connections had an 8-10pm peak-time average actual download speed of 30 Mbit/s or higher in November 2018, and 16% had a peak-time average actual speed of less than 10 Mbit/s.
- However, while 61% of panellists in urban areas received an average 8-10pm peak-time speed of 30 Mbit/s or higher in November 2018, the figure was lower in rural areas, at 44%.
- Conversely, the proportion of urban lines that received an average peak-time speeds of less than 10 Mbit/s (13%) was less than half the 33% figure for rural areas.
- Our research shows that average download speeds in rural areas (28.0 Mbit/s) were less than half those in urban areas (62.9 Mbit/s).

Figure 7: Distribution of average peak-time, 8-10pm, fixed broadband download speeds, by rurality: 2018 (proportion of lines)

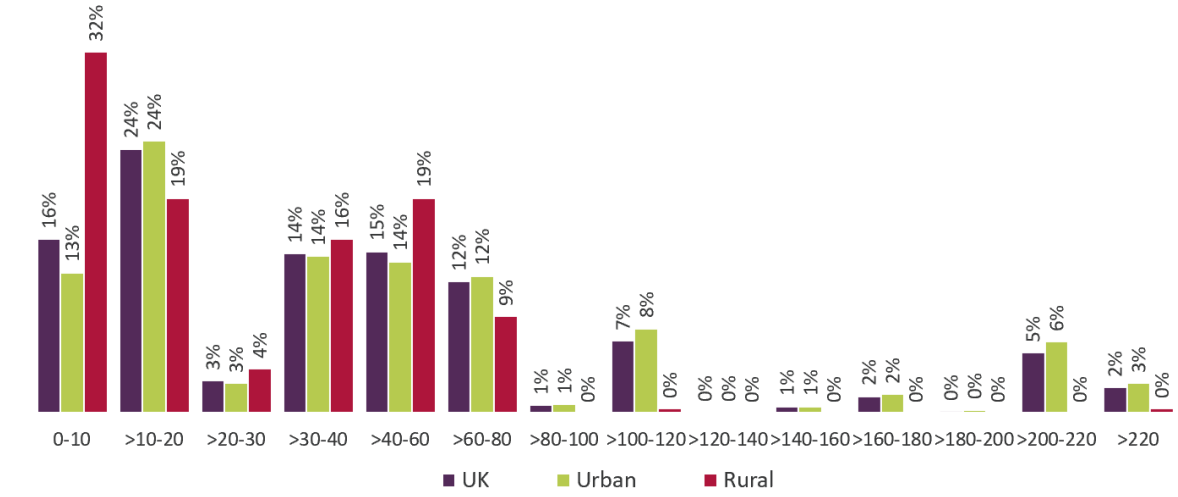


Source: Ofcom, using data provided by SamKnows; see note [5] in the Sources section.
Note: It is not possible to make direct comparisons between this data and figures published in previous reports due to panel composition differences and a change in the weighting methodology used for this analysis.

Just under a third of rural broadband lines receive download speeds of 10 Mbit/s or less

- Our research shows that in November 2018 just under a third (32%) of panellists in rural areas of the UK received an average 24-hour download speed of less than 10 Mbit/s, which we consider to be the speed which enables full participation in a digital society.
- This proportion was much higher than for the UK as a whole (16%) and the proportion in urban areas (13%).
- However, many rural and urban consumers may be able to achieve higher speeds by switching to fibre or cable services.

Figure 8: Distribution of average 24-hour fixed broadband download speeds, by rurality: 2018 (proportion of lines)

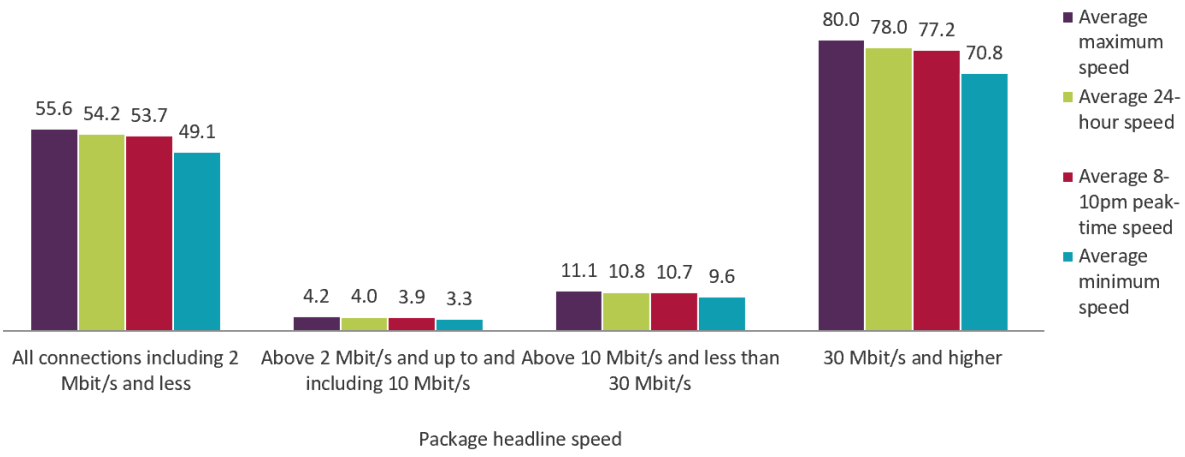


Source: Ofcom, using data provided by SamKnows; see note [5] in the Sources section.
Note: It is not possible to make direct comparisons between this data and figures published in previous reports due to panel composition differences and a change in the weighting methodology used for this analysis.

Download speeds vary through the day

- The performance of broadband services varies by time of day, with speeds slowing down during busy periods when network traffic volumes are highest.
- Across all connections, the average daily minimum speed (49.1 Mbit/s) was 88% of the average maximum speed (55.6 Mbit/s).
- The average download speed recorded during the 8-10pm peak-time period was 53.7 Mbit/s, 96% of the average maximum speed.

Figure 9: Average UK broadband speeds, by time of day: 2018 (Mbit/s)

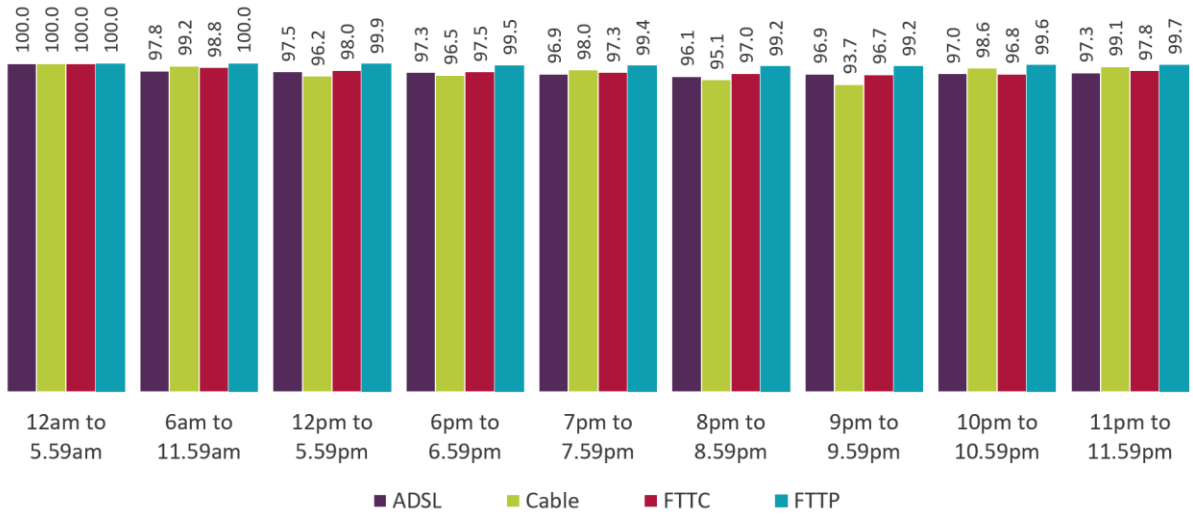


Source: Ofcom, using data provided by SamKnows; see note [1] in the Sources section.

FTTP has the least slowdown at busy times

- Our research shows that all technologies recorded their lowest average speeds between 8pm and 9.59pm.
- Cable packages had the greatest slowdown at busy times; the average speed between 9pm and 9.59pm was 93.7% of the highest recorded speed, which occurred between 12am and 5.59am.
- FTTP packages had the least slowdown at busy times; the average download speed between 9pm and 9.59pm was 99.2% of the highest speed recorded between 6am and 11.59pm.
- The lowest recorded average speeds as a proportion of the highest recorded speeds were similar for both the copper-based technologies, at 96.1% for ADSL and 96.7% for FTTC.

Figure 10: Proportion of maximum speed delivered through the day: 2018 (Mbit/s)



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.

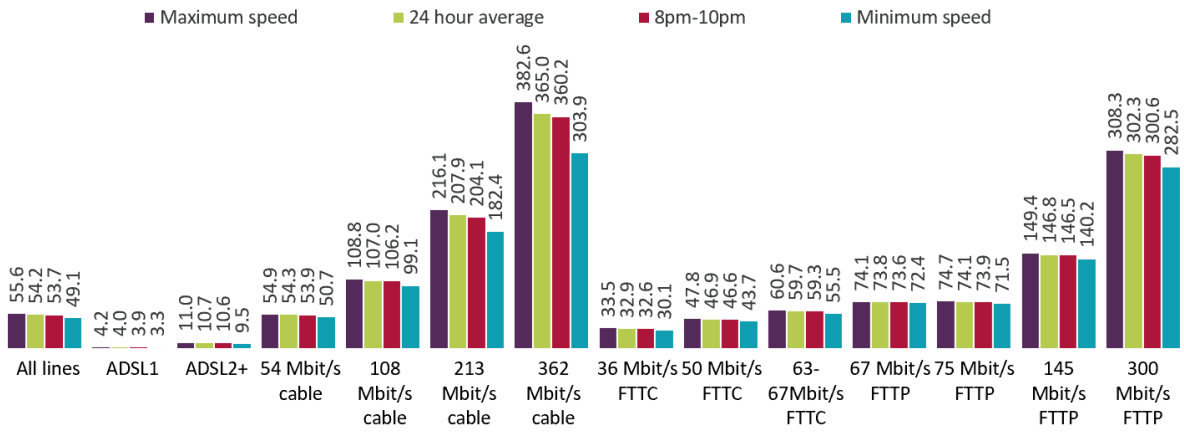
Cable connection performance during busy times continues to improve

- 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 advertised speed (although under the Voluntary Code of Practice for broadband speeds, ISPs must provide an estimate of the speed that the line can support, before purchase).
  - The actual speeds of all connection types tend to fall at busy times, when ISPs' networks are busy. The variation in speeds at peak times is more notable for cable connections, due to cable network topologies, which mean that network congestion occurs closer to the

customer (in the access network rather than the backhaul network) making it more difficult (and expensive) to add the additional capacity required to alleviate the effects of congestion.

- Our research shows that 24-hour, peak-time and minimum download speeds were lower than average maximum speeds for all connection types in 2018.
- Cable services continued to show improvements in peak-time download speeds in 2018, with the average peak-time download speed of 54 Mbit/s, 108 Mbit/s and 213 Mbit/s services increasing by between 1% and 6% year on year.

Figure 11: Variations in download speeds, by time of day: 2018 (Mbit/s)

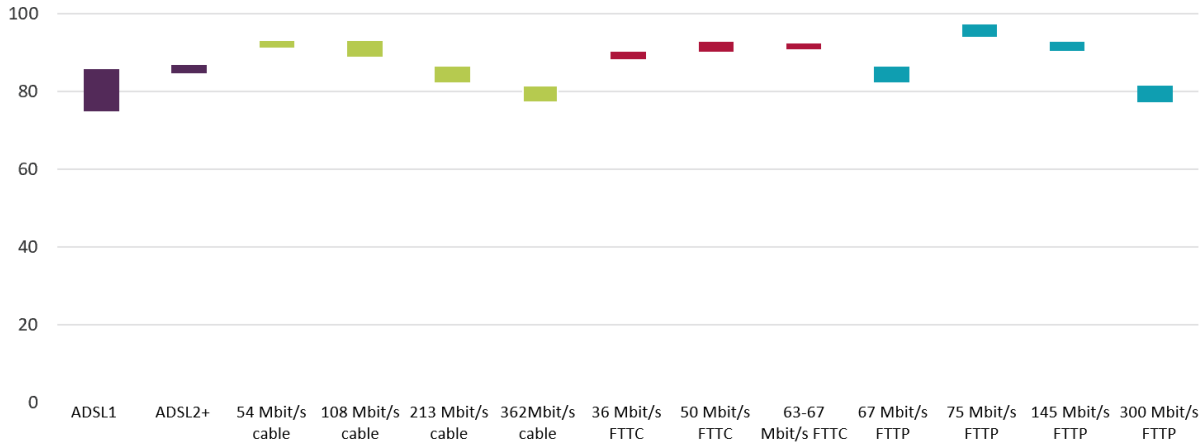


Source: Ofcom, using data provided by SamKnows; see note [7] in the Sources section.

Contention varies by network technology

- We measure network slowdown during busy periods (contention) by comparing ISP packages' average minimum and maximum speeds, our assumption being that the primary reason for any differences between the two is network congestion.
- For 54 Mbit/s, 108 Mbit/s 213 Mbit/s and 362 Mbit/s cable services, minimum download speeds were between 79% and 92% of maximum speeds.
- For 36 Mbit/s FTTC services, minimum download speeds were 90% of their maximum download speeds, while for 50 Mbit/s and 63-67Mbit/s FTTC, the proportions were 91% and 92% respectively.
- Among the FTTP packages included in the research, minimum speeds were between 92% and 98% of the maximum speeds.
- For ADSL2+ services, minimum download speeds were 87% of maximum speeds, while for ADSL1 the figure was 80%.

Figure 12: Minimum speed as proportion of maximum speed: 2018 (%)

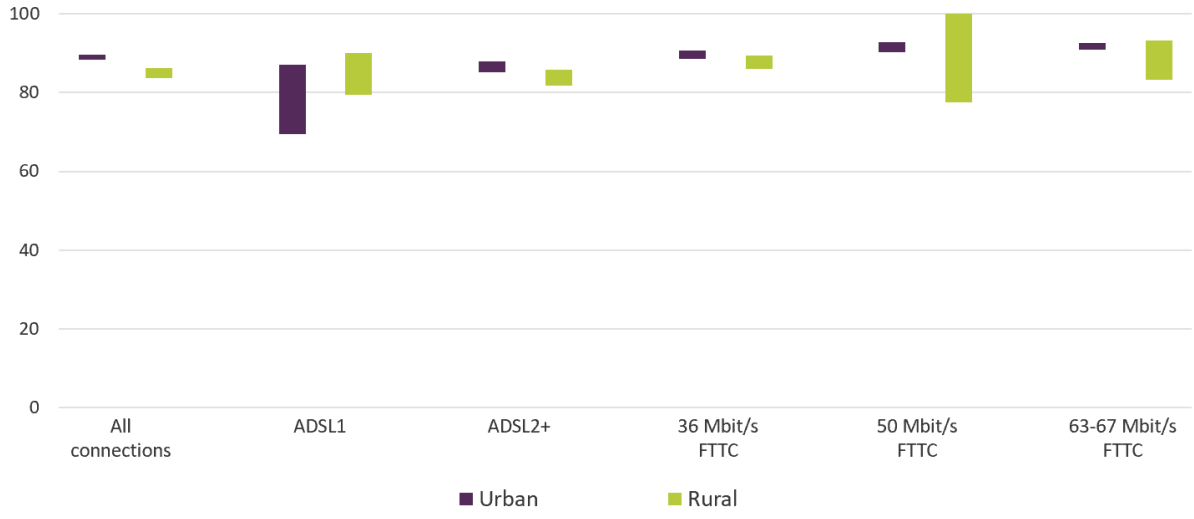


Source: Ofcom, using data provided by SamKnows; see note [8] in the Sources section.
Note: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown.

There is little variation in slowdown between urban and rural connections

- Our research found that across all residential fixed broadband connections, rural areas had higher average levels of contention than urban areas.
- The average minimum speed as a proportion of maximum speed among rural connections was 84%, compared to 89% in urban areas.
- There were no significant differences between contention in urban and rural areas of the UK for the ADSL2 and FTTC packages shown in the chart below.
- Therefore, the UK-level differences noted were due to contention in cable and FTTP services (for which we did not have enough panellists to allow us to compare urban and rural performance).

Figure 13: Minimum speeds as a proportion of maximum speed, by rurality: 2018 (%)



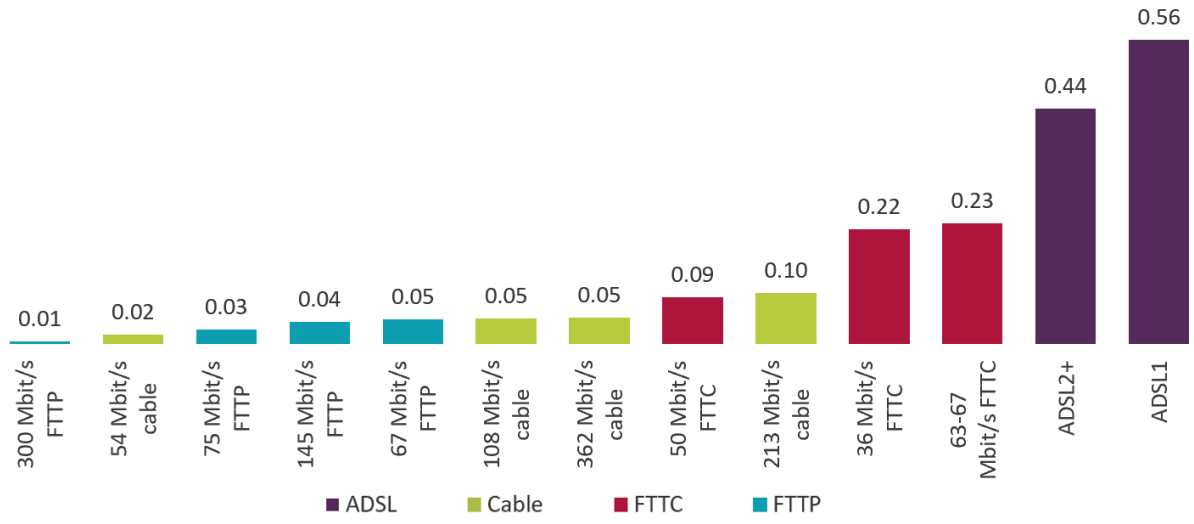
Source: Ofcom, using data provided by SamKnows; see note [9] in the Sources section.
Note: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown.

5. Distribution of download speeds

There is greater variation in the speeds delivered to panellists using copper-based services than to those with cable or FTTP

- As outlined previously, the speed of copper-based broadband services is affected by attenuation (when speeds degrade over the length of a copper line).
- All broadband services suffer from contention (when networks become congested in busy periods) although users may not be equally affected by peak-time slowdown, as network congestion can be localised.
- 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.
- 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.
- Figure 27 below shows the coefficient of variation of the 24-hour download speeds across the packages included in our analysis. This analysis showed that ADSL connections had the greatest variation in performance.
- Generally, FTTC connections had a greater variation in performance compared to FTTP connections, and the variation in performance of cable lines depended on the speed tier of the connection.
- Annex 1 looks at the performance of EE's 4GEE Home fixed wireless home broadband service and finds that the coefficient of variation for these connections was higher than those of the traditional fixed broadband technologies shown below.

Figure 14: Coefficient of variation for average 24-hour download speeds, by connection type

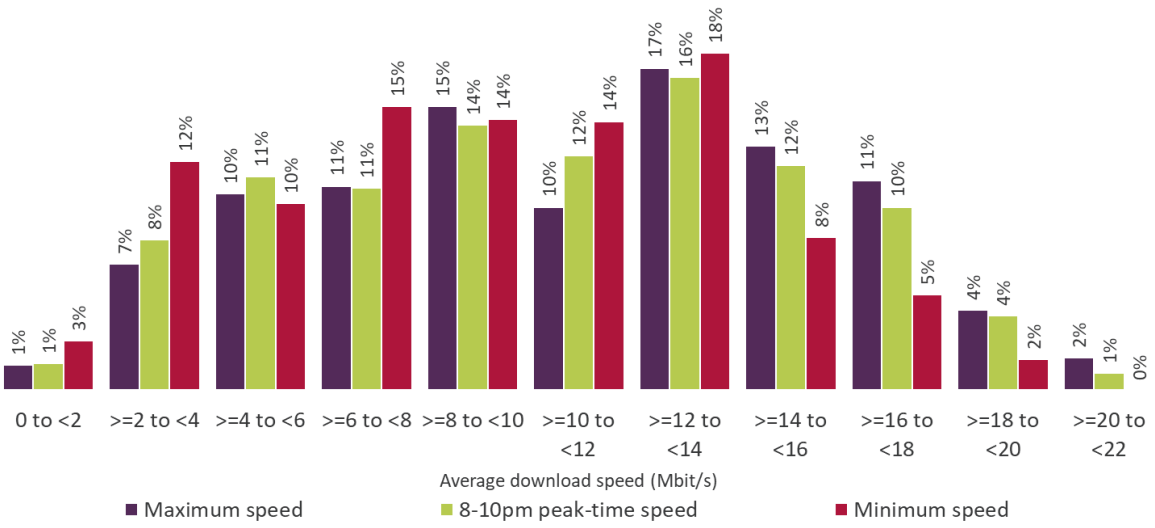


Source: Ofcom, using data provided by SamKnows; see note [10] in the Sources section.

Distribution of ADSL2+ download speeds

- For ADSL2+ packages, just under half of panellists (44%) received an average maximum speed of less than 10 Mbit/s in November 2018.
- Fifty-four per cent of ADSL2+ panellists received a minimum download speed below 10 Mbit/s.

Figure 15: Distribution of maximum, peak-time and minimum download speeds for ADSL2+ packages: 2018 (proportion of lines)

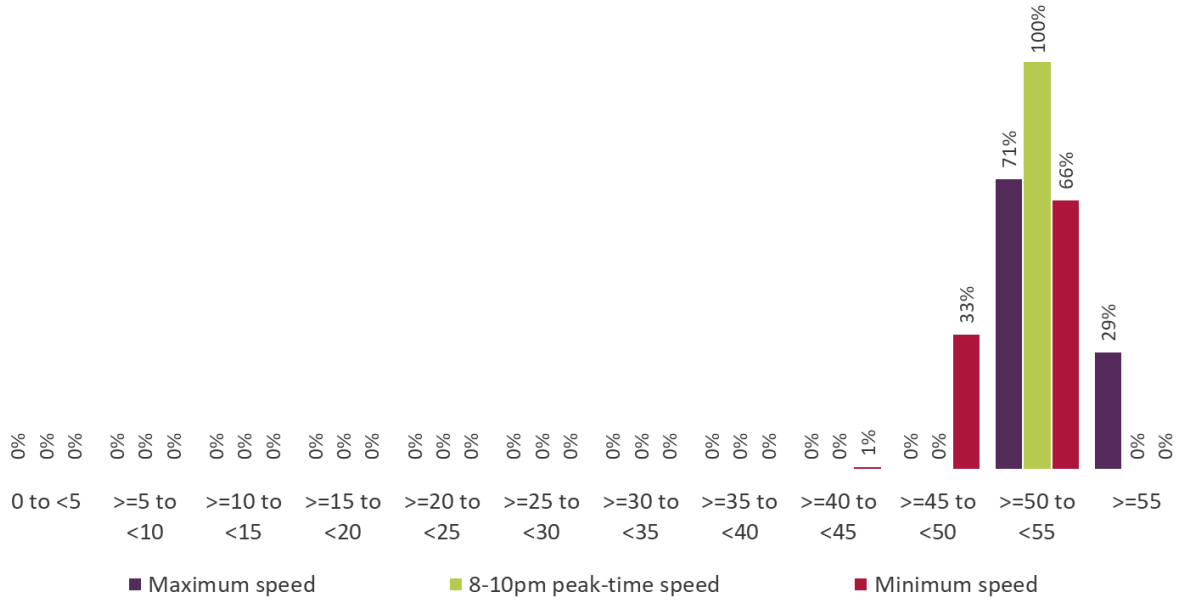


Source: Ofcom, using data provided by SamKnows; see note [13] in the Sources section.

Distribution of cable download speeds

- For 54 Mbit/s cable connections, all panellists received a minimum speed of 30 Mbit/s or higher and a maximum speed of 54 Mbit/s or higher.

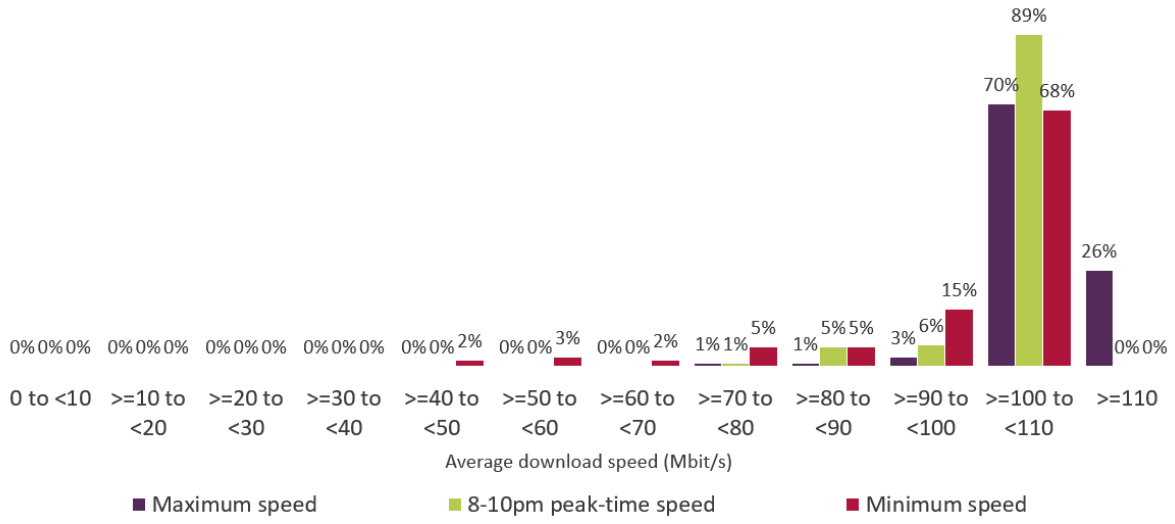
Figure 16: Distribution of maximum, peak-time and minimum download speeds for 54 Mbit/s cable connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [14] in the Sources section.

- For 108 Mbit/s cable connections, all panellists achieved a minimum speed of 30 Mbit/s or higher, and 85% received a maximum speed of over 108 Mbit/s.

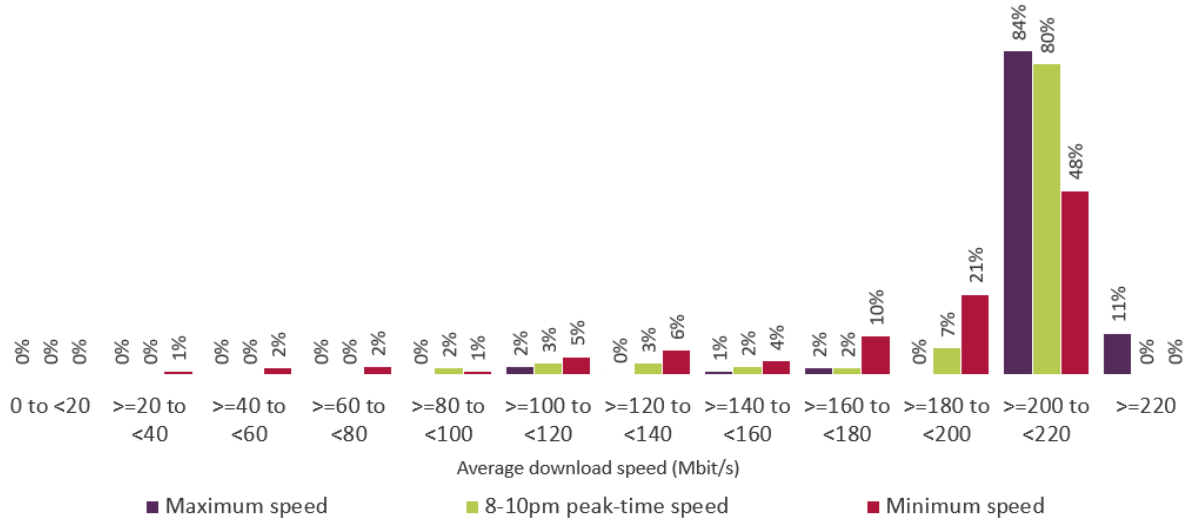
Figure 17: Distribution of maximum, peak-time and minimum download speeds for 108 Mbit/s cable connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [15] in the Sources section.

- All 213 Mbit/s cable panellists achieved a minimum speed of 30Mbit/s or higher and 88% received a maximum speed of over 213 Mbit/s.

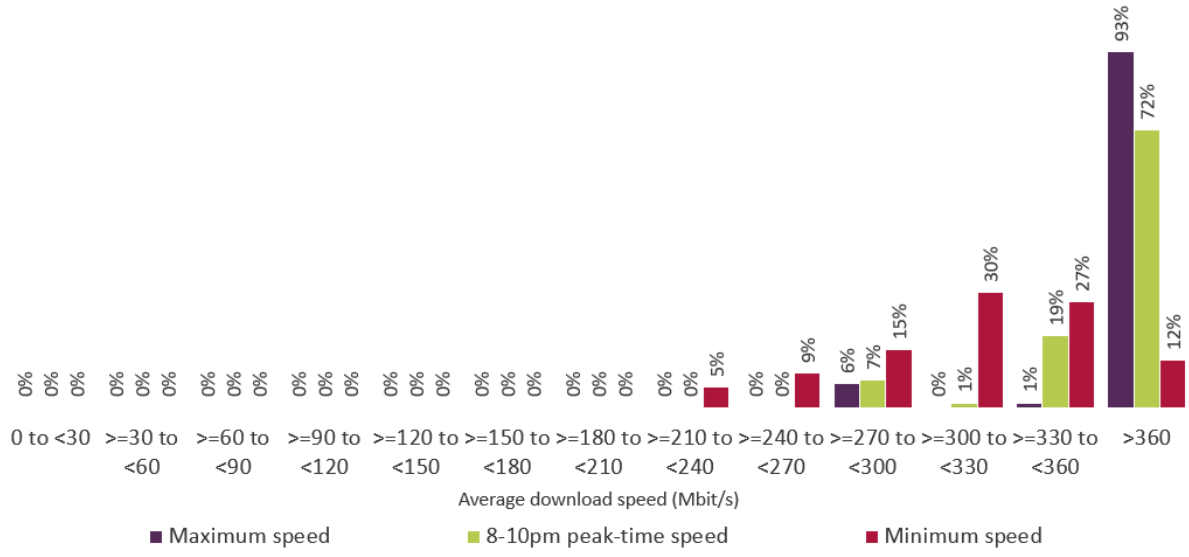
Figure 18: Distribution of maximum, peak-time and minimum download speeds for 213 Mbit/s cable connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [16] in the Sources section.

- For 362 Mbit/s cable connections, all panellists achieved an average minimum speed of 30 Mbit/s or higher and 93% received an average maximum speed of 362 Mbit/s or higher.

Figure 19: Distribution of maximum, peak-time and minimum download speeds for 362 Mbit/s cable connections: 2018 (proportion of lines)

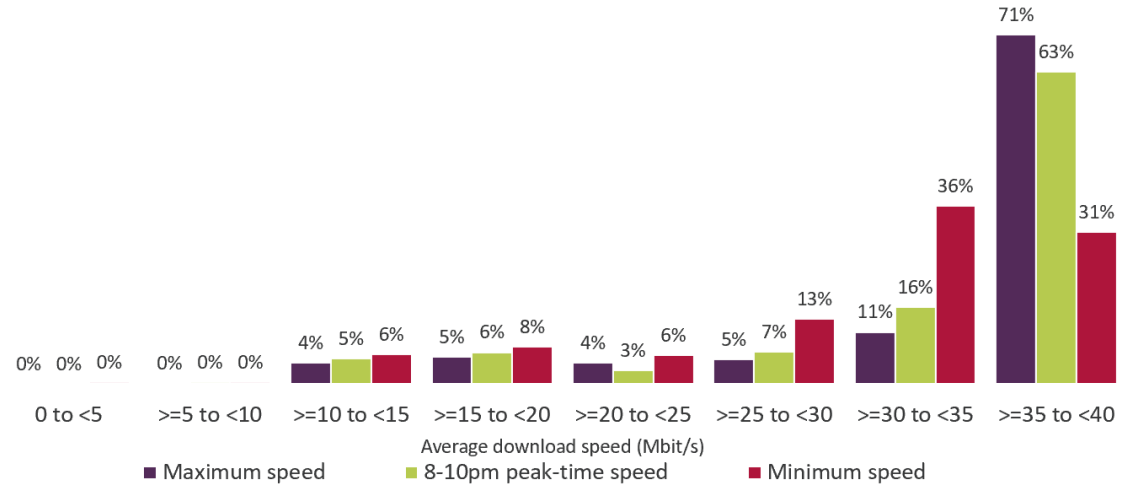


Source: Ofcom, using data provided by SamKnows; see note [25] in the Sources section.

Distribution of FTTC download speeds

- For 36 Mbit/s FTTC connections, 1% of panellists had an average minimum speed of less than 10 Mbit/s and 67% received an average minimum speed of 30 Mbit/s or higher.
- Sixty-eight per cent of 36 Mbit/s panellists received an average maximum speed of 36 Mbit/s or higher.

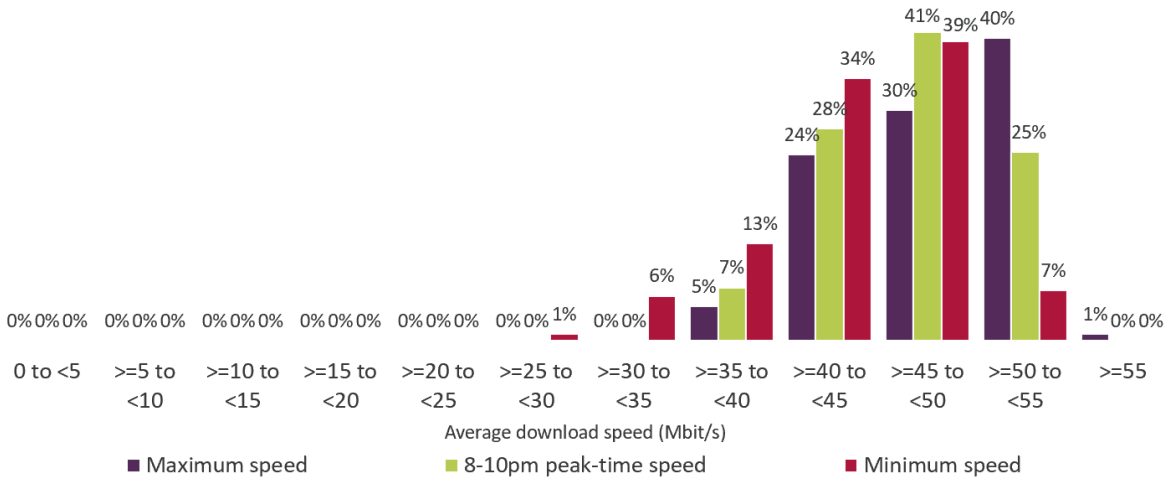
Figure 20: Distribution of maximum, peak-time and minimum download speeds for 36 Mbit/s FTTC connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [17] in the Sources section.

- No 50 Mbit/s FTTC panellists received a minimum speed of less than 10 Mbit/s, and 99% received a minimum speed greater than 30 Mbit/s.
- For 50 Mbit/s FTTC connections, 41% of panellists achieved a maximum speed of more than 50 Mbit/s.

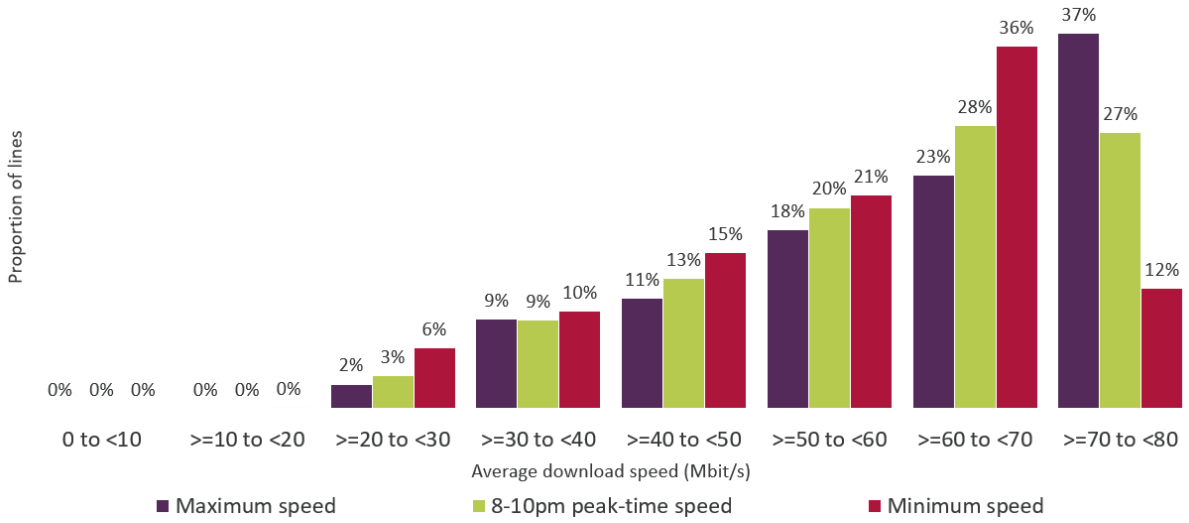
Figure 21: Distribution of maximum, peak-time and minimum download speeds for 50 Mbit/s FTTC connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [18] in the Sources section.

- No panellists on 63-67 Mbit/s FTTC connections received a minimum speed of less than 10 Mbit/s, and 94% received a minimum speed greater than 30 Mbit/s.
- For 63-67 Mbit/s FTTC connections, 45% of panellists achieved a maximum speed more than 65 Mbit/s.

Figure 22: Distribution of maximum, peak-time and minimum download speeds for 63-67 Mbit/s FTTC connections

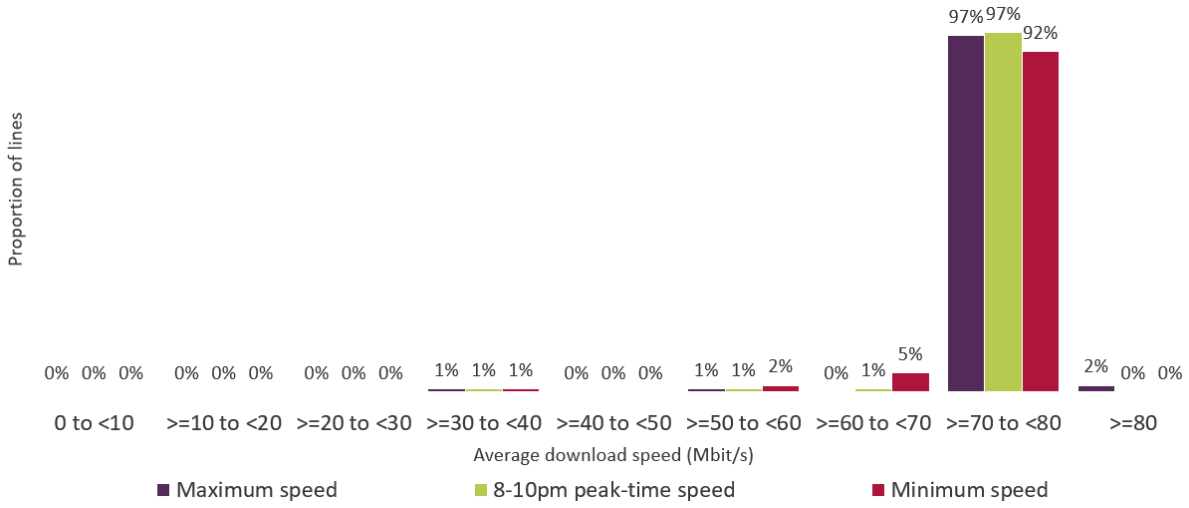


Source: Ofcom, using data provided by SamKnows; see note [19] in the Sources section.

Distribution of FTTP download speeds

- All 67 Mbit/s FTTP panellists received a minimum speed of more than 30 Mbit/s, and 98% received a maximum speed greater than 67 Mbit/s.

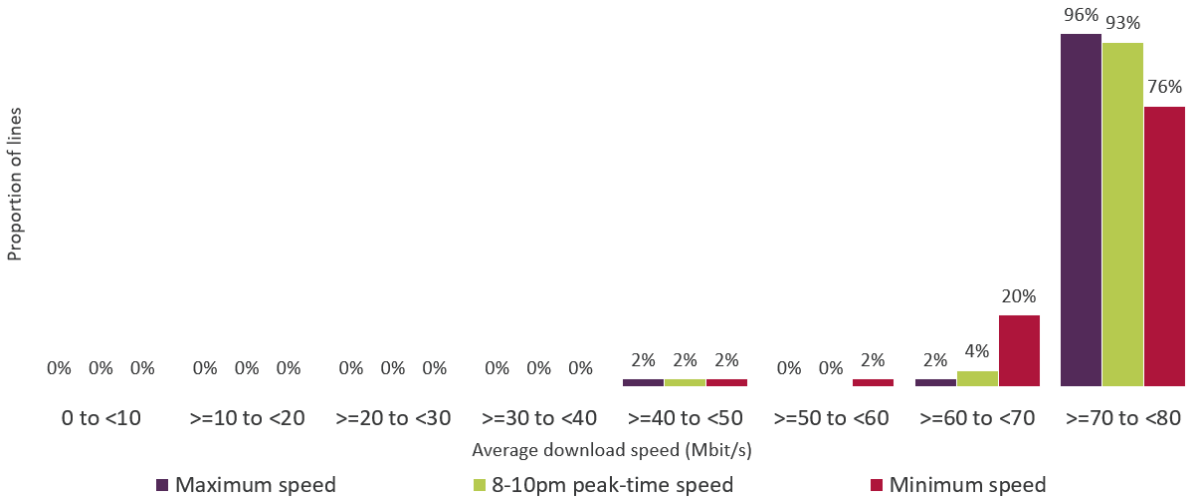
Figure 2323: Distribution of maximum, peak-time and minimum download speeds for 67 Mbit/s FTTP connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [27] in the Sources section.

- No panellists on 75 Mbit/s FTTP connections received a minimum speed of less than 30Mbit/s, and 74% received an average maximum speed greater than 75 Mbit/s.

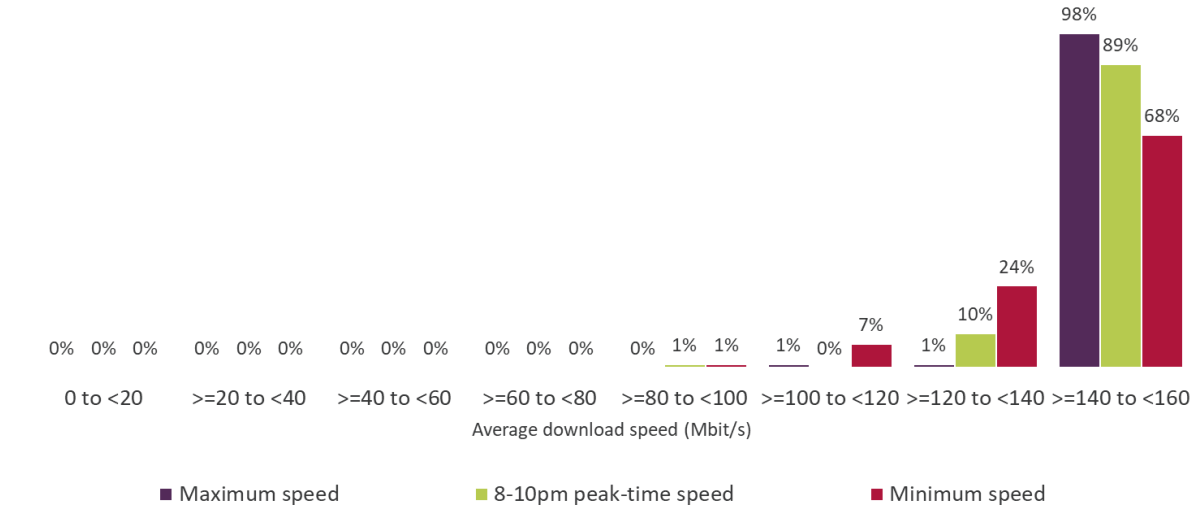
Figure 24: Distribution of maximum, peak-time and minimum download speeds for 75 Mbit/s FTTP connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [29] in the Sources section.

- No panellists on 145 Mbit/s FTTP received a minimum speed of less than 30 Mbit/s, and 97% received maximum speeds higher than 145 Mbit/s.

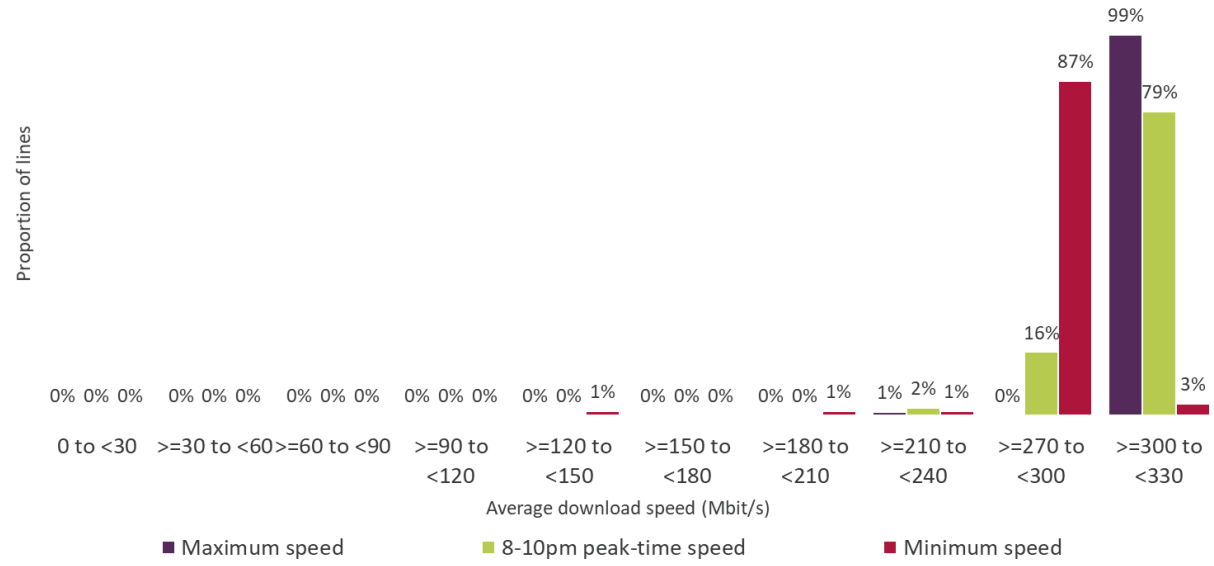
Figure 25: Distribution of maximum, peak-time and minimum download speeds for 145 Mbit/s FTTP connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [32] in the Sources section.
Distribution of 300 Mbit/s FTTP connections' maximum, peak-time and minimum speeds

- No panellists on 300 Mbit/s FTTP received a minimum speed of less than 30 Mbit/s, and 99% received maximum speeds higher than 300 Mbit/s.

Figure 26: Distribution of maximum, peak-time and minimum download speeds for 300 Mbit/s FTTP connections: 2018 (proportion of lines)



Source: Ofcom, using data provided by SamKnows; see note [35] in the Sources section.

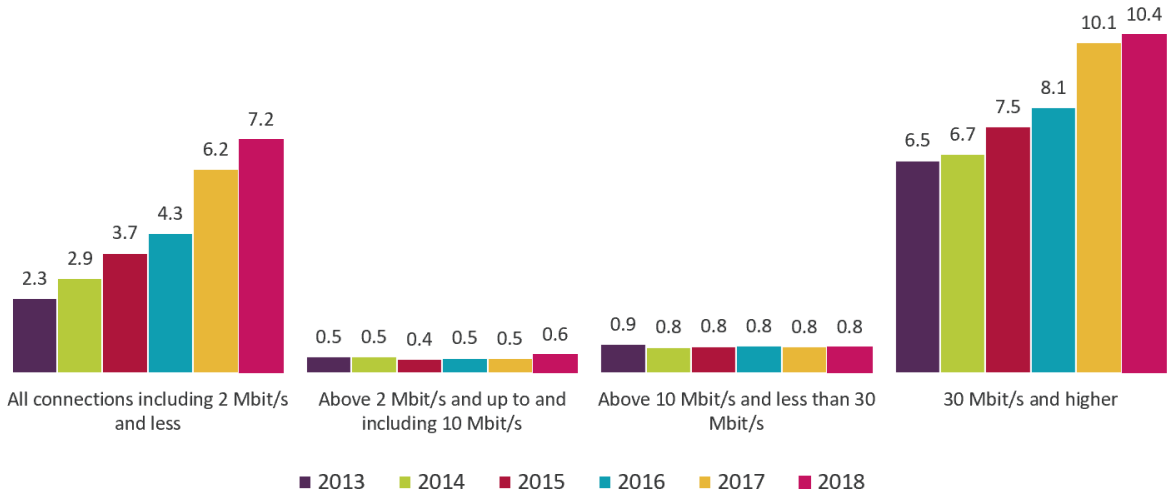
Distribution of 300 Mbit/s FTTP connections' maximum, peak-time and minimum speeds

6. Upload speeds

Average UK upload speeds increased by 15% in 2018

- Upload speeds are important to users who use real-time video communication services, play video games online or who upload or share files.
- The average upload speed of UK residential fixed broadband services increased by 15% to 7.2 Mbit/s in 2018; the main driver of this increase was growing superfast take-up.

Figure 27: Average UK fixed broadband upload speeds (Mbit/s): 2013 to 2018

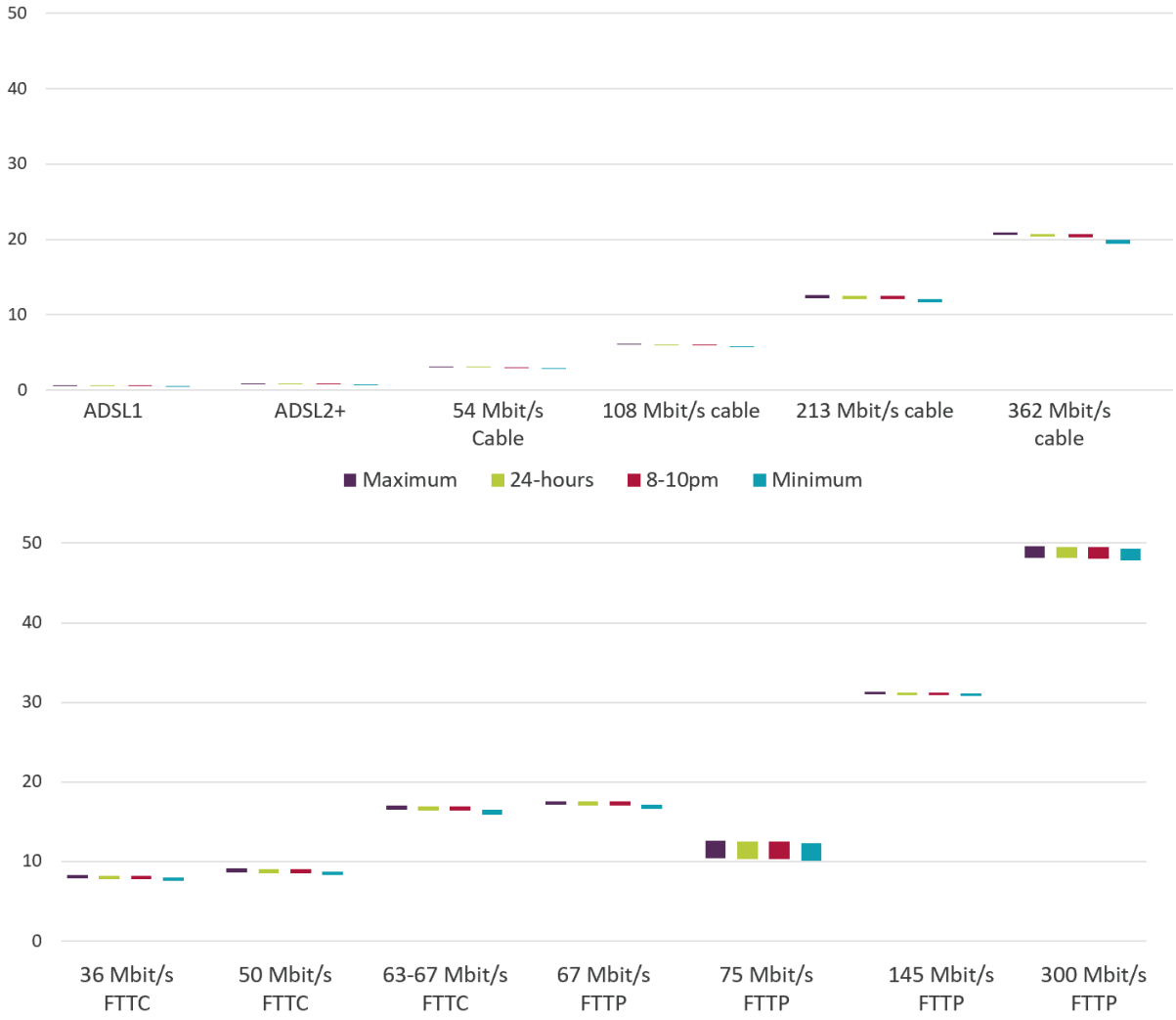


Source: Ofcom, using data provided by SamKnows; see note [11] in the Sources section.

Upload speeds vary widely by technology and speed tier

- There is significant variation in upload speeds between technology and service tiers.
- FTTP services recorded the highest average upload speeds over the 24-hour period at 48.8 Mbit/s and 31.1 Mbit/s for 300 Mbit/s and 145 Mbit/s connections respectively, followed by 20.6 Mbit/s for 362 Mbit/s cable services.
- The 24-hour average upload speed of 36 Mbit/s FTTC services was 8.0 Mbit/s, while for 50 Mbit/s FTTC connections it was slightly higher at 8.8 Mbit/s.
- Average upload speeds for 67 Mbit/s FTTP services (17.3 Mbit/s) were higher than those of the equivalent (63-67 Mbit/s) FTTC services (16.7 Mbit/s) and the average was 11.4 Mbit/s for 75 Mbit/s FTTP services.
- The 24-hour average for ADSL2+services was 0.8 Mbit/s.

Figure 28: Maximum, average, peak-time and minimum upload speeds, by technology and service tier: 2018 (Mbit/s)



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 consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown.

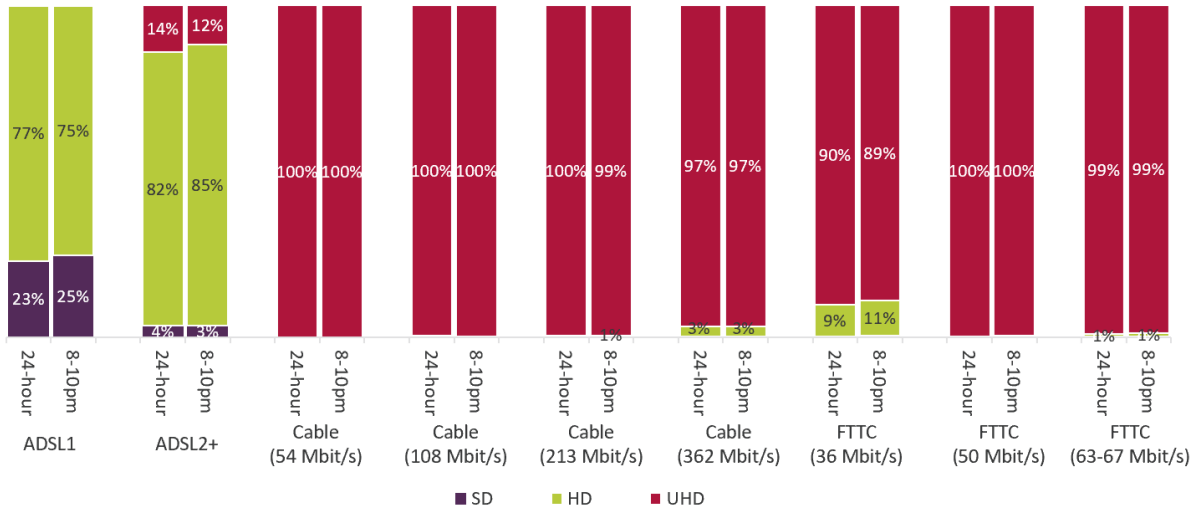
7. Netflix streaming performance

- The streaming of video content is one of the most capacity-hungry activities that consumers use their broadband connection for. 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.
- 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.
- It should be noted that these results represent the case where only one user is streaming on a broadband connection, and the streaming quality that can be reliably achieved may drop when multiple users are simultaneously using the same connection.

In most cases, superfast products can stream Netflix videos at UHD resolution

- Most Netflix streams delivered over FTTC and cable lines were delivered at UHD resolution during the 8pm-10pm peak-time period.
- For ADSL2+ services, over three-quarters of Netflix videos were streamed at HD resolution, while 14% and 12% 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).
- For consumers 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 29: 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 [20] in the Sources section.

8. Disconnections

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

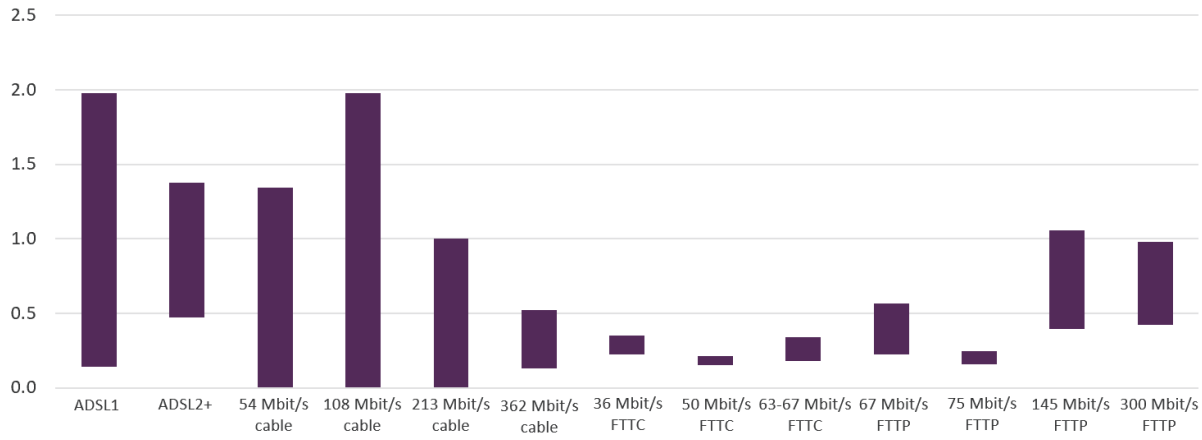
Users cannot undertake any online activities when their service loses internet connectivity, and interruptions to the fixed broadband service can be inconvenient and frustrating for users.

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.

There is little statistical variation in the number of disconnections by technology in November/December 2018

- Our research shows that ADSL services had the highest number of disconnections of 30 seconds or longer in 2018, averaging 1.1 per day for ADSL1 and 0.9 for ADSL2+.
- This compared to averages of less than 0.5 disconnections per day for almost all other connection types.
- The exceptions were 108 Mbit/s cable services, and 145Mbit/s and 300 Mbit/s FTTP services, which all had daily averages of 0.7 disconnections per day.

Figure 30: Average daily disconnections of 30 seconds or longer (lower values indicate better performance): 2018 (actuals)



Source: Ofcom, using data provided by SamKnows; see note [21] in the Sources section.
Note: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown.

9. Performance by internet service provider (ISP) package

Background

This section sets out the performance of individual ISP packages in terms of their connection speeds, comparing the average maximum, peak-time, 24-hour and minimum download and upload speeds for a number of ADSL2+, cable, fibre-to-the-cabinet (FTTC) and fibre-to-the-premises (FTTP) packages.

Panellist recruitment

A limitation of our panel-based measurements is that we can only include broadband services in the ISP package comparisons section of the report when we can recruit enough panellists for them. This makes it difficult to include services which have low-take-up, including those of emerging technologies such as FTTP. We have been able to include several higher-speed packages in the research for the first time in 2018, including full-fibre FTTP services. These are:

- BT's 67 Mbit/s FTTP service
- BT's 145 Mbit/s FTTP service
- BT's 300 Mbit/s FTTP service
- KCOM's 75 Mbit/s FTTP service
- Virgin Media's 362 Mbit/s cable service

For the BT and Virgin Media services, BT and Virgin Media allowed us to use data taken from SamKnows tests that are embedded in their routers. These tests are identical to those run on our own panel, other than that BT did not run the video streaming tests.

Low panellist numbers mean that we are unable to include EE and KCOM's ADSL2+ packages in this section of the report.

Alongside the research for this report, we ran tests on EE's 4GEE Home fixed wireless home broadband service to assess whether it is capable of delivering USO level broadband (10 Mbit/s download and 1 Mbit/s upload broadband), and the results of this testing can be found in Annex 1.

All the ADSL2+ and FTTC broadband packages included in the report are provided over the Openreach copper line from the local exchange/street cabinet to the end user's home.

This means it is unlikely that consumers will experience a substantial increase in the performance of their service by switching from an ADSL or FTTC package to another with the same advertised speed, unless the performance of their existing service is being limited by factors within their ISP's control, such as network congestion or the ADSL line configurations in their systems. This is because any such services will be provided over the same copper line, whose characteristics are a key determining factor of the performance of any ADSL or FTTC broadband service delivered over it.

As mentioned previously, there are several limitations to our research, and it does not capture certain important factors that help determine the end-user's experience, such as wi-fi router

performance, and there may be steps that consumers can take to improve their user experience, such as replacing in-home wiring and moving their router to a more suitable location.

Presentation of results

We present our findings in terms of bars showing the 95% confidence interval. This means that there is a 95% probability that the actual average performance for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown.

The sample size for each group, and the variation of performance among panellists within the same group, combine to determine the size of the bars. We emphasise that these bars indicate the average (mean) performance rather than the range of performance delivered.

We have designed the sampling and statistical methodologies to allow us to compare ISP packages on a like-for-like basis. For details, see the research methodology set out in Annex 2 and the statistical methodology set out in Annex 3.

ADSL2+ connections: download speeds

The main variable affecting the speeds delivered by ADSL2+ is the distance from the exchange to the end user's premises, over which the ISP has no control. Therefore, when looking at fixed-line broadband speeds, we exclude premises that are more than 5km from the local exchange, and we normalise the test results by distance from the exchange, to enable a like-for-like comparison of ISP packages. Further information on how we do this is in Annex 3 of this report.

The performance of FTTP connections

For the first time, we have been able to include FTTP packages in our research, and this report includes data for three BT FTTP ISP packages and one KCOM FTTP service. One of these services is BT's 67 Mbit/s FTTP service, which we were able to compare to the equivalent (63-67 Mbit/s) FTTC services.

These results are summarised in Figure 30 below, which shows that BT's 67 Mbit/s FTTP service outperformed 63-67 Mbit/s FTTC services to a 95% level of significance for all the metrics for which comparable figures were available, except the average number of daily disconnections of 30 seconds or longer, for which there were no differences.

The performance differences observed in packet loss and DNS failure rate were not significant at the 99% level of confidence.

Figure 31: Comparison of the performance of BT's 67 Mbit/s FTTC and FTTP services

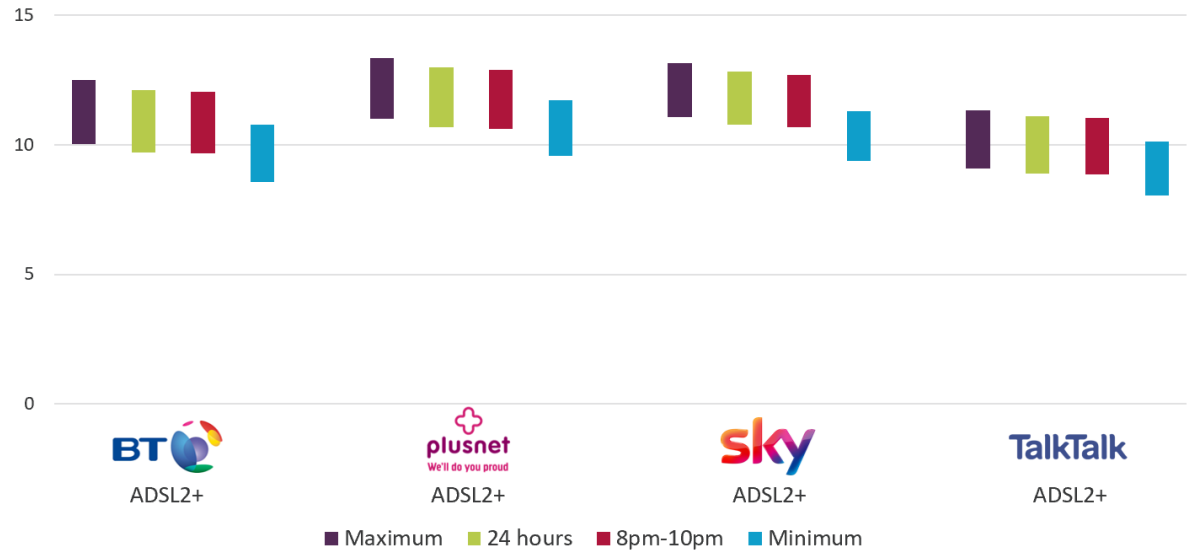
		63-67 Mbit/s FTTC	BT 67 Mbit/s FTTP	Differences to 95% level of confidence
Download speed (Mbit/s)	Maximum	58.6 - 63.2 Mbit/s	73.4-74.8 Mbit/s	FTTP better than FTTC*
	24-hour	57.7 - 62.3 Mbit/s	73.1-74.4 Mbit/s	FTTP better than FTTC*
	8-10pm	57.4 - 62.0 Mbit/s	72.9-74.2 Mbit/s	FTTP better than FTTC*
	Minimum	53.6 - 58.2 Mbit/s	71.6-73.2 Mbit/s	FTTP better than FTTC*
Upload speed (Mbit/s)	Maximum	16.5 - 17.0 Mbit/s	20.6-21.1 Mbit/s	FTTP better than FTTC*
	24-hour	16.4 - 16.9 Mbit/s	20.6-21.0 Mbit/s	FTTP better than FTTC*
	8-10pm	16.3 - 16.9 Mbit/s	20.6-21.0 Mbit/s	FTTP better than FTTC*
	Minimum	15.9 - 16.5 Mbit/s	20.5-20.9 Mbit/s	FTTP better than FTTC*
Daily disconnections (actuals)		0.3	0.4	No difference
Latency (ms)	24-hour	11.5	8.8	FTTP better than FTTC*
	8-10pm	11.6	8.8	FTTP better than FTTC*
Packet loss (%)	24-hour	0.1	0.0	FTTP better than FTTC
	8-10pm	0.1	0.0	FTTP better than FTTC
DNS resolution time (ms)	24-hour	14.0	9.5	FTTP better than FTTC*
	8-10pm	14.2	9.5	FTTP better than FTTC*
DNS failure rate (%)	24-hour	0.08%	0.01%	FTTP better than FTTC
	8-10pm	0.08%	0.00%	FTTP better than FTTC
Upstream jitter (ms)	24-hour	0.3	0.2	FTTP better than FTTC*
	8-10pm	0.3	0.2	FTTP better than FTTC*
Downstream jitter (ms)	24-hour	0.4	0.2	FTTP better than FTTC*
	8-10pm	0.5	0.3	FTTP better than FTTC*

Source: Ofcom, using data provided by SamKnows, see note [38] in the Sources section.
Note: An asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Variation in performance of ADSL2+ packages

- There were no significant differences in the download speeds provided by the ADSL2+ ISP packages included in our report in any time period.
- TalkTalk's ADSL2+ service had the highest average 8-10pm peak-time speed as a proportion of the maximum speed, at 98%.
- The largest drops in the average speed during busy times was observed for BT and Sky's ADSL2+ services, for which the average 8-10pm peak-time speeds were 96% of the average maximum speed.

Figure 32: Maximum, average, peak-time and minimum download speeds for ADSL2+ ISP packages, and significant differences at a 95% level of confidence: 2018 (Mbit/s)



	Maximum	24-hour average	8pm-10pm	Minimum
ISP	**Was faster than**	**Was faster than**	**Was faster than**	**Was faster than**
No differences	No differences	No differences	No differences	No differences

Source: Ofcom, using data provided by SamKnows; see note [22] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Contention in ADSL2+ connections

- We measure contention by comparing average minimum and maximum speeds, and assume that any difference between the two is due to network slowdown at busy times.
- Our research found that there were no significant differences in network slowdown for any of the ADSL2+ ISP packages included in our research.

Figure 33: Minimum speed as a proportion of maximum speed for ADSL+ ISP packages, and significant differences, to a 95% level of confidence: 2018 (%)

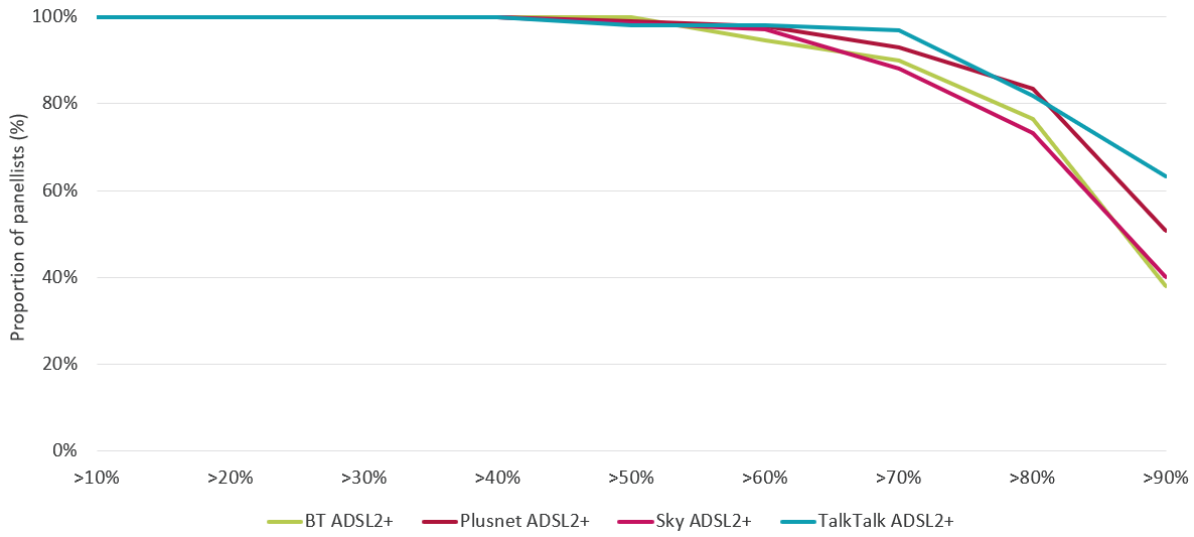
ISP	Was better than
All	No differences

Source: Ofcom, using data provided by SamKnows; see note [22] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; where a panellist's maximum speed is higher than the advertised speed of their service, the advertised speed has been used to calculate the figures above; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Distribution of contention for ADSL2+ connections

- Among the ADSL2+ ISP packages included in our analysis, the proportion of panellists whose connection had a minimum speed greater than 90% of its maximum speed ranged from 38% for BT's service to 63% for TalkTalk's.
- The proportion of ADSL2+panellists whose connection had a minimum speed less than half its maximum speed ranged from 0% for BT's service to 2% for TalkTalk's.

Figure 34: Distribution of average minimum speed as a proportion of maximum speed, for ADSL2+ ISP packages: 2018 (proportion of panellists)

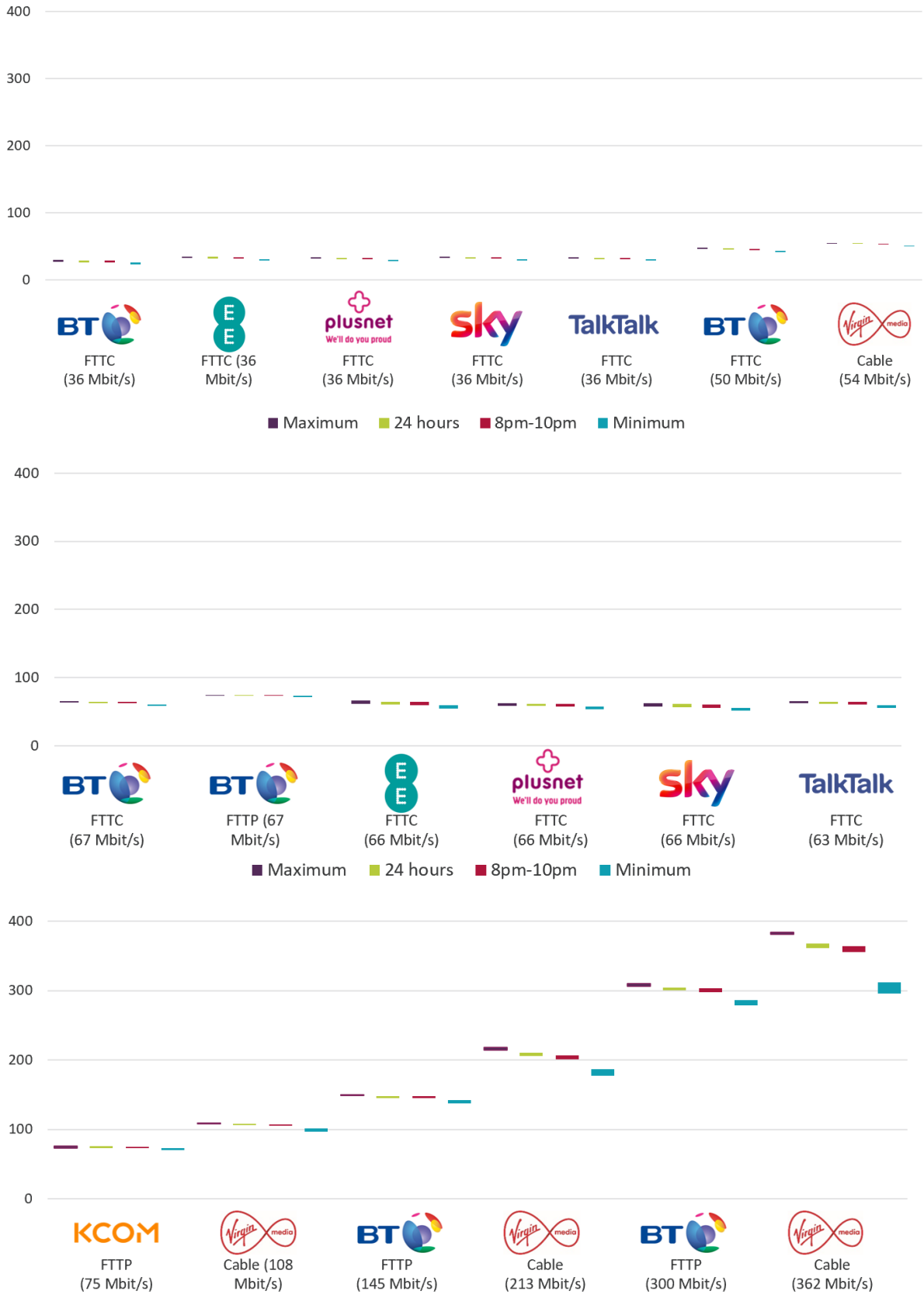


Source: Ofcom, using data provided by SamKnows; see note [23] in the Sources section.

Variation in performance of superfast broadband packages

- Overall, Virgin Media's 362 Mbit/s service had the highest average 24-hour and 8-10pm peak-time download speeds, at 365.0 Mbit/s and 360.2 Mbit/s respectively.
- Our research indicates that average 8-10pm peak-time FTTC download speeds do not vary much from their maximum speeds, and in 2018 all the FTTC packages included in our research had an average peak-time download speed that was higher than 95% of their maximum speed.
- For the full-fibre FTTP packages included in the research, average speeds during the peak-time period ranged from 97% to 99% of the average maximum speed.
- Among the four cable packages included in our research, average peak-time speeds represented between 94% and 98% of the average maximum speed.

Figure 35: Maximum, average, peak-time and minimum download speeds for 30 Mbit/s and above ISP packages, and significant differences to a 95% level of confidence: 2018 (Mbit/s)



	Maximum	24-hour average	8pm-10pm	Minimum
ISP package	Was faster than	Was faster than	Was faster than	Was faster than
VM362	BT300*, VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT300*, VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT300*, VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT300*, VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
BT300 FTTP	VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM213*, BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
VM213	BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT145*, VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
BT145 FTTP	VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM108*, BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
VM108	BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTP*, KCOM75*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
BT67 FTTP	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*

Continued on the next page

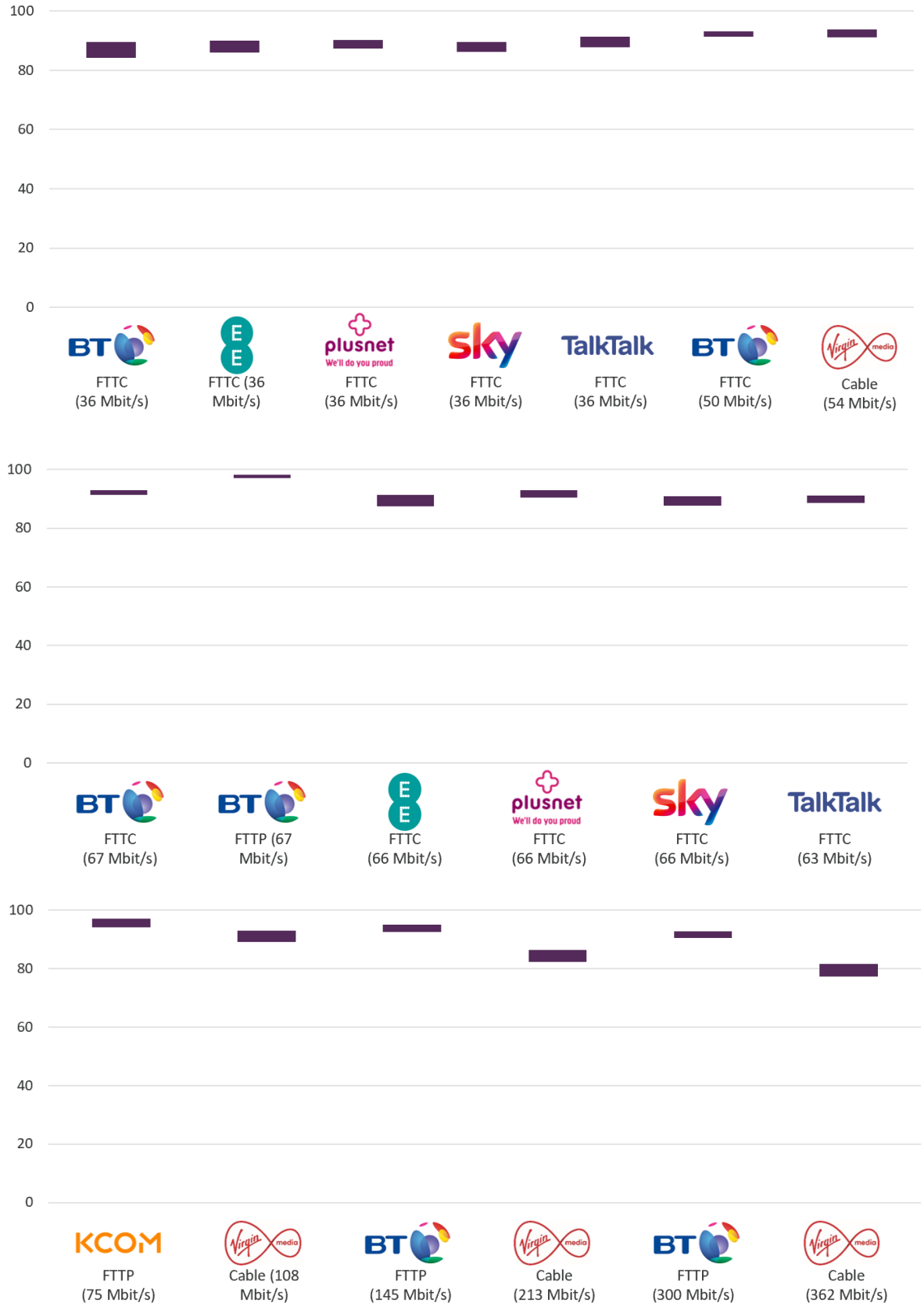
	Maximum	24-hour average	8pm-10pm	Minimum
ISP package	Was faster than	Was faster than	Was faster than	Was faster than
KCOM75 FTTP	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
BT67 FTTC	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*, Sky66*, PN66*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*, Sky66*, PN66*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*, Sky66*, PN66*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*, PN66*
TT63	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
EE66	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
PN66	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
Sky66	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	VM54*, BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
VM54	BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*	BT50*, EE36*, Sky36*, TT36*, PN36* & BT36*
BT50	EE36*, Sky36*, TT36*, PN36* & BT36*	EE36*, Sky36*, TT36*, PN36* & BT36*	EE36*, Sky36*, TT36*, PN36* & BT36*	EE36*, Sky36*, TT36*, PN36* & BT36*
EE36	BT36*	BT36*	BT36*	BT36*
Sky36	BT36*	EE36, TT36*, PN36*, BT36*	BT36*	BT36*
TT36	BT36*	BT36*	BT36*	BT36*
PN36	BT36*	BT36*	BT36*	BT36*

Source: Ofcom, using data provided by SamKnows; see note [24] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Contention in superfast broadband services

- We measure contention by comparing average minimum speeds against average maximum speeds, our assumption being that any differences between the two are due to contention.
- BT's 67 Mbit/s FTTP service had the lowest contention among the superfast products included in our research, with average minimum speeds at 98% of the average maximum speed.
- Other FTTP services also had little contention: KCOM's 75 Mbit/s service's average minimum speed was 96% of the average maximum speed, while for BT's 145 Mbit/s and 300 Mbit/s services it was 94% and 92% respectively.
- The highest level of contention was observed for Virgin Media's 362 Mbit/s service, with average minimum speeds at 79% of the average maximum speed.

Figure 36: Minimum speed as a proportion of maximum speed for 30Mbit/s and above ISP packages, and significant differences to a 95% level of confidence: 2018 (%)



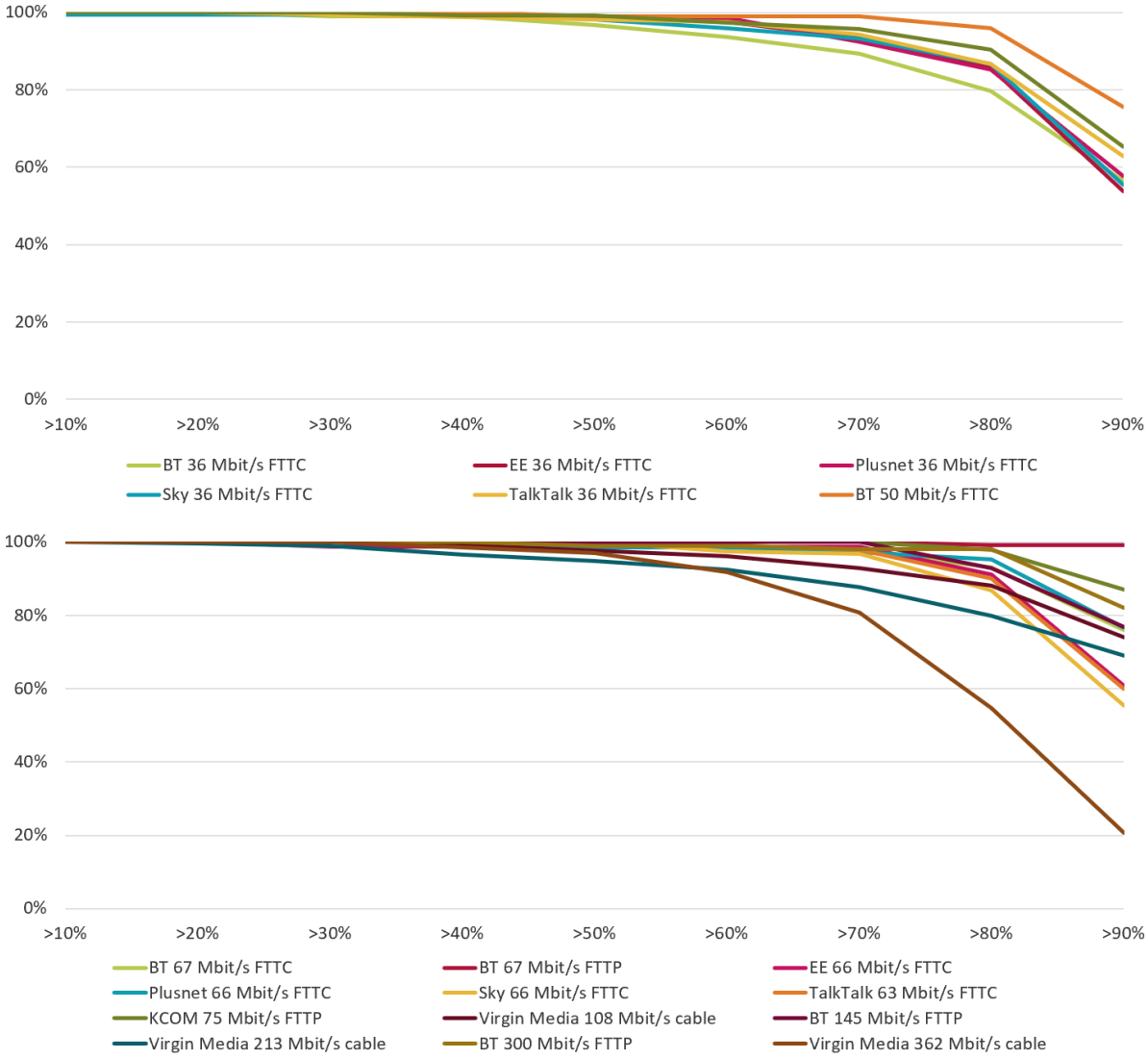
ISP package	Was better than
BT67 FTTP	BT145*, BT300*, BT67 FTTC*, VM54*, PN66*, VM108*, BT50*, TT63*, TT36*, Sky66*, EE66*, PN36*, Sky36*, EE36*, BT36*, VM213*, VM362*
KCOM75 FTTP	BT300*, BT67 FTTC*, VM54*, PN66*, VM108*, BT50*, TT63*, TT36*, Sky66*, EE66*, PN36*, Sky36*, EE36*, BT36*, VM213*, VM362*
BT145 FTTP	BT50*, TT63*, TT36*, Sky66*, EE66*, PN36*, Sky36*, EE36*, BT36*, VM213*, VM362*
BT300 FTTP	TT63, TT36, Sky66, EE66, PN36*, Sky36*, EE36*, BT36*, VM213*, VM362*
BT67 FTTC	TT63, TT36, Sky66, EE66, PN36*, Sky36*, EE36*, BT36*, VM213*, VM362*
VM54	Sky66, PN36, Sky36*, EE36*, BT36*, VM213*, VM362*
PN66	PN36, Sky36*, EE36, BT36, VM213*, VM362*
VM108	VM213*, VM362*
BT50	VM213*, VM362*
TT63	VM213*, VM362*
TT36	VM213*, VM362*
Sky66	VM213*, VM362*
EE66	VM213, VM362*
PN36	VM213, VM362*
Sky36	VM362*
EE36	VM362*
BT36	VM362*
VM213	VM362

Source: Ofcom, using data provided by SamKnows; see note [26] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; where a panellist's maximum speed is higher than the advertised speed of their service, the advertised speed has been used to calculate the figures above; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence."

Distribution of contention for superfast broadband services

- Among the superfast products included in our analysis, the proportion of panellists whose connection had a minimum speed greater than 90% of its maximum speed was lowest for Virgin Media's 362 Mbit/s cable service, at 21%.
- The best performance was for BT's 67 Mbit/s FTTP service, for which 99% of panellists received minimum speeds greater than 90% of the maximum speed.
- The proportion of panellists whose connection had a minimum speed that was less than half its maximum speed was highest for Virgin Media's 213 Mbit/s cable service, at 5%.

Figure 37: Distribution of average minimum speed as a proportion of maximum speed for 30Mbit/s and above ISP packages: 2018 (proportion of panellists)



Source: Ofcom, using data provided by SamKnows; see note [28] in the Sources section.

Summary of average download speeds of all ISP packages

Figure 38: Average maximum, 24-hour, peak-time and minimum download speeds, by ISP package: 2018

	Maximum	24 hours	8pm-10pm	Minimum
BT ADSL2+	10.0-12.5 Mbit/s	9.7-12.1 Mbit/s	9.7-12.1 Mbit/s	8.6-10.8 Mbit/s
Plusnet ADSL2+	11.0-13.4 Mbit/s	10.7-13.0 Mbit/s	10.6-12.9 Mbit/s	9.6-11.7 Mbit/s
Sky ADSL2+	11.1-13.2 Mbit/s	10.8-12.8 Mbit/s	10.7-12.7 Mbit/s	9.4-11.3 Mbit/s
TalkTalk ADSL2+	9.1-11.3 Mbit/s	8.9-11.1 Mbit/s	8.8-11.0 Mbit/s	8.1-10.1 Mbit/s
BT 36 Mbit/s FTTC	27.6-30.2 Mbit/s	26.6-29.2 Mbit/s	26.5-29.0 Mbit/s	23.7-26.6 Mbit/s
EE 36 Mbit/s FTTC	33.2-35.5 Mbit/s	32.5-34.8 Mbit/s	32.2-34.5 Mbit/s	29.0-31.7 Mbit/s
Plusnet 36 Mbit/s FTTC	32.4-34.2 Mbit/s	31.4-33.1 Mbit/s	31.0-32.8 Mbit/s	28.7-30.7 Mbit/s
Sky 36 Mbit/s FTTC	33.1-34.9 Mbit/s	32.3-34.2 Mbit/s	32.0-34.0 Mbit/s	29.0-31.1 Mbit/s
TalkTalk 36 Mbit/s FTTC	32.3-34.2 Mbit/s	31.6-33.6 Mbit/s	31.4-33.4 Mbit/s	29.0-31.2 Mbit/s
BT 50 Mbit/s FTTC	46.6-48.2 Mbit/s	45.6-47.2 Mbit/s	45.2-46.9 Mbit/s	41.8-44.0 Mbit/s
Virgin Media 54 Mbit/s cable	54.8-54.9 Mbit/s	54.0-54.5 Mbit/s	53.5-54.3 Mbit/s	50.0-51.5 Mbit/s
BT 67 Mbit/s FTTC	63.3-65.5 Mbit/s	62.4-64.6 Mbit/s	62.1-64.3 Mbit/s	58.3-60.7 Mbit/s
BT 67 Mbit/s FTTP	73.4-74.8 Mbit/s	73.1-74.4 Mbit/s	72.9-74.2 Mbit/s	71.6-73.2 Mbit/s
EE 67 Mbit/s FTTC	61.3-66.2 Mbit/s	60.0-64.9 Mbit/s	59.4-64.5 Mbit/s	54.5-59.8 Mbit/s
Plusnet 66 Mbit/s FTTC	58.9-62.3 Mbit/s	58.0-61.4 Mbit/s	57.6-61.0 Mbit/s	53.9-57.3 Mbit/s
Sky 63 Mbit/s FTTC	57.5-62.2 Mbit/s	56.3-61.0 Mbit/s	55.9-60.7 Mbit/s	51.1-55.9 Mbit/s
TalkTalk 63 Mbit/s FTTC	62.0-65.6 Mbit/s	61.0-64.5 Mbit/s	60.5-64.1 Mbit/s	55.6-59.4 Mbit/s
KCOM 75 Mbit/s FTTP	73.4-76.1 Mbit/s	72.7-75.4 Mbit/s	72.5-75.3 Mbit/s	69.8-73.3 Mbit/s
Virgin Media 108 Mbit/s cable	108.1-109.5 Mbit/s	106.0-107.9 Mbit/s	105-107.3 Mbit/s	96.7-101.4 Mbit/s
BT 145 Mbit/s FTTP	148.6-150.3 Mbit/s	145.5-148.1 Mbit/s	145-148.0 Mbit/s	137.9-142.5 Mbit/s
Virgin Media 213 Mbit/s cable	214.4-217.9 Mbit/s	205.5-210.3 Mbit/s	201.1-207.0 Mbit/s	177.7-187.1 Mbit/s
BT 300 Mbit/s FTTP	306.7-309.9 Mbit/s	300.5-304.1 Mbit/s	298.0-303.2 Mbit/s	278.7-286.3 Mbit/s
Virgin Media 362 Mbit/s cable	381.4-383.8 Mbit/s	361.8-368.2 Mbit/s	356.0-364.3 Mbit/s	295.7-312.1 Mbit/s

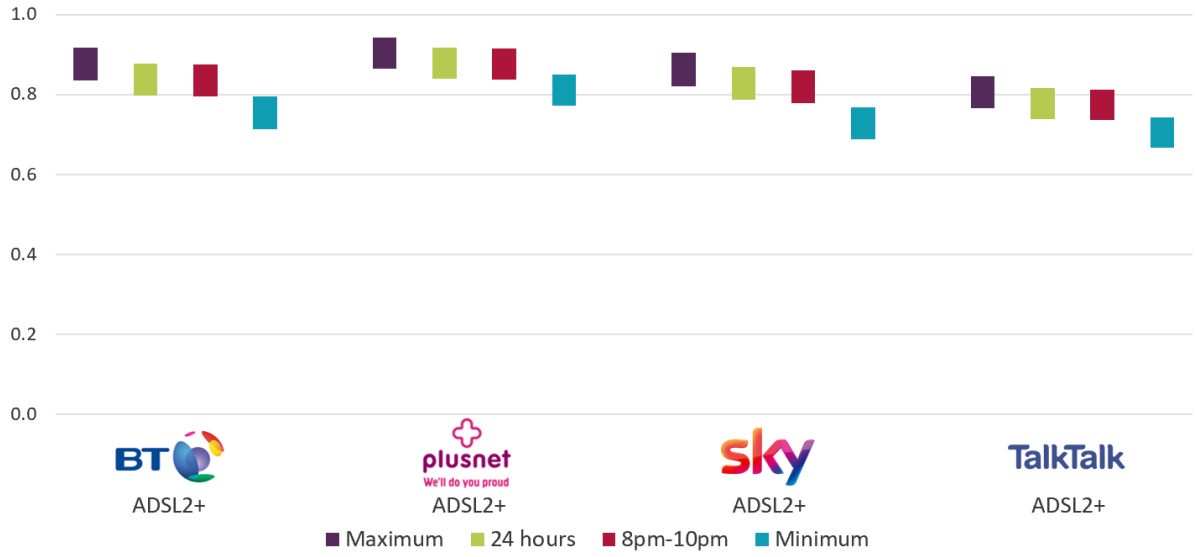
Source: Ofcom, using data provided by SamKnows.

Upload speeds

Upload speeds play an important part in the performance of the broadband services for many consumers, especially those who use applications that involve uploading data, including sharing files, real-time online gaming and video calling.

- Based on our research, Plusnet's ADSL2+ service had the highest average maximum, 24-hour average, 8pm 10pm peak-time and minimum upload speeds across all the ADSL2+ packages we considered in 2018.
- TalkTalk's ADSL2+ service had the lowest average upload speeds across all time periods among the services included in our research.

Figure 39: Maximum, average, peak-time and minimum upload speeds for ADSL2+ ISP packages and significant differences, to a 95% level of confidence: 2018 (Mbit/s)



	Maximum	24-hour average	8pm-10pm	Minimum
ISP	**Was faster than**	**Was faster than**	**Was faster than**	**Was faster than**
Plusnet	TalkTalk	TalkTalk*	TalkTalk*	Sky & TalkTalk*

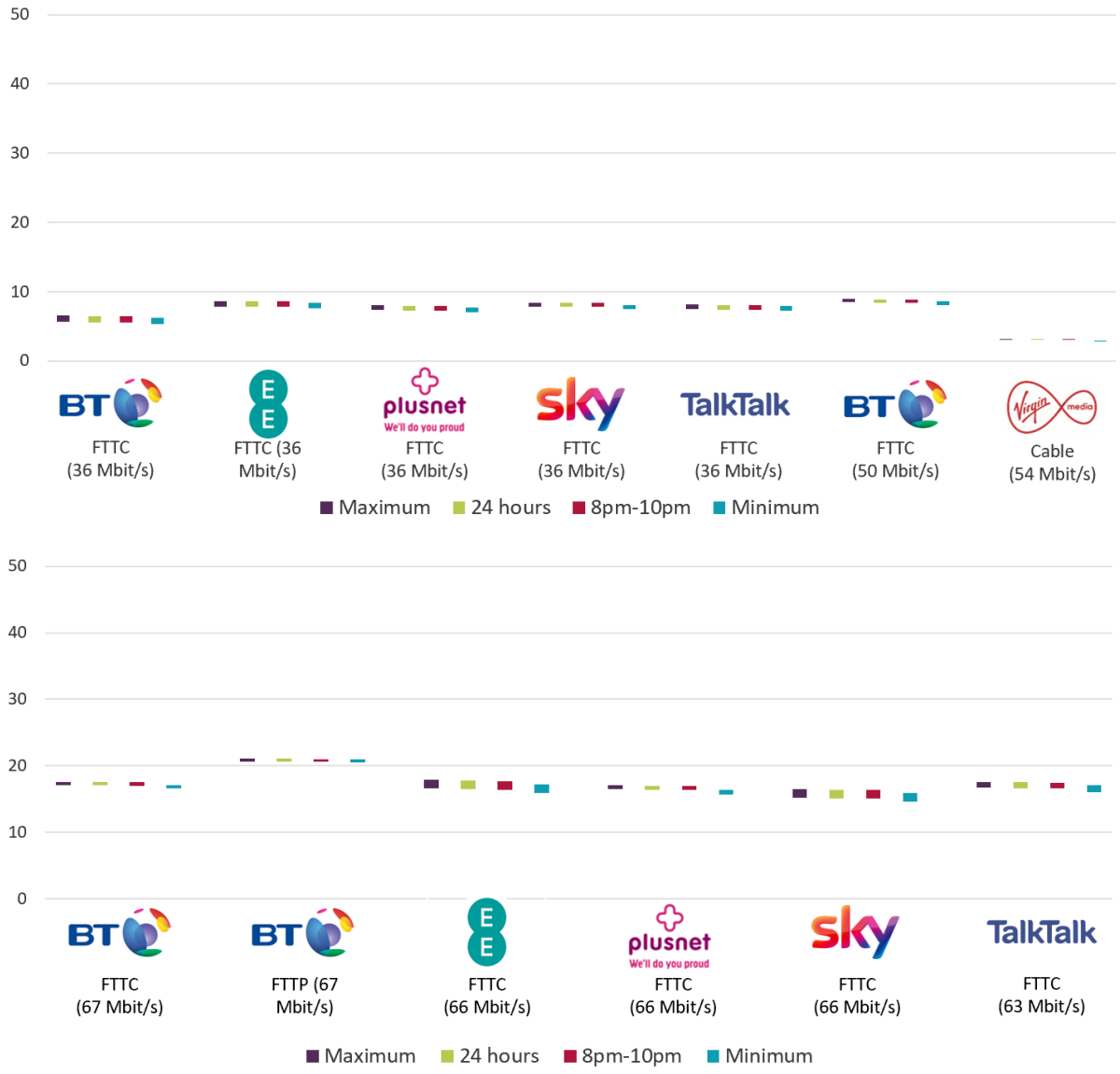
Source: Ofcom, using data provided by SamKnows; see note [30] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

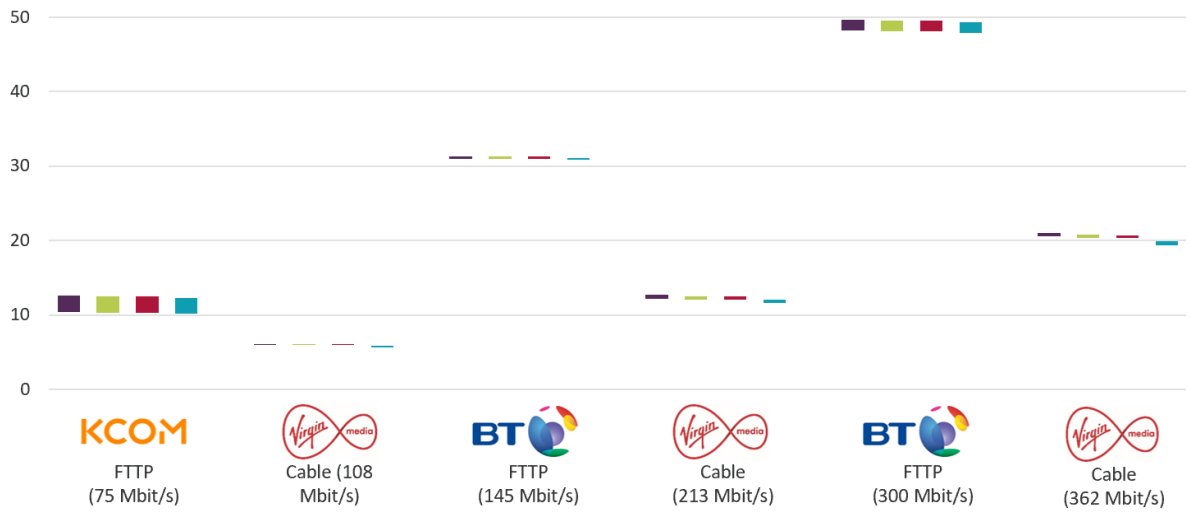
Upload speeds for superfast connections

- Based on our research, BT's 300 Mbit/s FTTP service had the highest upload speeds among the superfast products included in our analysis, averaging 48.8 Mbit/s over 24 hours and 8-10pm peak-time.
- For FTTC packages, the highest upload speed was BT's 67 Mbit/s service, which averaged 17.3 Mbit/s over 24 hours and the 8-10pm peak-time period.

- For cable packages, the highest upload speeds were achieved by Virgin Media's 362 Mbit/s package, which had average 24-hour and peak-time speeds of 20.6 Mbit/s and 20.5 Mbit/s respectively.

Figure 40: Maximum, average and peak-time upload speeds for ISP packages 30 Mbit/s and above, and significant differences, to a 95% level of confidence: 2018 (Mbit/s)




50
40
30
20
10
0
KCOM
FTTP
(75 Mbit/s)
Cable (108
Mbit/s)
FTTP
(145 Mbit/s)
Cable
(213 Mbit/s)
FTTP
(300 Mbit/s)
Cable
(362 Mbit/s)

	Maximum	24-hour average	8pm-10pm	Minimum
ISP package	**Was faster than**	**Was faster than**	**Was faster than**	**Was faster than**
BT300 FTTP	BT145 FTTP*, BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT145 FTTP*, BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT145 FTTP*, BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT145 FTTP*, BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
BT145 FTTP	BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTP*, VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
BT67 FTTP	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM362, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM362*, BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
VM362	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT67 FTTC*, TT63*, EE66*, PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
BT67 FTTC	Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	PN66, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	PN66, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	PN66*, Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
TT63	Sky66, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	Sky66*, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	Sky66, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	Sky66, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
EE66	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	Sky66, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
PN66	Sky66, VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
Sky66	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	VM213*, KCOM75*, BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
VM213	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*

Continued on the next page

	Maximum	24-hour average	8pm-10pm	Minimum
ISP package	Was faster than	Was faster than	Was faster than	Was faster than
KCOM75	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*	BT50*, Sky36*, EE36*, TT36*, PN36*, VM108*, BT36* & VM54*
BT50	Sky36, TT36*, PN36*, VM108*, BT36* & VM54*	TT36*, PN36*, VM108*, BT36* & VM54*	TT36*, PN36*, VM108*, BT36* & VM54*	Sky36, TT36, PN36*, VM108*, BT36* & VM54*
Sky36	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*
EE36	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*
TT36	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*
PN36	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*	VM108*, BT36* & VM54*
VM108	VM54*	VM54*	VM54*	VM54*
BT36	VM54*	VM54*	VM54*	VM54*

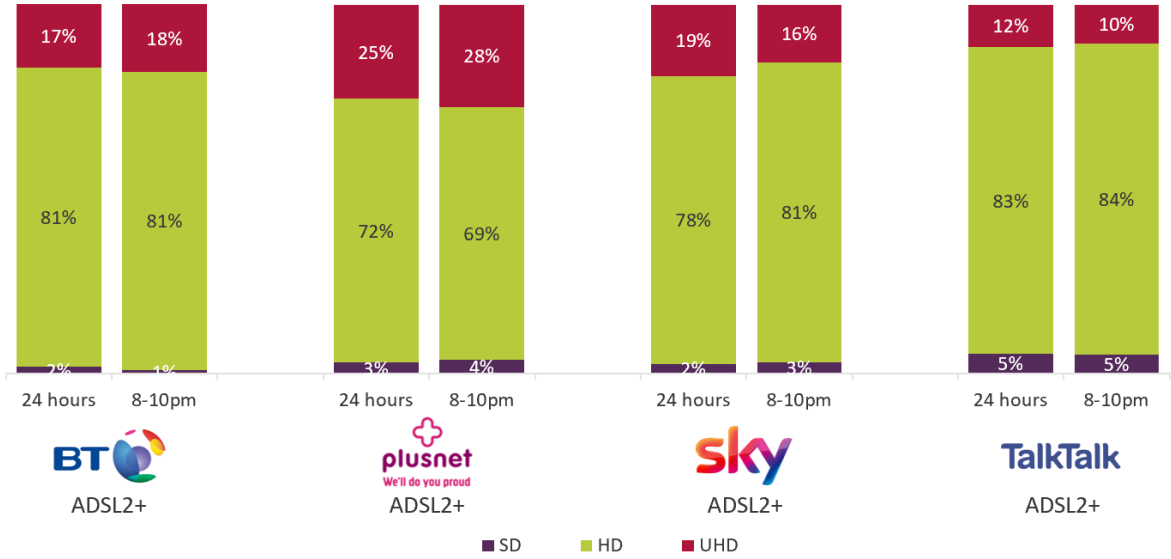
Source: Ofcom, using data provided by SamKnows; see note [31] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Single-stream video streaming quality, by ISP package

Streaming Netflix videos over ADSL2+ ISP packages

- It should be noted that these results represent one user streaming Netflix content over a broadband connection, and the streaming quality that can be achieved may drop when multiple users are simultaneously using the same connection.
- For all the ADSL2+ services included in our analysis, the majority of Netflix streams could be reliably streamed at HD resolution over both the 24-hour and peak-time periods.
- Plusnet's ADSL2+ service had the highest proportion of 8-10pm peak-time streams that could be reliably streamed only in UHD (28%), while TalkTalk's service had the highest proportion of peak-time streams that could only be delivered in SD (5%).

Figure 41: Proportion of Netflix videos delivered at the given video quality without rebuffering events, for ADSL2+ ISP packages over 24 hours and at peak times (%)

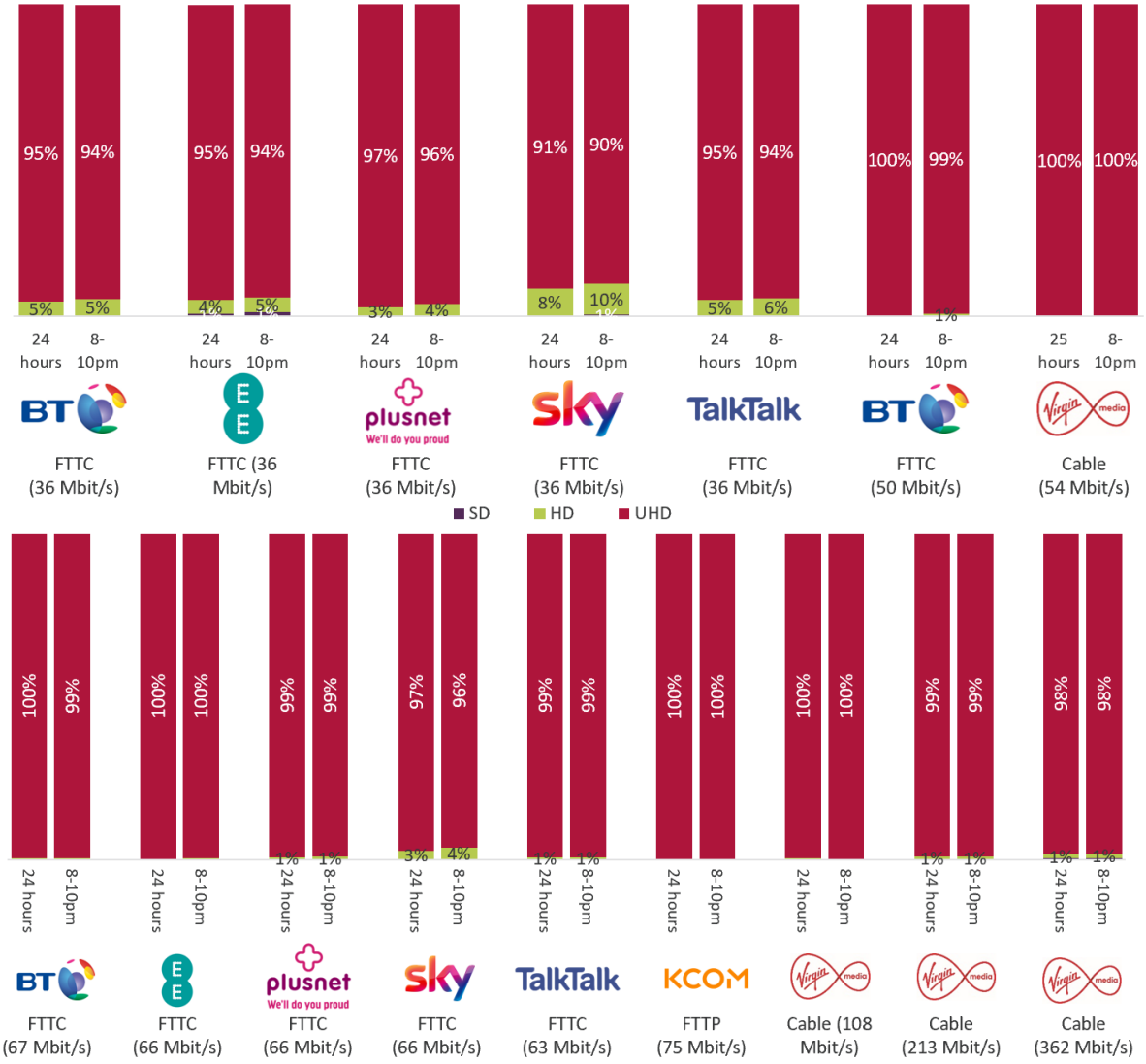


Source: Ofcom, using data provided by SamKnows; see note [33] in the Sources section.

Streaming Netflix videos over superfast broadband packages

- All the superfast services included in our research reliably achieved UHD resolution for more than 90% of Netflix streams over the 24-hour period.
- Sky's 36 Mbit/s FTTC service had the highest proportions of Netflix streams that could only be delivered in HD resolution during both the 24-hour (8%) and 8-10pm peak-time periods (10%), and 1% of peak-time Netflix streams that could be delivered only in standard definition (SD).

Figure 42: Proportion of Netflix videos delivered at the given video quality without rebuffering events, for superfast products over 24 hours and at peak times (%)



Source: Ofcom, using data provided by SamKnows; see note [34] in the Sources section.

Disconnections, by ISP package

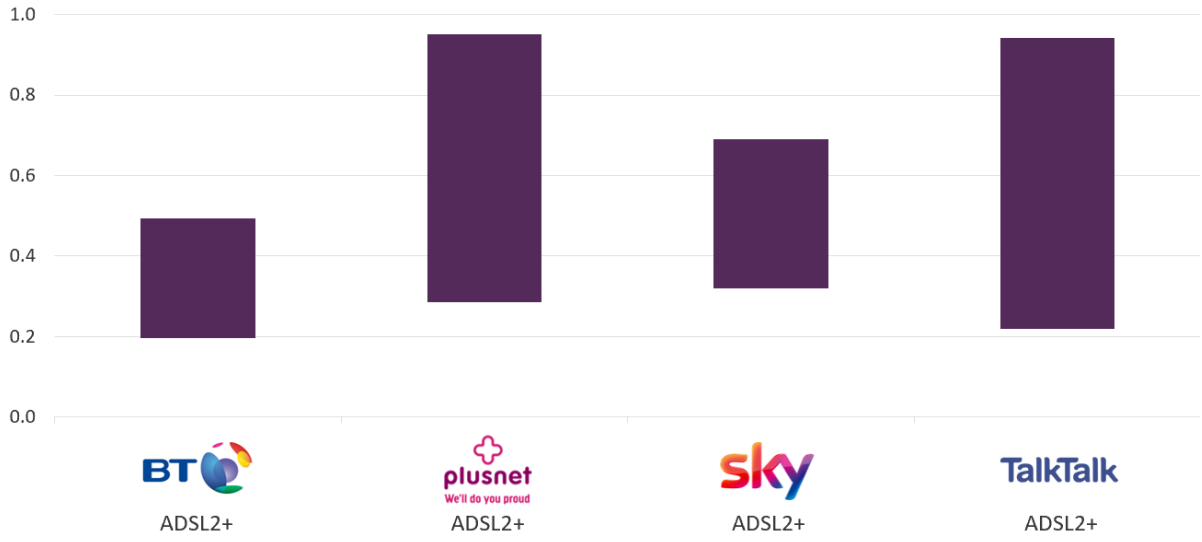
The average daily disconnections metric measures the frequency and duration of broadband service disconnections. Users cannot undertake any online activities when their service loses internet connectivity, and disconnections can be inconvenient and frustrating for users.

Again, 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.

Disconnections for ASDL2+ ISP packages

- There were no statistically significant differences between the numbers of actual daily disconnections of the ADSL2+ ISP packages included in our research in 2018.

Figure 43: Average daily disconnections of 30 seconds or longer for ADSL2+ ISP packages (lower values indicate better performance) and significant differences, to a 95% level of confidence: 2018 (actuals)



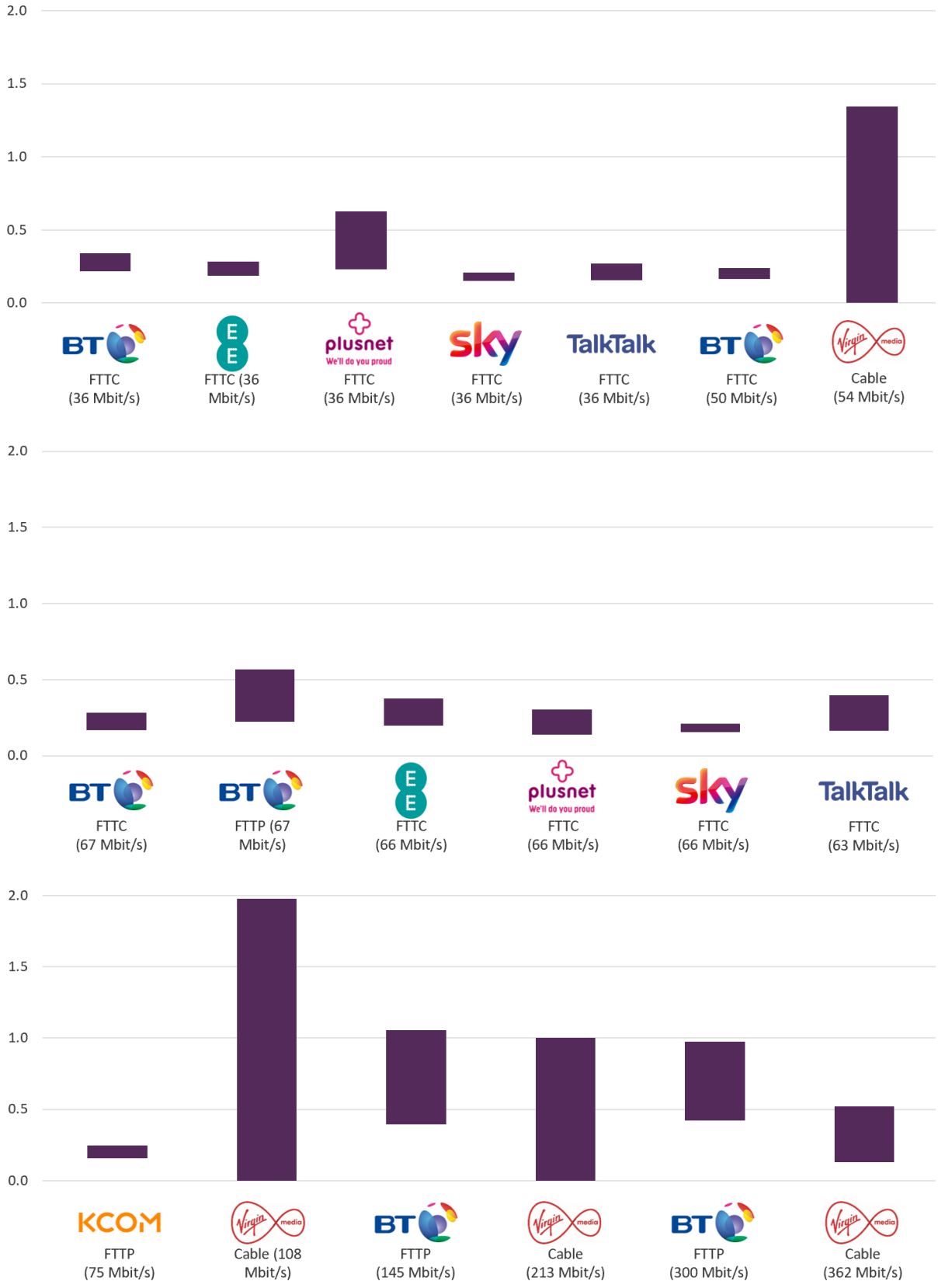
ISP	Performed better than
No differences	No differences

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Disconnections for superfast broadband packages

- Among the superfast broadband products included in our analysis the average number of daily disconnections ranged from 0.2 to 0.7.

Figure 44: Average daily disconnections of 30 seconds or longer (lower values indicate better performance) for 30 Mbit/s and above ISP packages, and significant differences, to a 95% level of confidence: 2018 (actuals)



ISP package	Performed better than
Sky36	BT36, PN36 and BT300*
Sky66	PN36 and BT300*
BT50	BT300*
KCOM75 FTTP	BT300*
TT36	BT300*
BT67 FTTC	BT300*
EE36	BT300*
PN66	BT300*
BT36	BT300
EE66	BT300
TT63	BT300

Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

10. Other metrics affecting performance

There are several other metrics that determine the performance of fixed-line broadband services, and the most important of these are outlined in the table below.

As the technologies and providers that deliver the highest download speeds do not necessarily deliver the best performance on other metrics, it is important that consumers also consider other sets of performance measurements to understand the overall performance of individual ISP packages.

Figure 45: Summary of additional metrics covered in the research

Variable	Definition & importance
Web browsing speed	**The time taken to fetch the main HTML & assets (text, basic code & content files) from a webpage** *Dependent on download speeds, latency & DNS resolution times*
Latency	**The time it takes a packet of data to travel to a third-party server & back** *A connection with low latency will feel more responsive for simple tasks like web browsing & certain applications perform far better with lower latency*
Packet loss	**The proportion of data packets that are lost in transmission over a connection** *Important to online gamers & those streaming content or using VoIP as extended periods of loss lead to choppy & broken-up video & audio*
DNS resolution	**The time taken for an ISP to translate website names into IP addresses** When DNS servers operate slowly, web browsing & other activities suffer
DNS failure	**The proportion of requests for which the DNS server cannot translate a domain name to an IP address** *DNS failure results in error messages such as "Host could not be found"*
Jitter	**Measures the rate of change of latency** *The lower the measure of jitter the more stable a connection is & latency is important to gamers & VoIP users*

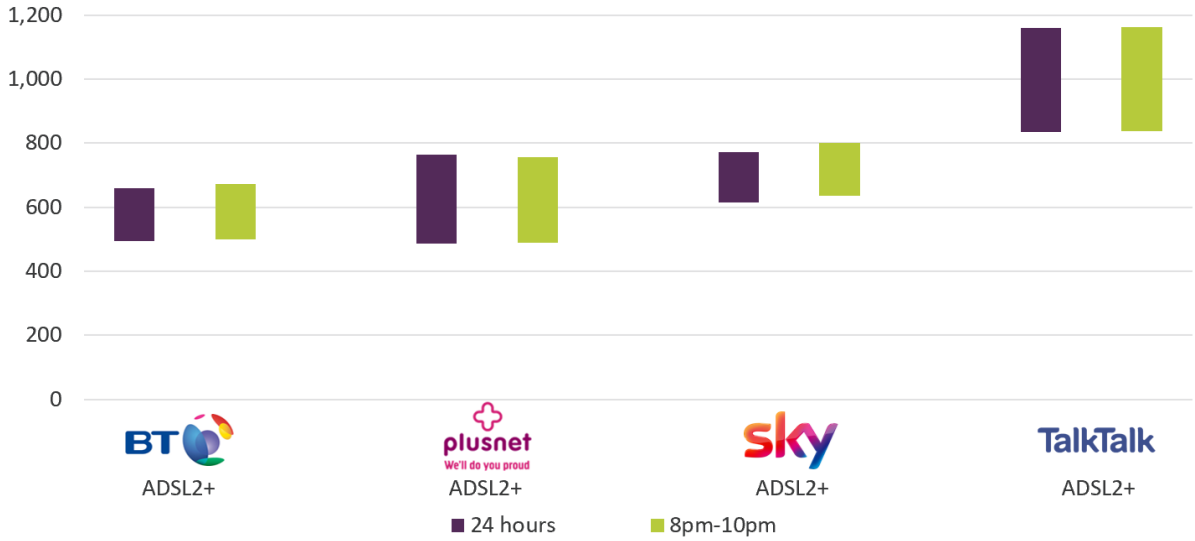
Source: Ofcom.

The comparative performance of different ISP packages with respect to these metrics can be found below and in the data visualisation tool that that accompanies this report.

Web browsing

To measure the basic web browsing performance of the different ISP packages, we measured the time in milliseconds to fetch the main HTML and assets (i.e. text, basic code and content files) from three test pages. Lower bars indicate better performance.

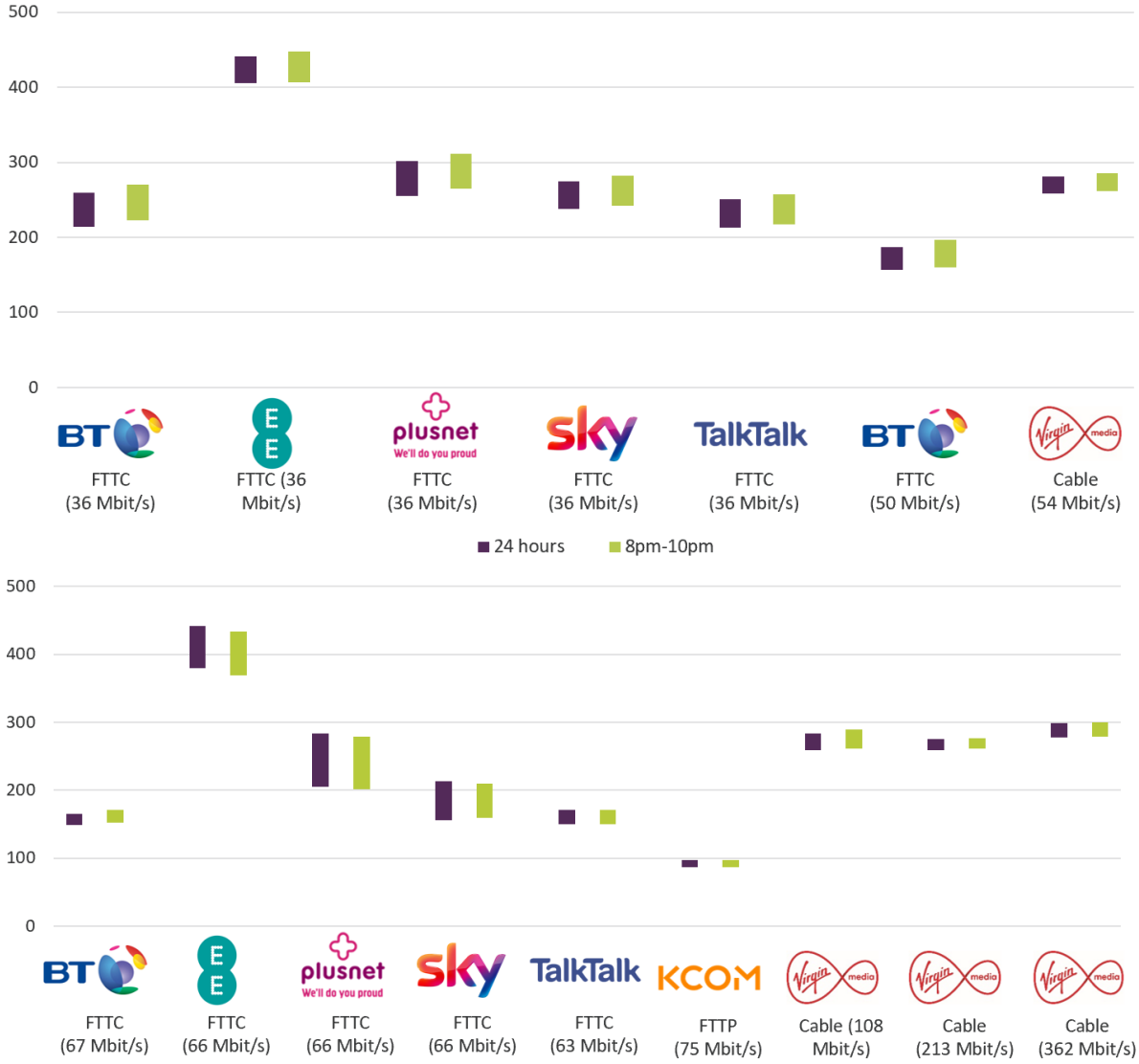
Figure 46: Average and peak-time loading of web pages for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)



	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
BT	TalkTalk*	TalkTalk*
Sky	TalkTalk*	TalkTalk*
Plusnet	TalkTalk*	TalkTalk*

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 47: Average and peak-time loading of web pages for 30 Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)



	24-hour average	8pm-10pm
ISP package	**Performed better than**	**Performed better than**
KCOM75 FTTP	BT67 FTTC*, TT63*, BT50*, Sky66*, BT36*, VM213*, Sky36*, TT36*, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*	BT67 FTTC*, TT63*, BT50*, Sky66*, BT36*, VM213*, Sky36*, TT36*, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*
BT67 FTTC	BT36*, VM213*, Sky36*, TT36*, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*	BT36*, VM213*, Sky36*, TT36, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*
TalkTalk63 FTTC	BT36*, VM213*, Sky36*, TT36, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*	BT36*, VM213*, Sky36*, TT36, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*
BT50 FTTC	BT36*, VM213*, TT36, VM54*, VM108*, PN66*, VM362*, PN36*, EE36*, EE66*	BT36*, VM213*, Sky36*, VM54*, VM108*, PN66, VM362*, PN36*, EE36*, EE66*
Sky66 FTTC	BT36, VM213*, TT36, VM54*, VM108*, PN66, VM362*, PN36*, EE36*, EE66*	BT36*, VM213*, Sky36*, VM54*, VM108*, VM362*, PN36*, EE36*, EE66*
BT36 FTTC	VM362*, EE36*, EE66*	VM362, EE36*, EE66*
VM213	VM362, EE36*, EE66*	VM362, EE36*, EE66*
Sky36 FTTC	EE36*, EE66*	VM362, EE36*, EE66*
TalkTalk36 FTTC	EE36*, EE66*	EE36*, EE66*
VM54	EE36*, EE66*	EE36*, EE66*
VM108	EE36*, EE66*	EE36*, EE66*
Plusnet66 FTTC	EE36*, EE66*	VM362, EE36*, EE66*
VM362	EE36*, EE66*	EE36*, EE66*
Plusnet36 FTTC	EE36*, EE66*	EE36*, EE66*

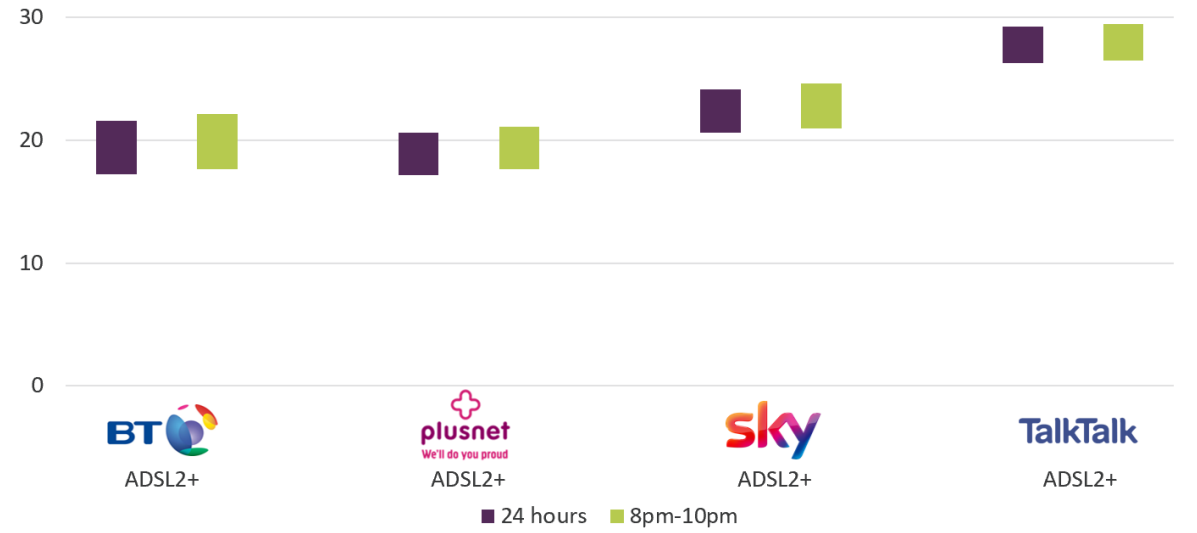
Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.

Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Latency

Latency is the time it takes for a single packet of data to travel to a third-party server and back again. The figure is commonly measured in milliseconds, and a connection with low latency will seem more responsive for the delivery of simple tasks such as web browsing. Some applications also perform significantly better with a low latency, particularly some online games. Lower bars indicate better performance.

Figure 48: Average and peak-time latency for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)

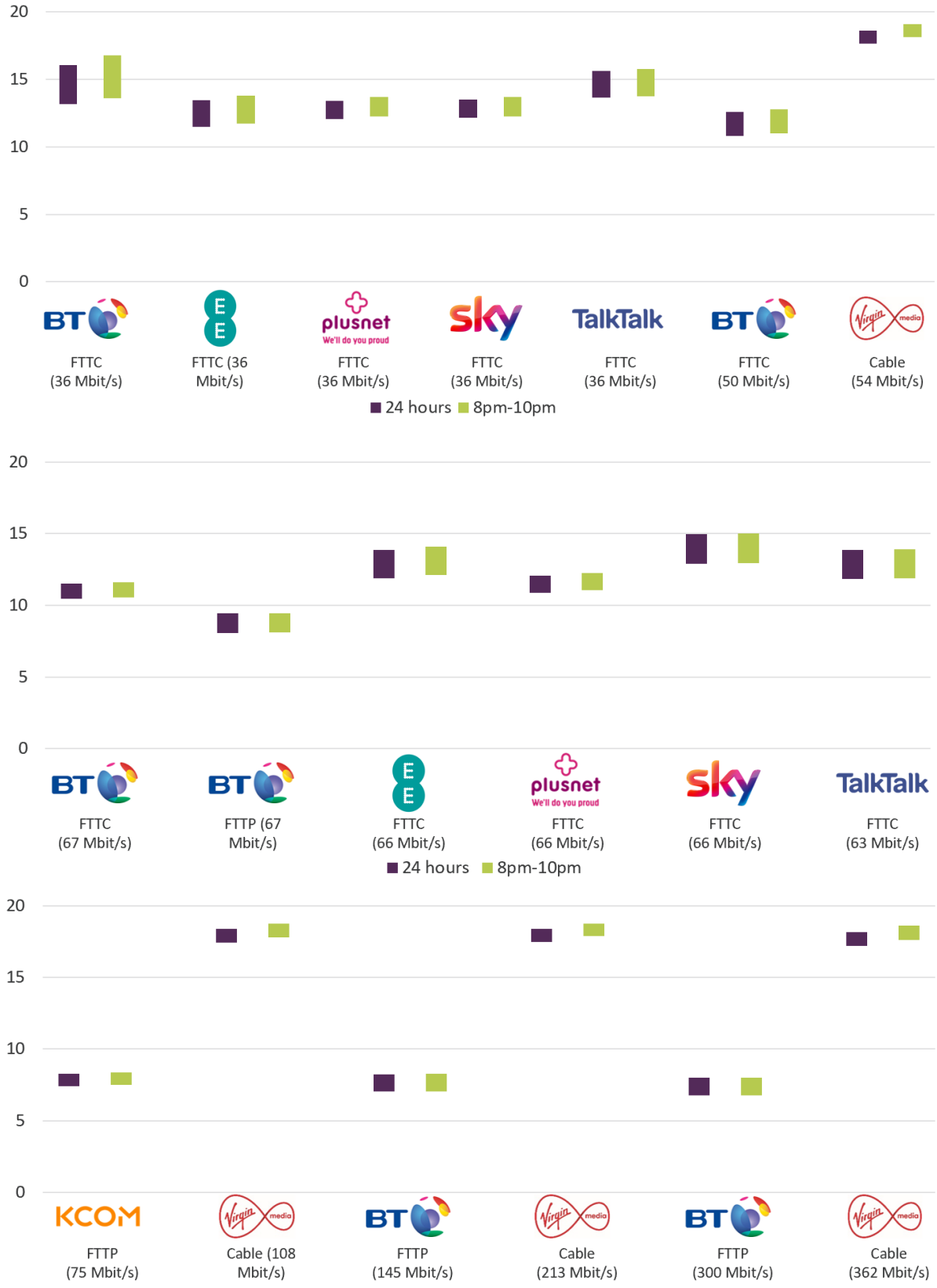


	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
BT	TalkTalk*	TalkTalk*
Plusnet	TalkTalk*	TalkTalk*
Sky	TalkTalk*	TalkTalk*

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.

Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 49: Average and peak-time latency for 30 Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)



	24-hour average	8pm-10pm
ISP package	**Performed better than**	**Performed better than**
BT300 FTTP	BT67 FTTP, BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
BT145 FTTP	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
KCOM75 FTTP	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
BT67 FTTP	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	BT67 FTTC*, PN66*, BT50*, PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
BT67 FTTC	PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	PN36*, EE36*, Sky36*, TT63*, EE66*, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
PN66	Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	PN36, Sky36, Sky66*, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
BT50	Sky66, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*	Sky66, TT36*, BT36*, VM362*, VM213*, VM108*, VM54*
PN36	TT36, BT36, VM362*, VM213*, VM108*, VM54*	TT36, VM362*, VM213*, VM108*, VM54*
EE36	TT36, VM362*, VM213*, VM108*, VM54*	VM362*, VM213*, VM108*, VM54*
Sky36	TT36, VM362*, VM213*, VM108*, VM54*	TT36, VM362*, VM213*, VM108*, VM54*
TT63	VM362*, VM213*, VM108*, VM54*	VM362*, VM213*, VM108*, VM54*
EE66	VM362*, VM213*, VM108*, VM54*	VM362*, VM213*, VM108*, VM54*
Sky66	VM362*, VM213*, VM108*, VM54*	VM362*, VM213*, VM108*, VM54*
TT36	VM362*, VM213*, VM108*, VM54*	VM362*, VM213*, VM108*, VM54*
BT36	VM362*, VM213*, VM108*, VM54*	VM362*, VM213*, VM108*, VM54*

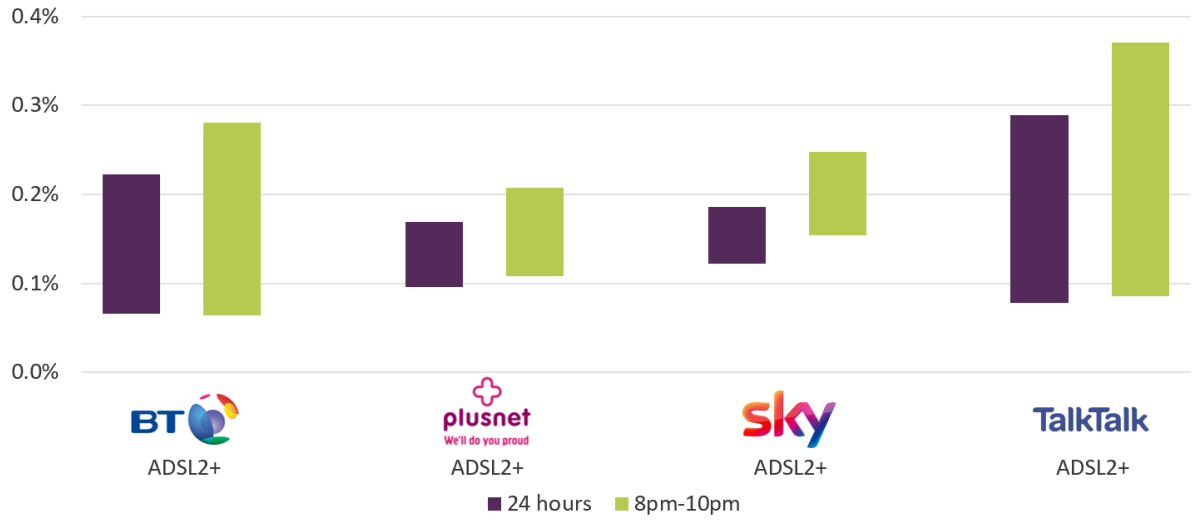
Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Packet loss

Packets of data can be lost during transmission over an internet connection. Packet loss can degrade the performance of real-time applications, and although network transmission protocols such as transmission control protocol (TCP) automatically deal with packet loss, to minimise the impact to the end-user, there may still be a temporary slowdown.

This is of concern to online gamers, users of voice over IP (VoIP) telephony and those streaming audio or video content. A small number of dropped packets is acceptable as each packet in the test accounts for only 0.2 seconds, but extended periods of loss lead to choppy audio or video content. Lower bars indicate better performance.

Figure 50: Average and peak-time packet loss for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (%)

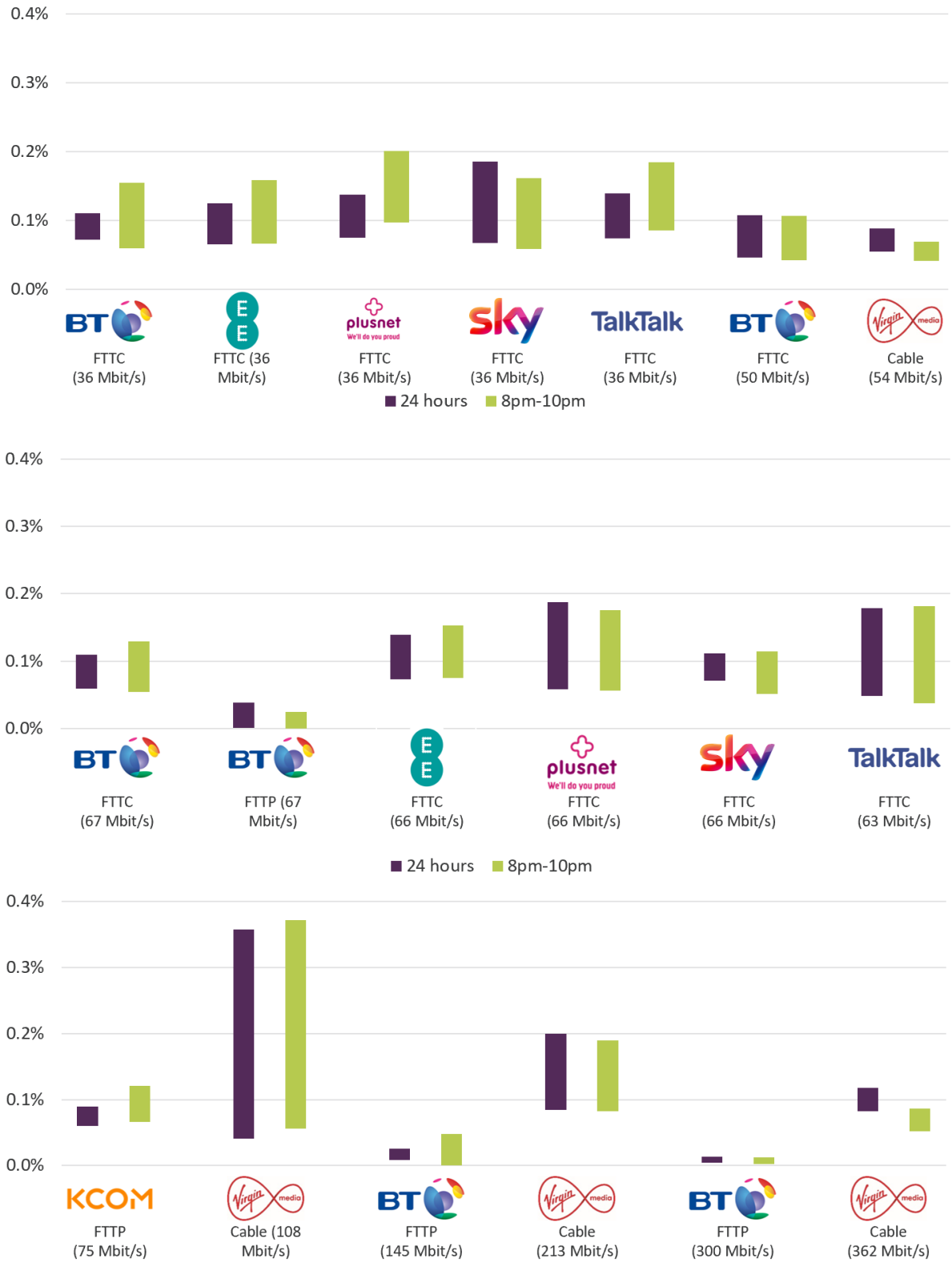


	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
No differences	No differences	No differences

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.

Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 51: Average and peak-time packet loss for 30 Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (%)



	24-hour average	8pm-10pm
ISP package	**Performed better than**	**Performed better than**
BT300 FTTP	VM54*, KCOM75*, BT50*, BT67 FTTC*, BT36*, Sky66*, VM362*, EE36*, PN36*, TT36*, EE66*, TT63*, Sky36*, PN66*, VM213*, VM108	VM54*, KCOM75*, BT50*, BT67 FTTC*, BT36*, Sky66*, VM362*, EE36*, PN36*, TT36*, EE66*, TT63*, Sky36*, PN66*, VM213*, VM108
BT145 FTTP	VM54*, KCOM75*, BT50*, BT67 FTTC*, BT36*, Sky66*, VM362*, EE36*, PN36*, TT36*, EE66*, TT63, Sky36*, PN66*, VM213*, VM108	VM54, KCOM75, BT50*, BT67 FTTC, BT36*, Sky66*, VM362*, EE36*, PN36*, TT36*, EE66*, Sky36, PN66, VM213*, VM108
BT67 FTTP	VM54*, KCOM75*, BT50, BT67 FTTC*, BT36*, Sky66*, VM362*, EE36*, PN36*, TT36*, EE66*, TT63, Sky36*, PN66*, VM213*, VM108	VM54*, KCOM75*, BT50*, BT67 FTTC*, BT36*, Sky66*, VM362*, EE36*, PN36*, TT36*, EE66*, TT63*, Sky36*, PN66*, VM213*, VM108
VM54	VM213	EE66, TT36, VM213, PN36*

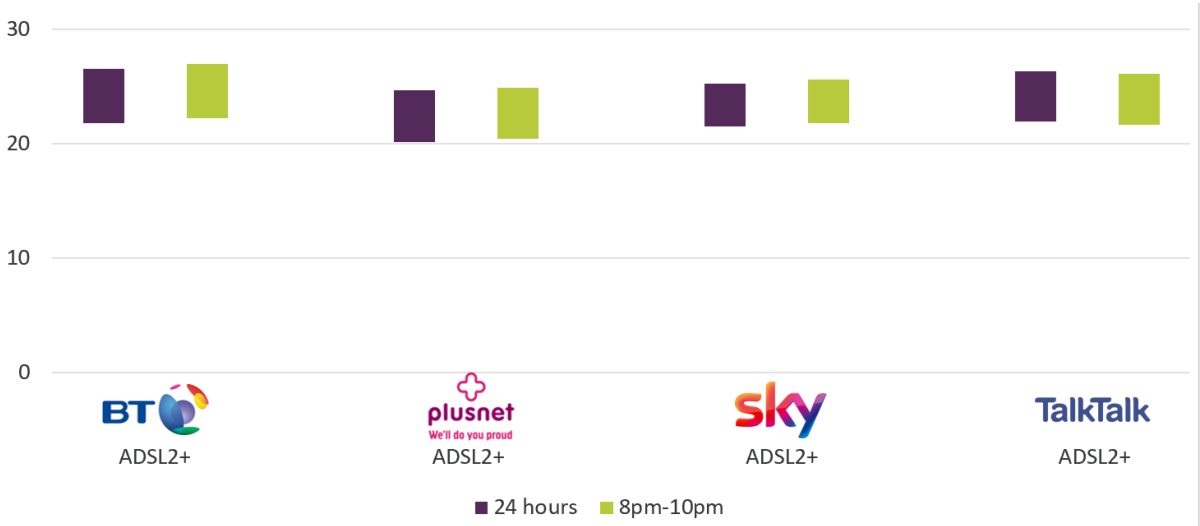
Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

DNS resolution

DNS (the domain name service) plays a crucial part in the way the internet operates. This protocol translates domain names (such as ofcom.org.uk) into the IP addresses that are used to route traffic (e.g. 194.33.179.XX).

Every ISP maintains its own DNS servers through which customers' computers issue queries to translate names into IP addresses. When these services fail, or operate slowly, browsing and other online activities suffer. A slow DNS does not affect download speed but can severely affect the responsiveness of the internet while browsing. Lower bars indicate better performance.

Figure 52: Average and peak-time DNS resolution time for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)

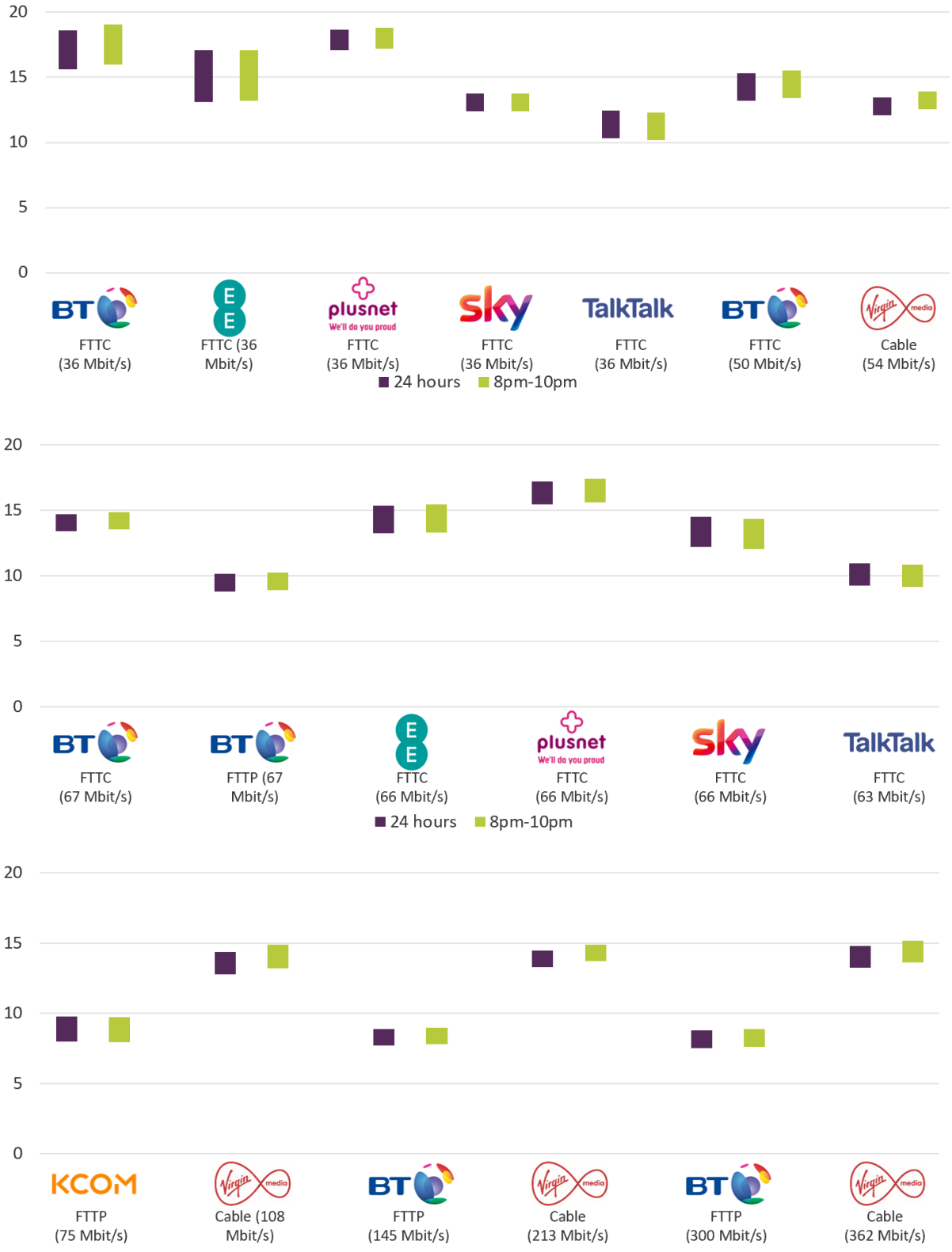


	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
No differences	No differences	No differences

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.

Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 53: Average and peak-time DNS resolution time for 30 Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)



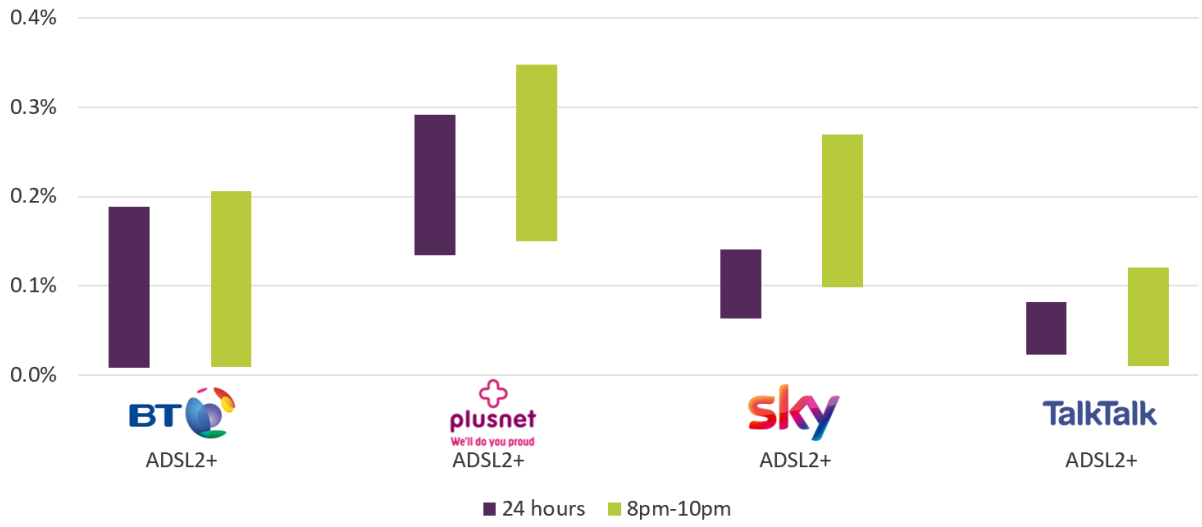
	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
BT300 FTTP	BT67 FTTP, TT63*, TT36*, VM54*, Sky36*, VM108*, VM213*, Sky66*, BT67 FTTC*, VM362*, EE66*, BT50*, EE36*, PN66*, BT36*, PN36*	BT67 FTTP, TT63, TT36*, Sky36*, VM54*, Sky66*, BT67*, VM108*, VM213*, VM362*, EE66*, BT50*, EE36*, PN66*, PN36*, BT36*
BT145 FTTP	TT63*, TT36*, VM54*, Sky36*, VM108*, VM213*, Sky66*, BT67 FTTC*, VM362*, EE66*, BT50*, EE36*, PN66*, BT36*, PN36*	TT63, TT36*, Sky36*, VM54*, Sky66*, BT67*, VM108*, VM213*, VM362*, EE66*, BT50*, EE36*, PN66*, PN36*, BT36*
KCOM75 FTTP	TT36, VM54*, Sky36*, VM108*, VM213*, Sky66*, BT67 FTTC*, VM362*, EE66*, BT50*, EE36*, PN66*, BT36*, PN36*	TT36, Sky36*, VM54*, Sky66*, BT67*, VM108*, VM213*, VM362*, EE66*, BT50*, EE36*, PN66*, PN36*, BT36*
BT67 FTTP	TT36, VM54*, Sky36*, VM108*, VM213*, Sky66*, BT67 FTTC*, VM362*, EE66*, BT50*, EE36*, PN66*, BT36*, PN36*	Sky36*, VM54*, Sky66*, BT67*, VM108*, VM213*, VM362*, EE66*, BT50*, EE36*, PN66*, PN36*, BT36*
TT63	VM54*, Sky36*, VM108*, VM213*, Sky66*, BT67 FTTC*, VM362*, EE66*, BT50*, EE36*, PN66*, BT36*, PN36*	Sky36*, VM54*, Sky66*, BT67*, VM108*, VM213*, VM362*, EE66*, BT50*, EE36*, PN66*, PN36*, BT36*
TT36	VM108, VM213*, Sky66*, BT67 FTTC*, VM362*, EE66*, BT50*, EE36*, PN66*, BT36*, PN36*	Sky36, VM54, Sky66*, BT67*, VM108*, VM213*, VM362*, EE66*, BT50*, EE36, PN66*, PN36*, BT36*
VM54	PN66*, BT36*, PN36*	PN66*, PN36*, BT36*
Sky36	PN66*, BT36*, PN36*	PN66*, PN36*, BT36*
VM108	PN66*, BT36*, PN36*	PN66*, PN36*, BT36*
VM213	PN66*, BT36*, PN36*	PN66*, PN36*, BT36*
Sky66	PN66*, BT36*, PN36*	PN66*, PN36*, BT36*
BT67 FTTC	PN66*, BT36*, PN36*	PN66*, PN36*, BT36*
VM362	PN66*, BT36*, PN36*	PN66, PN36, BT36
EE66	PN66, BT36, PN36*	PN66, PN36, BT36
BT50	PN66, BT36, PN36*	PN66, PN36, BT36
EE36	PN36	-

Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

DNS failure

DNS failure occurs when an ISP's DNS server is unable to translate a domain name to an IP address in a TCP/IP network. When a DNS failure occurs, the user is presented with an error message such as "this server is unavailable" or "host could not be found" and is unable to access the requested page on that occasion. Lower bars indicate better performance.

Figure 54: Average and peak-time DNS failure rates for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (%)

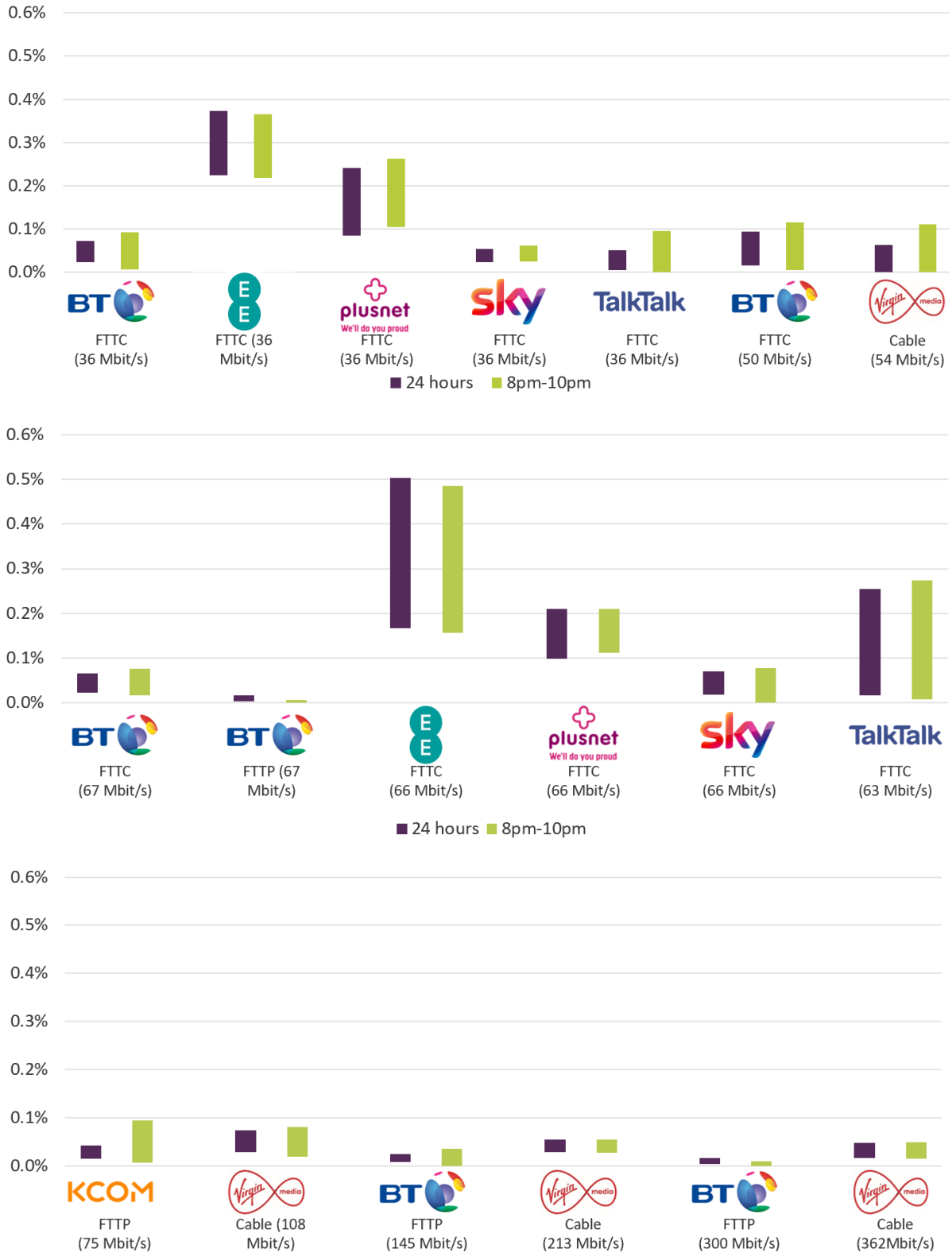


	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
TalkTalk	Plusnet*	Plusnet

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.

Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 55: Average and peak-time DNS failure rates for 30 Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (%)



	24-hour average	8pm-10pm
ISP package	**Performed better than**	**Performed better than**
BT300 FTTP	VM213*, Sky36, BT67 FTTC, Sky66, BT36, VM108*, BT67 FTTC, PN36*, PN66*, TT63, EE36*, EE66	VM362*, VM213*, Sky36*, BT67 FTTC, VM108*, BT36, KCOM75, BT50, PN66*, PN36*, TT63*, EE36*, EE66*
BT67 FTTP	VM213*, Sky36, BT67 FTTC, Sky66, BT36, VM108*, BT67 FTTC, PN36*, PN66*, EE36*, EE66	VM362*, VM213*, Sky36*, BT67 FTTC*, VM108*, BT36, KCOM75, BT50, PN66*, PN36*, TT63*, EE36*, EE66*
BT145 FTTP	VM108, PN66*, PN36*, EE36*, EE66*	VM362*, VM213*, Sky36*, BT67 FTTC, VM108*, BT36, KCOM75, BT50, PN66*, PN36*, TT63*, EE36*, EE66*
KCOM75 FTTP	PN66*, PN36*, EE36*, EE66*	PN66, PN36, EE36*, EE66
VM362	PN66*, PN36*, EE36*, EE66*	PN66*, PN36*, EE36*, EE66*
TT36	PN66*, PN36*, EE36*, EE66*	PN66, PN36, EE36*, EE66*
VM213	PN66*, PN36*, EE36*, EE66*	PN66*, PN36*, EE36*, EE66*
Sky36	PN66*, PN36*, EE36*, EE66*	PN66*, PN36*, EE36*, EE66*
VM54	PN66*, PN36, EE36*, EE66*	PN66, PN36, EE36*, EE66
BT67 FTTC	PN66*, PN36, EE36*, EE66*	PN66, PN36, EE36*, EE66*
Sky66	PN66*, PN36, EE36*, EE66*	PN66*, PN36*, EE36*, EE66*
BT36	PN66*, PN36, EE36*, EE66*	PN66, PN36, EE36*, EE66
VM108	PN66*, PN36, EE36*, EE66*	PN66, PN36*, EE36*, EE66*
BT50	PN66*, EE36*, EE66*	EE36*, EE66
PN66	EE36	EE36

Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

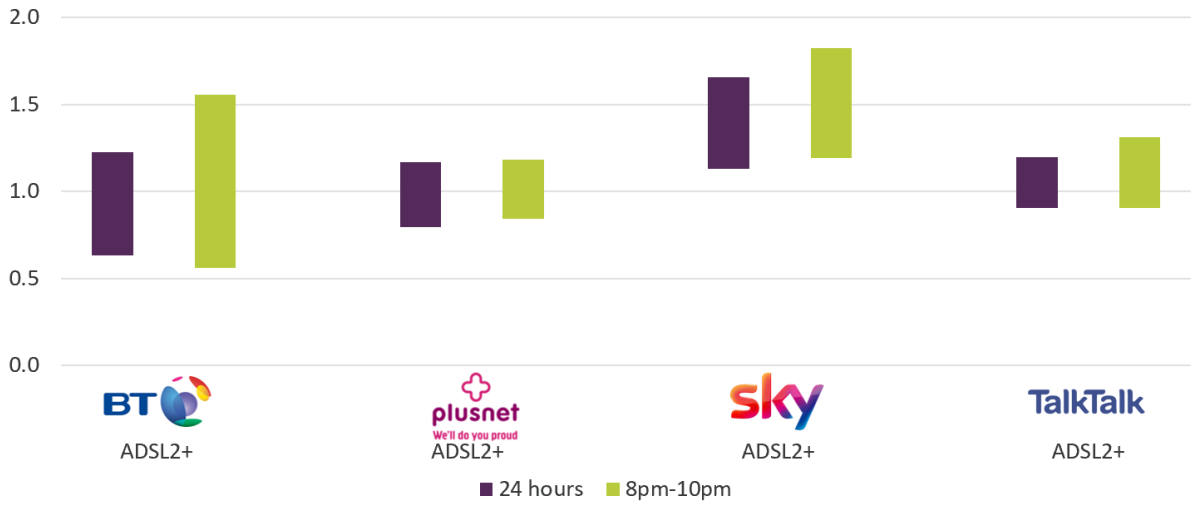
Jitter

'Jitter' can be described as the rate of change of latency. The lower the measure of jitter, the more stable the connection. Jitter and packet loss are the two biggest contributors to the quality of a voice over internet protocol (VoIP) phone call. Online gamers will also desire low jitter (low latency is useless if the connection has a high jitter rate).

Modern specialist VoIP devices will often include a 'jitter buffer' of around 20 milliseconds. This effectively allows for up to a 20-millisecond jitter, with no noticeable effect for the end-user. Lower bars indicate better performance.

Upstream jitter

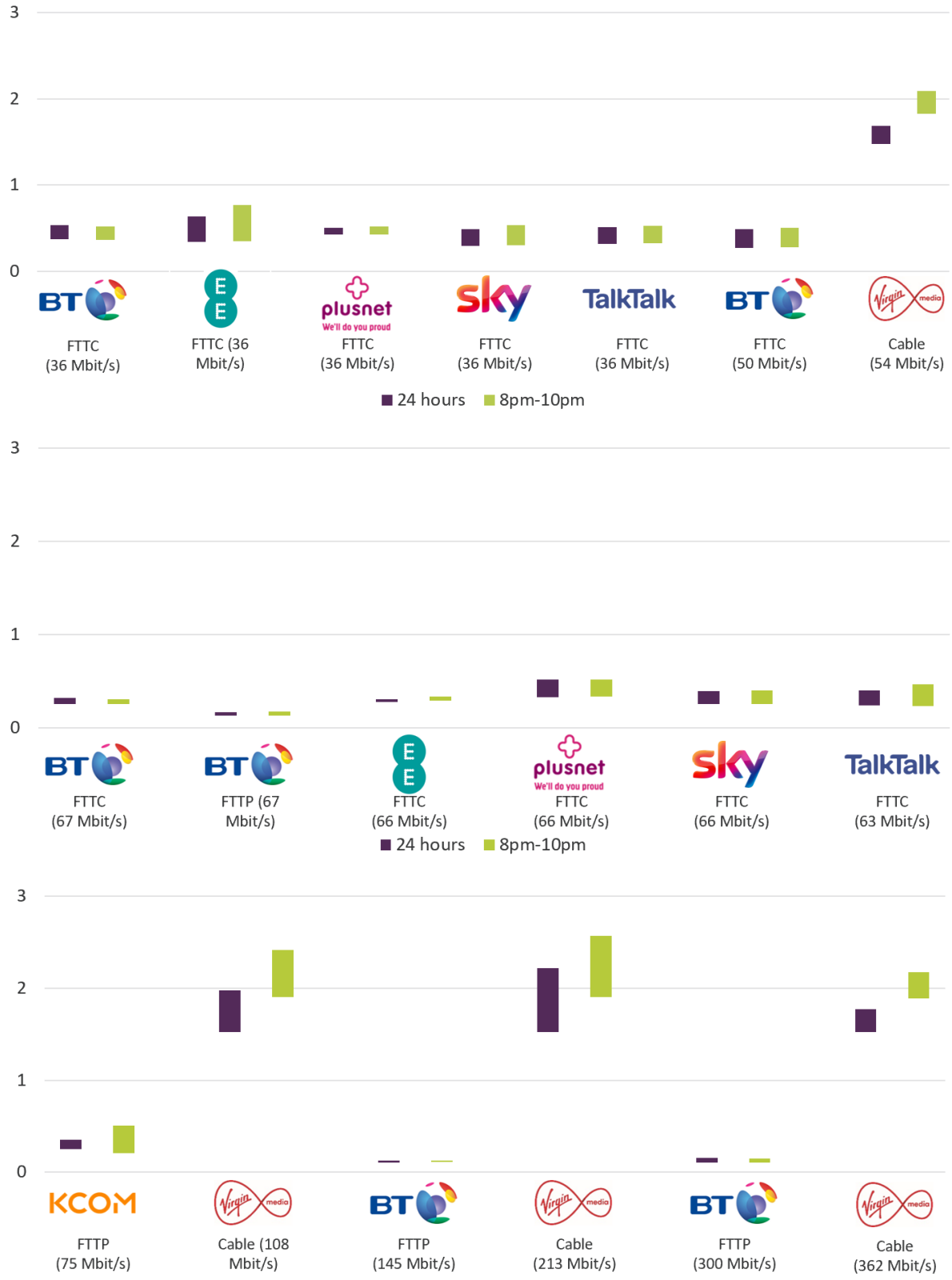
Figure 56: Average and peak-time upstream jitter for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018 (ms)



	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
No differences	No differences	No differences

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 57: Average and peak-time upstream jitter for 30Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018



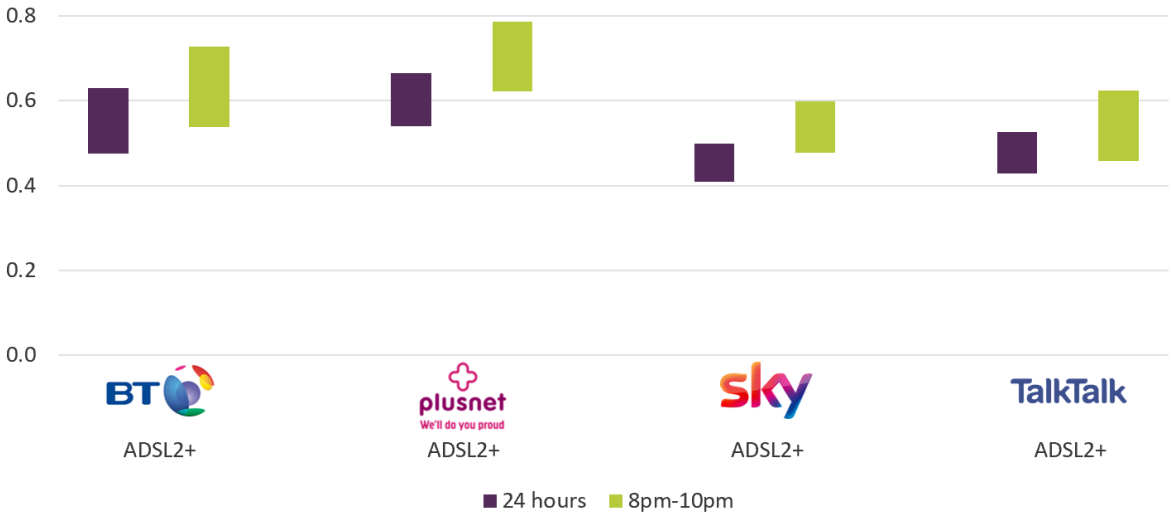
	24-hour average	8pm-10pm
ISP package	**Performed better than**	**Performed better than**
BT300 FTTP	BT67 FTTP*, EE66*, BT67 FTTC*, KCOM75*, Sky66*, TT63*, BT50*, Sky36*, PN36*, TT36*, PN66*, BT36*, EE36*, VM54*, VM362*, VM108*, VM213*	BT67 FTTP*, BT67 FTTC*, EE66*, Sky66*, TT63*, BT50*, KCOM75*, BT36*, PN66*, PN36*, TT36*, Sky36*, EE36*, VM54*, VM362*, VM108*, VM213*
BT145 FTTP	EE66*, BT67 FTTC*, KCOM75*, Sky66*, TT63*, BT50*, Sky36*, PN36*, TT36*, PN66*, BT36*, EE36*, VM54*, VM362*, VM108*, VM213*	BT67 FTTP, BT67 FTTC*, EE66*, Sky66*, TT63*, BT50*, KCOM75*, BT36*, PN66*, PN36*, TT36*, Sky36*, EE36*, VM54*, VM362*, VM108*, VM213*
BT67 FTTP	BT67 FTTC*, KCOM75*, Sky66*, TT63*, BT50*, Sky36*, PN36*, TT36*, PN66*, BT36*, EE36*, VM54*, VM362*, VM108*, VM213*	BT67 FTTC*, EE66*, Sky66*, TT63*, BT50*, KCOM75*, BT36*, PN66*, PN36*, TT36*, Sky36*, EE36*, VM54*, VM362*, VM108*, VM213*
EE66 FTTC	PN36*, TT36, PN66, BT36*, EE36, VM54*, VM362*, VM108*, VM213*	BT36, PN66, PN36*, TT36, Sky36, EE36, VM54*, VM362*, VM108*, VM213*
BT67 FTTC	PN36, TT36, PN66, BT36*, EE36, VM54*, VM362*, VM108*, VM213*	BT36*, PN66, PN36*, TT36, Sky36, EE36, VM54*, VM362*, VM108*, VM213*
KCOM75 FTTP	PN36*, VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
Sky66	PN36, VM54*, VM362*, VM108*, VM213*	PN36, VM54*, VM362*, VM108*, VM213*
TT63	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
BT50	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
Sky36	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
PN36	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
TT36	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
PN66	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
BT36	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*
EE36	VM54*, VM362*, VM108*, VM213*	VM54*, VM362*, VM108*, VM213*

Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.

Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a 95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Downstream jitter

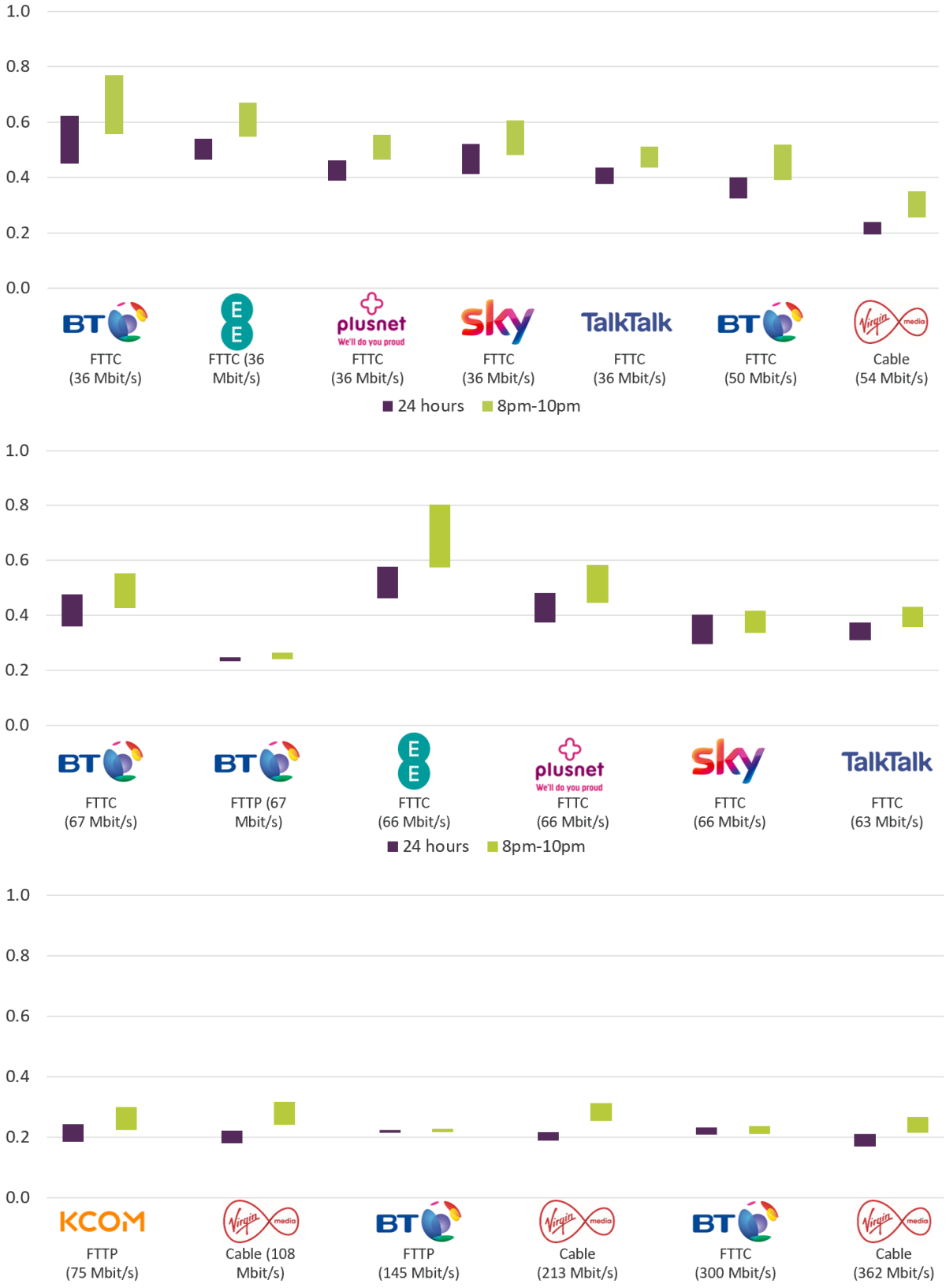
Figure 58: Average and peak-time downstream jitter for ADSL2+ ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018



	24-hour average	8pm-10pm
ISP	**Performed better than**	**Performed better than**
Sky	Plusnet*	Plusnet
TalkTalk	Plusnet	-

Source: Ofcom, using data provided by SamKnows; see note [36] in the Sources section.
Notes: The chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Figure 59: Average and peak-time downstream jitter for 30 Mbit/s and above ISP packages (lower values indicate better performance), and significant differences, to a 95% level of confidence: 2018



	24-hour average	8pm-10pm
ISP package	**Performed better than**	**Performed better than**
VM362	BT145*, BT300*, BT67 FTTP*, TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	Sky66*, TT63*, TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
VM213	BT145, BT300*, BT67 FTTP*, TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	Sky66, TT63*, TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
VM108	BT300*, BT67 FTTP*, TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	Sky66, TT63*, TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
BT145 FTTP	BT67 FTTP*, TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	VM213*, VM108, VM54*, Sky66*, TT63*, TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
BT300 FTTP	BT67 FTTP*, TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	VM213*, VM108, VM54*, Sky66*, TT63*, TT36*, BT50*, BT67 FTTC*,BT67 FTTP*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
VM54	TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
KCOM75 FTTP	TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	Sky66*, TT63*, TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
BT67 FTTP	TT63*, BT50*, Sky66*, TT36*, PN36*, BT67 FTTC*, PN66*, Sky36*, BT36*, EE36*, EE66*	Sky66*, TT63*, TT36*, BT50*, BT67 FTTC*, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
TT63	TT36, PN36, PN66, Sky36*, BT36*, EE36*, EE66*	TT36, BT50, BT67 FTTC, PN36*, PN66, Sky36*, EE36*, BT36*, EE66*
BT50	Sky36, BT36*, EE36*, EE66*	EE36, BT36, EE66
Sky66	Sky36, BT36*, EE36*, EE66*	BT67 FTTC, PN36*, PN66*, Sky36*, EE36*, BT36*, EE66*
TT36	Sky36, BT36*, EE36*, EE66*	EE36, BT36, EE66*
PN36	Sky36, BT36*, EE36*, EE66*	EE66
BT67 FTTC	EE36*, EE66*	BT36, EE66
PN66	EE36*, EE66*	-
Sky36	EE36, EE66	-

Source: Ofcom, using data provided by SamKnows; see note [37] in the Sources section.
Notes: BT FTTC upgrades in 2017 mean that the data in this report may slightly understate the performance new customers signing up to its 36 Mbit/s and 50Mbit/s FTTC services will receive, and slightly overstate the performance new customers buying its 67 Mbit/s FTTC service will receive. For more details see page 5; the chart bars show that there is a 95% probability that the actual average speed for all consumers (i.e. not just the consumer panellists in our sample) falls within the ranges shown; the table shows significant differences to a

95% confidence level; an asterisk (*) denotes that a difference is also significant to a (higher) 99% level of confidence.

Sources

[1] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: 1781 (Above 2 Mbit/s' and including 10Mbit/s – 34; Above '10Mbit/s and less than 30Mbit/s – 405; 30Mbit/s and higher – 1342) Notes: (1) Data have been weighted by ISP package market share, rural/urban 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.

[2] 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.

[3] Source: SamKnows measurement data for all national panel with a connection in November 2018. Panel members with a connection in November 2018. Panel base: 1781 (ADSL – 438; FTTC – 905 and cable – 628) Notes: (1) All connections, ADSL and FTTC data have been weighted by ISP package market share, rural/urban 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 2018. Panel base: urban ADSL – 565; rural ADSL – 129; urban FTTC – 577 and rural FTTC – 144) 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 2018. Panel base: 1820 (urban – 1545; rural – 275) 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 2018. Panel members with a connection in November 2018. Panel base: 1781 (ADSL – 438; FTTC – 905, FTTP – 358 and cable – 628) Notes: (1) All connections, ADSL and FTTC data have been weighted by ISP package market share, rural/urban 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 and FTTP; (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 2018. Panel base: 1781 (ADSL1 – 34; ADSL2+ – 404; FTTC36 – 443; FTTC50 – 125; FTTC 63-67 – 326; cable54 – 98, cable108 – 127, cable213 – 268, cable362 – 135, FTTP67 – 117, FTTP75 – 46, FTTP145 – 97 and FTTP300 – 98) Notes: (1) All connections, ADSL and FTTC data have been weighted by ISP package market share, rural/urban 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 54 Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s, cable 362Mbit/s, FTTP 67 Mbit/s, FTTP 75 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s (4) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[8] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: 1781 (ADSL1 – 34, ADSL2+ – 404, FTTC36 – 443, FTTC50 – 125, FTTC 63-67 – 326, cable54 – 98, cable108 – 127, cable213 – 268, cable362 – 135, FTTP67 – 117, FTTP75 – 46, FTTP145 – 97 and FTTP300 – 98) Notes: (1) Data have been weighted by ISP package market share, rural/urban 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 54 Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s, cable 362 Mbit/s, FTTP 67 Mbit/s, FTTP 75 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 2018. Panel base: 1781 (urban: ADSL1 – 16, ADSL2+ – 267, FTTC36 – 362, FTTC50 – 117, FTTC 63-67 – 301; Rural: ADSL1 – 18, ADSL2+ – 137, FTTC36 – 93, FTTC50 – 8, FTTC 63-67 – 25) Notes: (1) Data have been weighted by ISP package market share, rural/urban 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) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[10] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: ADSL1 – 34, ADSL2+ – 404, FTTC36 – 443, FTTC50 – 125, FTTC 63-67 – 326, cable54 – 98, cable108 – 127, cable213 – 268, cable362 – 135, FTTP67 – 117, FTTP75 – 46, FTTP145 – 97 and FTTP300 – 98 Notes: (1) Data have been weighted by ISP package market share, rural/urban 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 54 Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s, cable 362 Mbit/s, FTTP 67 Mbit/s, FTTP 75 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s.

[11] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: 1781 (Above 2Mbit/s' and including 10Mbit/s – 34; Above 10 Mbit/s and less than 30Mbit/s – 405; 30Mbit/s and higher – 1342) Notes: (1) Data have been weighted by ISP package market share, rural/urban 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.

[12] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: 1781 (ADSL1 – 34, ADSL2+ – 404, FTTC36 – 443, FTTC50 – 125, FTTC 63-67 – 326, cable54 – 98, cable108 – 127, cable213 – 268, cable362 – 135, FTTP67 – 117, FTTP75 – 46, FTTP145 – 97 and FTTP300 – 98) Notes: (1) Data have been weighted by ISP package market share,

rural/urban 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 54 Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s, cable 362 Mbit/s, FTTP 67 Mbit/s, FTTP 75 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s (3) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[13] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: ADSL2+ – 404 Notes: (1) Data have been weighted by ISP package market share, rural/urban and geographic market classification, 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.

[14] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: Cable 54 Mbit/s – 98 Notes: (1) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 54Mbit/s, cable 108Mbit/s, cable 213 Mbit/s and cable 362 Mbit/s; (2) Data are collected from multi-thread download speed tests.

[15] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: Cable 108 Mbit/s – 127 Notes: (1) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 54Mbit/s, cable 108Mbit/s, cable 213Mbit/s and cable 362Mbit/s; (2) Data are collected from multi-thread download speed tests.

[16] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: Cable 213Mbit/s – 268 Notes: (1) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 54Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s and cable 362 Mbit/s; (2) Data are collected from multi-thread download speed tests.

[17] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: FTTC 36 Mbit/s – 443 Notes: (1) Data have been weighted by ISP package market share, rural/urban and geographic market UK fixed-line broadband performance and max attainable speed (FTTC) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests.

[18] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: FTTC 50 Mbit/s – 125 Notes: (1) Data have been weighted by ISP package market share, rural/urban and geographic market classification, max attainable speed (FTTC) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests.

[19] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: FTTC 63-67 Mbit/s – 326 Notes: (1) Data have been weighted by ISP package market share, rural/urban and geographic market classification, max attainable speed (FTTC) to ensure that they are representative of the UK as a whole; (2) Data are collected from multi-thread download speed tests.

[20] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: 1781 (ADSL1 – 28, ADSL2+ – 343, FTTC36 – 431, FTTC50 – 102, FTTC 63-67 – 324, cable54 – 98, cable108 – 127, cable213 – 268, cable362 – 134) Notes: (1) Data have been weighted by ISP package market share, rural/urban 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 and FTTP units.

[21] Source: SamKnows measurement data for all national panel members with a connection in November 2018. Panel base: 1781 (ADSL1 – 34; ADSL2+ – 404; FTTC36 – 443; FTTC50 – 125; FTTC 63-67 – 326; cable54 – 98, cable108 – 127, cable213 – 268, cable362 – 135, FTTP67 – 117, FTTP75 – 46, FTTP145 – 97 and FTTP300 – 98) Notes: (1) Data have been weighted by ISP package market share, rural/urban 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 54 Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s, cable 362 Mbit/s, FTTP 67 Mbit/s, FTTP 75 Mbit/s, FTTP 145 Mbit/s and FTTP 300 Mbit/s (3) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[22] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT ADSL2+ – 63; Plusnet ADSL2+ – 68; Sky ADSL2+ – 78; TalkTalk ADSL2+ – 62 Notes: (1) Data have been normalised to the UK profile by distance from exchange (ADSL) to ensure that operators can be compared on a like-for-like basis; (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) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[23] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT ADSL2+ – 63; Plusnet ADSL2+ – 68; Sky ADSL2+ – 78; TalkTalk ADSL2+ – 62 Notes: (1) Data have been normalised to the UK profile by distance from exchange (ADSL) to ensure that operators can be compared on a like-for-like basis; (2) Data are collected from multi-thread download speed tests.

[24] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT36 – 94, BT50 – 115, BT67 FTTC – 307, BT67 FTTP – 117, BT145 – 97, BT300 – 98, EE36 – 88, EE66 – 79, Plusnet36 – 176, Plusnet66 – 196, Sky36 – 197, Sky66 – 118, TalkTalk36 – 175, TalkTalk63 – 140, Virgin54 – 98, Virgin108 – 127, Virgin213 – 268, Virgin362 – 135, KCOM75 – 46 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis; (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.

[25] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: Cable 362 Mbit/s – 135 Notes: (1) Due to the low representation of high-speed cable packages in the UK, ISP panel results are used for cable 54 Mbit/s, cable 108 Mbit/s, cable 213 Mbit/s and cable 362 Mbit/s; (2) Data are collected from multi-thread download speed tests.

[26] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT36 – 94, BT50 – 115, BT67 FTTC – 307, BT67 FTTP – 117, BT145 – 97, BT300 – 98, EE36 – 88, EE66 – 79, Plusnet36 – 176, Plusnet66 – 196, Sky36 – 197, Sky66 – 118, TalkTalk36 – 175, TalkTalk63 – 140, Virgin54 – 98, Virgin108 – 127, Virgin213 – 268, Virgin362 – 135, KCOM75 – 46 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis; (2) Maximum speed is calculated as the average of the daily maximum speeds achieved throughout the month; (3) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[27] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: FTTP 67 Mbit/s – 117 Notes: (1) Due to the low representation of high-speed packages in the UK, ISP panel results are used for cable and FTTP data; (2) Data are collected from multi-thread download speed tests.

[28] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT36 – 94, BT50 – 115, BT67 FTTC – 307, BT67 FTTP – 117, BT145 – 97, BT300 – 98, EE36 – 88, EE66 – 79, Plusnet36 – 176, Plusnet66 – 196, Sky36 – 197, Sky66 – 118, TalkTalk36 – 175, TalkTalk63 – 140, Virgin54 – 98, Virgin108 – 127, Virgin213 – 268, Virgin362 – 135, KCOM75 – 46 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis; (2) Maximum speed is calculated as the average of the daily maximum speeds achieved throughout the month.

[29] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: FTTP 75 Mbit/s – 46 Notes: (1) Due to the low representation of high-speed packages in the UK, ISP panel results are used for cable and FTTP data; (2) Data are collected from multi-thread download speed tests.

[30] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT ADSL2+ – 63; Plusnet ADSL2+ – 68; Sky ADSL2+ – 78; TalkTalk ADSL2+ – 62 Notes: (1) Data have been normalised to the UK profile by distance from exchange (ADSL) to ensure that operators can be compared on a like-for-like basis; (2) Data are collected from multi-thread download speed tests.

[31] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT36 – 94, BT50 – 115, BT67 FTTC – 307, BT67 FTTP – 117, BT145 – 97, BT300 – 98, EE36 – 88, EE66 – 79, Plusnet36 – 176, Plusnet66 – 196, Sky36 – 197, Sky66 – 118, TalkTalk36 – 175, TalkTalk63 – 140, Virgin54 – 98, Virgin108 – 127, Virgin213 – 268, Virgin362 – 135, KCOM75 – 46 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis; (2) Maximum speed is calculated as the average of the daily maximum speeds achieved throughout the month; (3) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[32] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: FTTP 145 Mbit/s – 97 Notes: (1) Due to the low representation of high-speed packages in the UK, ISP panel results are used for cable and FTTP data; (2) Data are collected from multi-thread download speed tests.

[33] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT ADSL2+ – 63; Plusnet ADSL2+ – 68; Sky ADSL2+ – 78; TalkTalk ADSL2+ – 62 Notes: (1) Data have been normalised to the UK profile by distance from exchange (ADSL) to ensure that operators can be compared on a like-for-like basis.

[34] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT36 – 86, BT50 – 93, BT67 – 306, EE36 – 88, EE66 – 79, Plusnet36 – 113, Plusnet66 – 193, Sky36 – 197, Sky66 – 118, TalkTalk36 – 175, TalkTalk63 – 139, Virgin54 – 98, Virgin108 – 127, Virgin213 – 268, Virgin362 – 134, KCOM75 – 41 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis.

[35] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: FTTP 300 Mbit/s – 98 Notes: (1) Due to the low representation of high-

speed packages in the UK, ISP panel results are used for cable and FTTP data; (2) Data are collected from multi-thread download speed tests.

[36] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: Panel base: BT ADSL2+ – 63; Plusnet ADSL2+ – 68; Sky ADSL2+ – 78; TalkTalk ADSL2+ – 62 Notes: (1) ADSL data have been normalised to the UK profile by distance from exchange to ensure that operators can be compared on a like-for-like basis; (2) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[37] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT36 – 94, BT50 – 115, BT67 FTTC – 307, BT67 FTTP – 117, BT145 – 97, BT300 – 98, EE36 – 88, EE66 – 79, Plusnet36 – 176, Plusnet66 – 196, Sky36 – 197, Sky66 – 118, TalkTalk36 – 175, TalkTalk63 – 140, Virgin54 – 98, Virgin108 – 127, Virgin213 – 268, Virgin362 – 135, KCOM75 – 46 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis; (2) The bars indicate that there is a 95% probability that the actual average speed for all corresponding consumers fall within the given range.

[38] Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT67 FTTC – 307, BT67 FTTP – 117 Notes: (1) FTTC data have been normalised to the UK profile by max attainable line speed to ensure that operators can be compared on a like-for-like basis.

Annex 1: Performance of EE fixed wireless broadband connections

The performance of home broadband delivered over mobile networks

In parallel with the measurements summarised elsewhere in this report, we have undertaken some work to evaluate the potential role of fixed wireless access (FWA) services as an alternative to traditional home broadband services. These services are currently deployed in the UK on either unlicensed or shared-use spectrum, such as that commonly used for wi-fi connections or, increasingly, on mobile networks using 4G LTE. This latter approach may become more commonplace with the roll-out of 5G networks, the first of which are due to launch later in 2019.

To date, capacity constraints have limited FWA's ability to be a completely effective substitute to fixed broadband in anywhere other than rural areas. However, recent technological development (for example, beam-forming and the use of millimetre-wave technology in 5G) may mean that that capacity is less of a constraint in future.

Currently, FWA services are offered by two mobile network operators; EE and Three. EE launched its *4GEE Home* service in early 2018, while Three's *Home-Fi* service (previously known as Relish) launched in 2014, although in was initially only available in a limited number of locations. Both services include a home broadband router, with broadband connectivity being delivered using FWA over mobile spectrum, and are offered at prices comparable with traditional home broadband services.

To understand the performance of FWA home broadband, we worked with BT/EE and SamKnows to conduct measurements and gather more information on the performance received by current 4GEE Home customers. Through this we hoped to better understand the capability of FWA to meet the technical specification of the Government's universal service obligation (USO) to provide minimum download speeds of 10 Mbit/s and an upload speed of 1 Mbit/s.

To ensure comparability with the measurements elsewhere in the report, we ran the same SamKnows upload and download speed tests on 58 4GEE Home connections. It should be noted that the small sample size means that our findings are not statistically representative. Figure 1.1 below shows the difference between the average maximum speed for each individual connection against the speeds achieved in the peak time periods of 8pm-10pm.

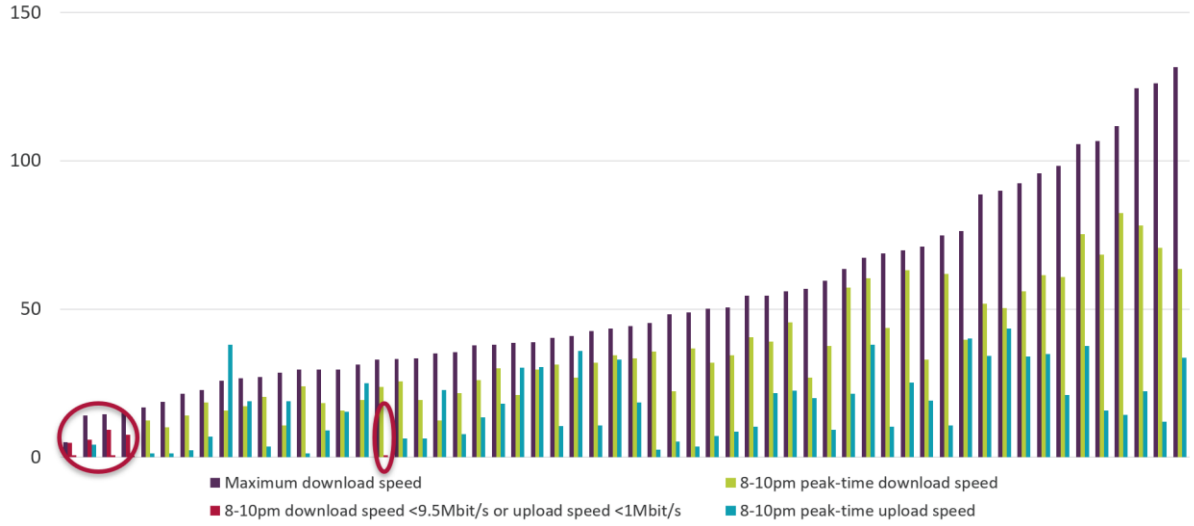
As the maximum download speed of a line should be above 10 Mbit/s and the upload speed above 1 Mbit/s to meet the specifications of the USO, we benchmarked connections to deliver at least 9.5 Mbit/s downstream (95% of 10 Mbit/s)and 0.95 Mbit/s upstream (95% of 1 Mbit/s) during the 8-10pm peak-time period to provide an insight into their comparability with conventional 'wireline' fixed connections, where this would be the expected level of variation during peak periods.

Out of our 58 4GEE Home panellists, four had average peak-time download below 9.5 Mbit/s and four had an average peak-time upload speed of less than 0.95 Mbit/s. Overall, five of the 58 panellists did not receive 9.5 Mbit/s downstream and 0.95 Mbit/s upstream.

We also found high levels of variation in the performance of FWA connections. Coefficient of variation is used to measure 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.

The 24-hour download speeds of our panel of 4GEE Home FWA connections had a coefficient of variation of 0.59: higher than that of any of the traditional fixed broadband services included in the report (as is show in Figure 14, the coefficient of variation of the packages in the main report ranged from 0.01 for 300 Mbit/s FTTP services to 0.56 for ADSL1 services).

Figure 1.1: Average maximum download and average 8-10pm peak-time download and upload speeds for 4GEE Home panellists (Mbit/s)



Source: Ofcom, using data provided by SamKnows.

Annex 2: Technical methodology

Technical methodology

This report is Ofcom's seventeenth fixed-line residential broadband speeds report and the fourteenth in which we have published ISP package-specific data and comparisons between ISPs. 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 consumers 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 ISP-provided data where the SamKnows Router SDK had been embedded directly into the customers CPE. The Router SDK includes all the SamKnows QoS and 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 with data caps still in place, 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 ISPs 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. For those with data caps, 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. Eight speed-test servers are deployed in a range of different data centres in and immediately around London to handle the traffic. 32Gbit/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 an ISP’s recursive DNS resolution can be accomplished using many tools, such as nslookup, dnsip and dig. For the purposes of the research, dig was chosen for the flexibility it offers.

Typically, an ISP will have two or more recursive DNS resolvers. Rather than using the DNS servers provided by the DHCP leases to the testing units, the software on the units tests the ISP DNS resolvers directly. This allows us to determine failure of a single DNS server. It also overcomes another issue – that of people changing the DNS servers being returned in DHCP leases from their router (this proved quite common with customers of some ISPs).

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 ISP and geographic location of the requesting IP address. Where the ISP 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 10 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, 1050Kbps, 1750Kbps, 2350Kbps, 3000Kbps, 4500Kbps, 6000Kbps and 15600Kbps.

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.

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 4,918 (including data from 2,182 panellists on SamKnows' independent global platform, SamKnows One) panellists who either had a broadband monitoring unit connected to their routers in November 2018 or had the SamKnows SDK embedded in to their CPE. Figure 1.1 sets out Ofcom's definitions of geographic broadband markets (based on the definitions for the wholesale broadband access (WBA) market. 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 ISP 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 ISP package performance, we used only panellists who live within geographic markets B. This means that all panellists used for the ISP 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 ISPs 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 ISP. 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 ISPs 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.

Annex 3: Statistical methodology

Key statistical concepts used in this report

This report presents the findings from research which has involved the collection and interpretation of 6.31 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 IPstream 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 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:

- To replace panellists who leave the panel due to natural attrition, such as moving house or losing interest in participating in the research.
- Ensuring 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.
- To 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 4,284 – active meaning contributing results to either the ISP, or national analysis. 2,193 of these respondents belong to the

Ofcom recruited panel and 2,091 to SamKnows' wider UK 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 despatch 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 tests for each time interval 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 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 2018 and 10 December 2018 was 372, from a theoretical maximum of 480 per respondents (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 less 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 4,284 panellists' measurement results were divided into two separate datasets, each weighted to targets.

- National panel (over 2Mbit/s packages): 1,781 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: 3,012 panellists. Respondents for this panel consist of panellists from geographic markets 2 and 3 only. Panellists from LLU operators Sky and TalkTalk and cable provider Virgin Media were on-net 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: 1,819 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 very similar to the national panel, however the rural ADSL1, urban ADSL1, rural FTTC50 and rural FTTC63-67 samples were boosted to give a larger, more robust sub-sample to weight the data.

Sample weighting

- National panel: Weighting by ISP market and package shares by LLU/ non-LLU connections supplied by ISPs as at November 2018, urban/rural, geographic market classification, xDSL distance to exchange (fitted to UK representative exchange line distribution provided by BT Openreach) 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 or 63-67Mbit/s). Although BT Openreach provided four curves – 36Mbit/s, 50Mbit/s and 63-67Mbit/s, the 50Mbit/s FTTC lines were not normalised as only BT actively markets this product.
- 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 2018 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 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. Four 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, ISPs' packages and technology, to ensure that any differences identified were due to differing performance and not due to a differing distribution of line lengths. BT Openreach provides 2 curves which indicate the national distance profile of ADSL1 and ADSL2+ lines for all lines in the UK. Each relevant ADSL2+ ISP package in the national panel is adjusted to match this national profile.

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. Different weights by distance were applied to each of the UK national, datasets.

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. BT Openreach 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 54%. The under-0.5s are primarily driven by the over-representation (against current market shares) both of some FTTC packages, and shorter line lengths in the panel. The over-2s are driven by the interaction between market shortfall and distance from exchange.

Figure 2.2: National panel range of weights

Range	Count	Column N%
Less than 0.5	1193	67%
0.5 to 1	476	26.7%
1 to 1.5	43	2.4%
1.5 to 2	29	1.6%
2+	40	2.2%

Source: Ofcom

Overall, against the entire weight frame, the ISP package panel achieved a weighting efficiency of 86%. 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	Column N %
Less than 0.5	0	0%
0.5 to 1	2520	83.7%
1 to 1.5	393	13%
1.5 to 2	68	2.3%
2+	31	1%

Source: Ofcom

Figure 2.4: Weighting efficiency, by ISP package

ISP package	Weighting efficiency	ISP package	Weighting efficiency
BT ADSL2+	79.8%	EE 66 Mbit/s	100%
Plusnet ADSL2+	96.3%	Plusnet 66 Mbit/s	57.5%
Sky ADSL2+	99%	Sky 66 Mbit/s	66.1%
TalkTalk ADSL2+	89.4%	TalkTalk 63 Mbit/s	100%
BT 36 Mbit/s	100%	BT 67 Mbit/s FTTP	100%
EE 36 Mbit/s	91.4%	KCOM 75 FTTP	100%
Plusnet 36 Mbit/s	49.9%	BT 160 Mbit/s FTTP	100%
Sky 36 Mbit/s	86.7%	BT 330 Mbit/s FTTP	100%
TalkTalk 36 Mbit/s	98.9%	Virgin Media 108Mbit/s	100%
Virgin Media 54 Mbit/s	100%	Virgin Media 213 Mbit/s	100%
BT 50 Mbit/s	100%	Virgin Media 362 Mbit/s	100%
BT 67 Mbit/s	100%		

Source: Ofcom

Overall, the rurality panel achieved a weighting efficiency of 83%. 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	Column N %
Less than 0.5	4	0.2%
0.5 to 1	727	39.9%
1 to 1.5	497	27.3%
1.5 to 2	55	3.0%
2+	537	29.5%

Source: Ofcom

Weighted and unweighted measurement data for ADSL2+ ISP packages

The effect of the combined overall ISP panel weighting on ADSL2+ ISP package performance is shown in the following tables.

Figure 3.5: Average maximum download speeds for ADSL2+ packages: weighted and unweighted data

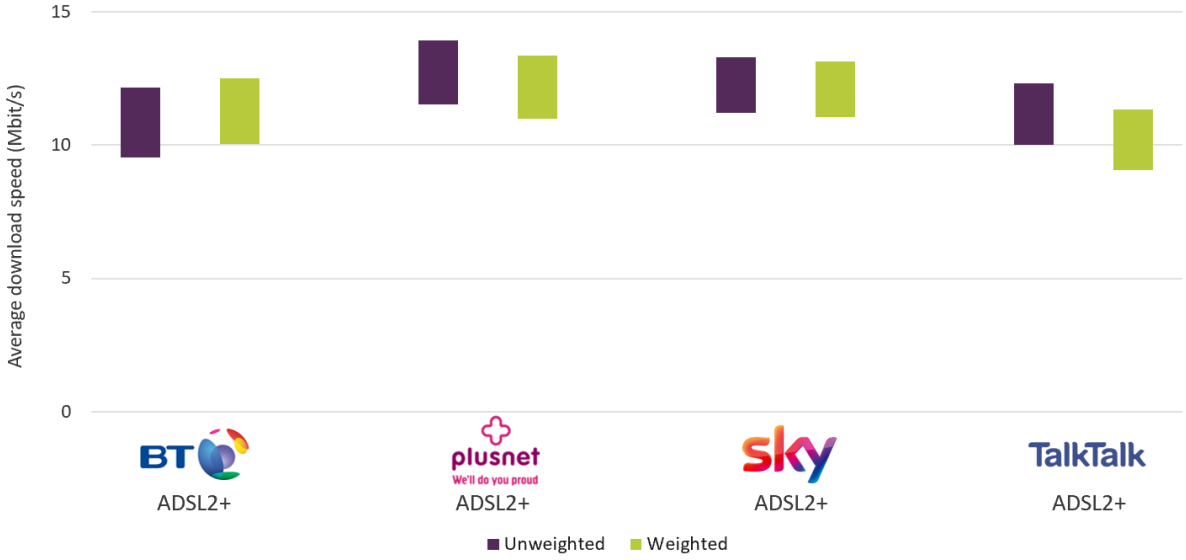


Figure 3.6: 24-hour average download speeds for ADSL2+ packages: weighted and unweighted data

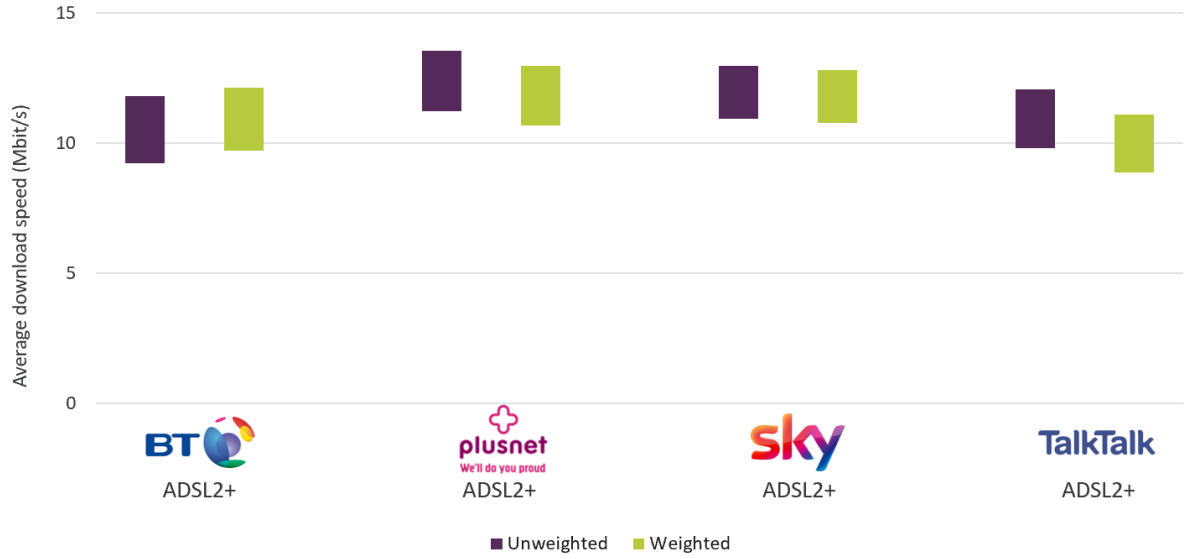


Figure 3.7: Average 8-10pm peak-time download speeds for ADSL2+ packages: weighted and unweighted data

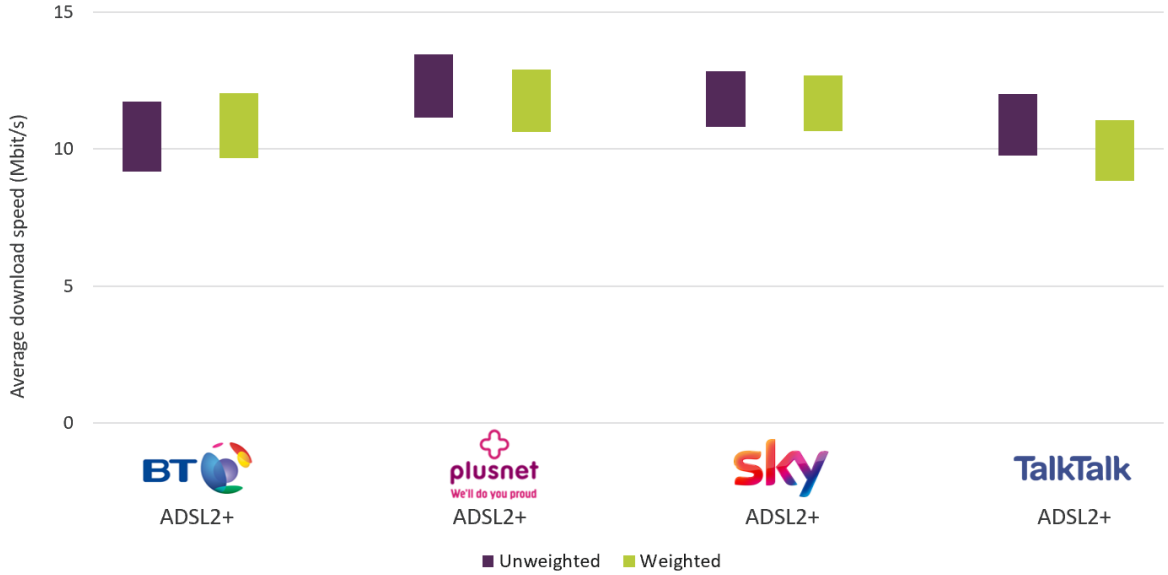


Figure 3.8: Average minimum download speeds for ADSL2+ packages: weighted and unweighted data

Source: SamKnows measurement data for all ISP panel members with a connection in November 2018. Panel base: BT ADSL2+ 63; Plusnet ADSL2+ 68; Sky ADSL2+ 78; TalkTalk ADSL2+ 62 Notes: (1) Data have been normalised to the UK profile by distance from exchange (ADSL) to ensure that operators can be compared on a like-for-like basis; (2) Data are collected from multi-thread download speed tests.

Weighted and unweighted measurement data for FTTC ISP packages

Figure 3.9: Average maximum download speeds for FTTC ISP packages: weighted and unweighted data

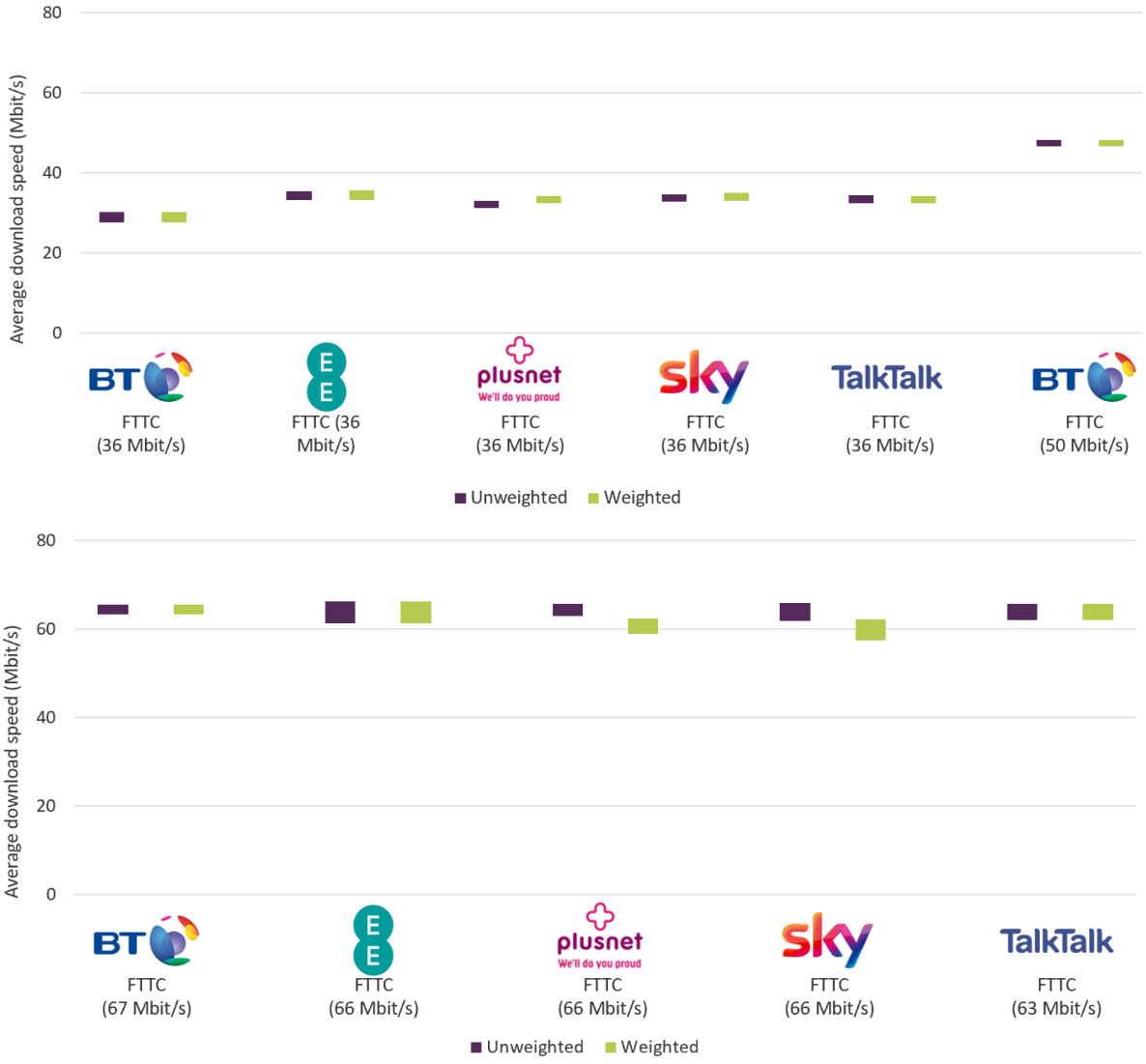


Figure 3.10: 24-hour average download speeds for FTTC ISP packages: weighted and unweighted data

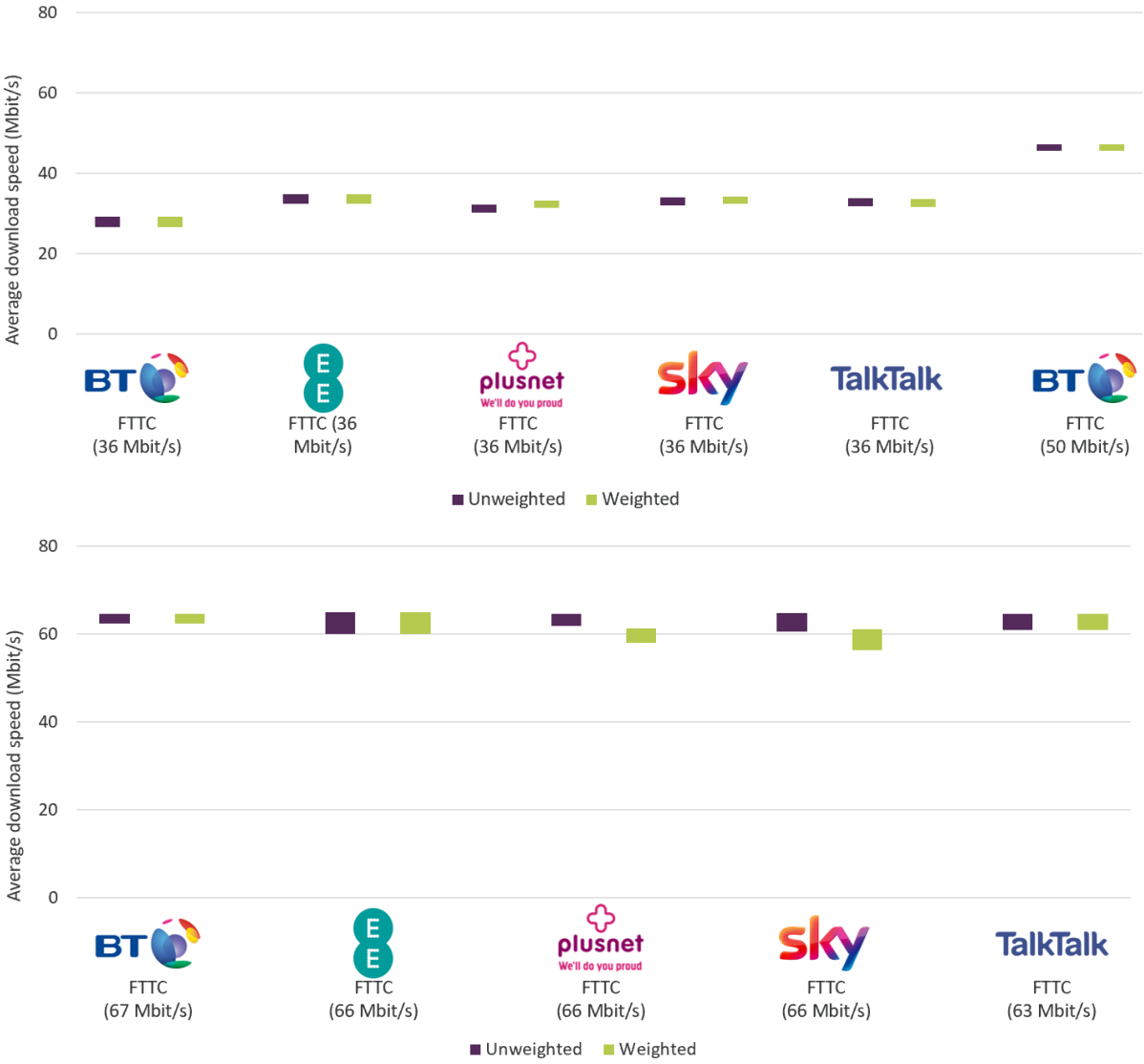


Figure 3.11: Average 8-10pm peak-time download speeds for FTTC ISP packages: weighted and unweighted data

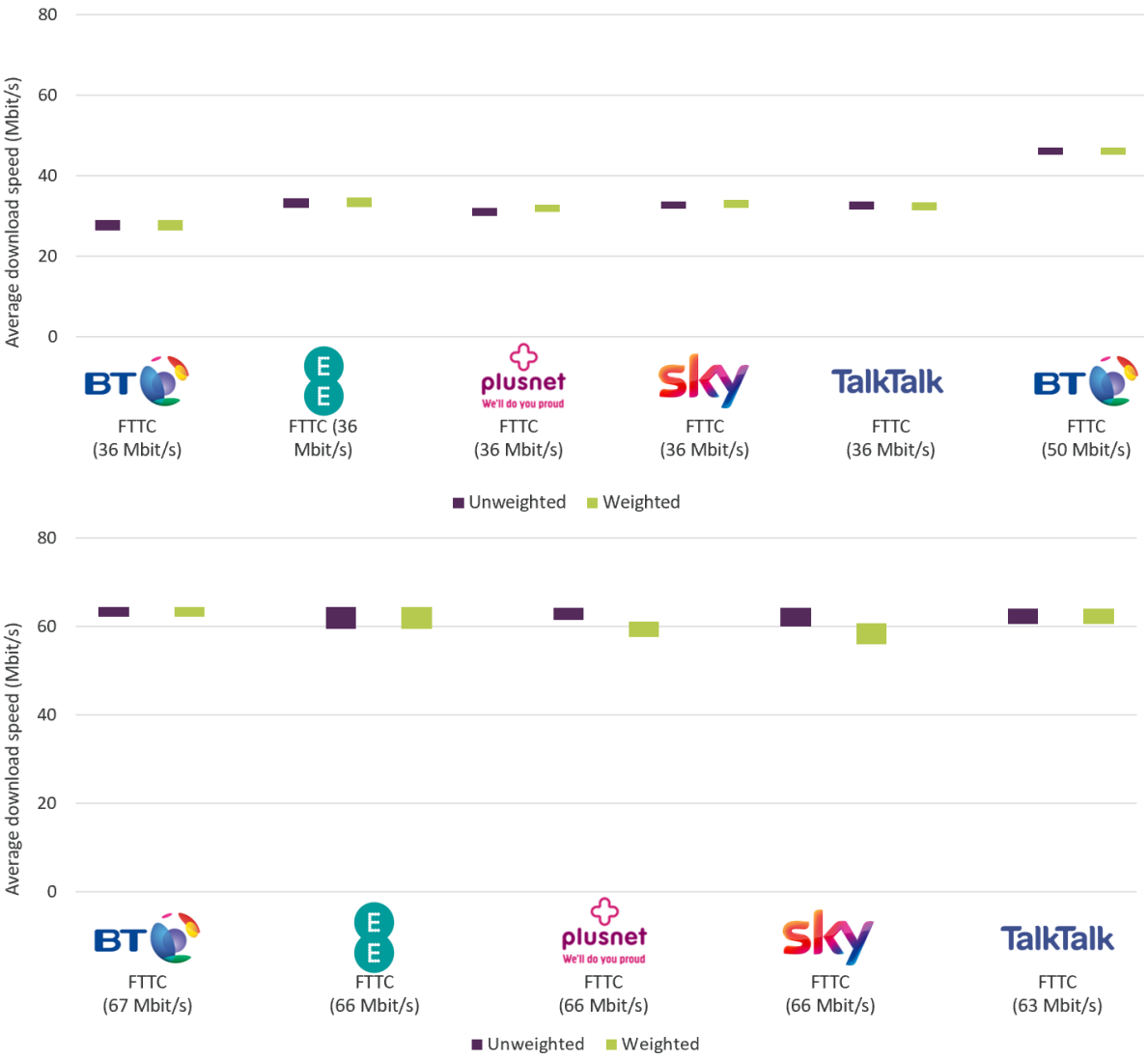
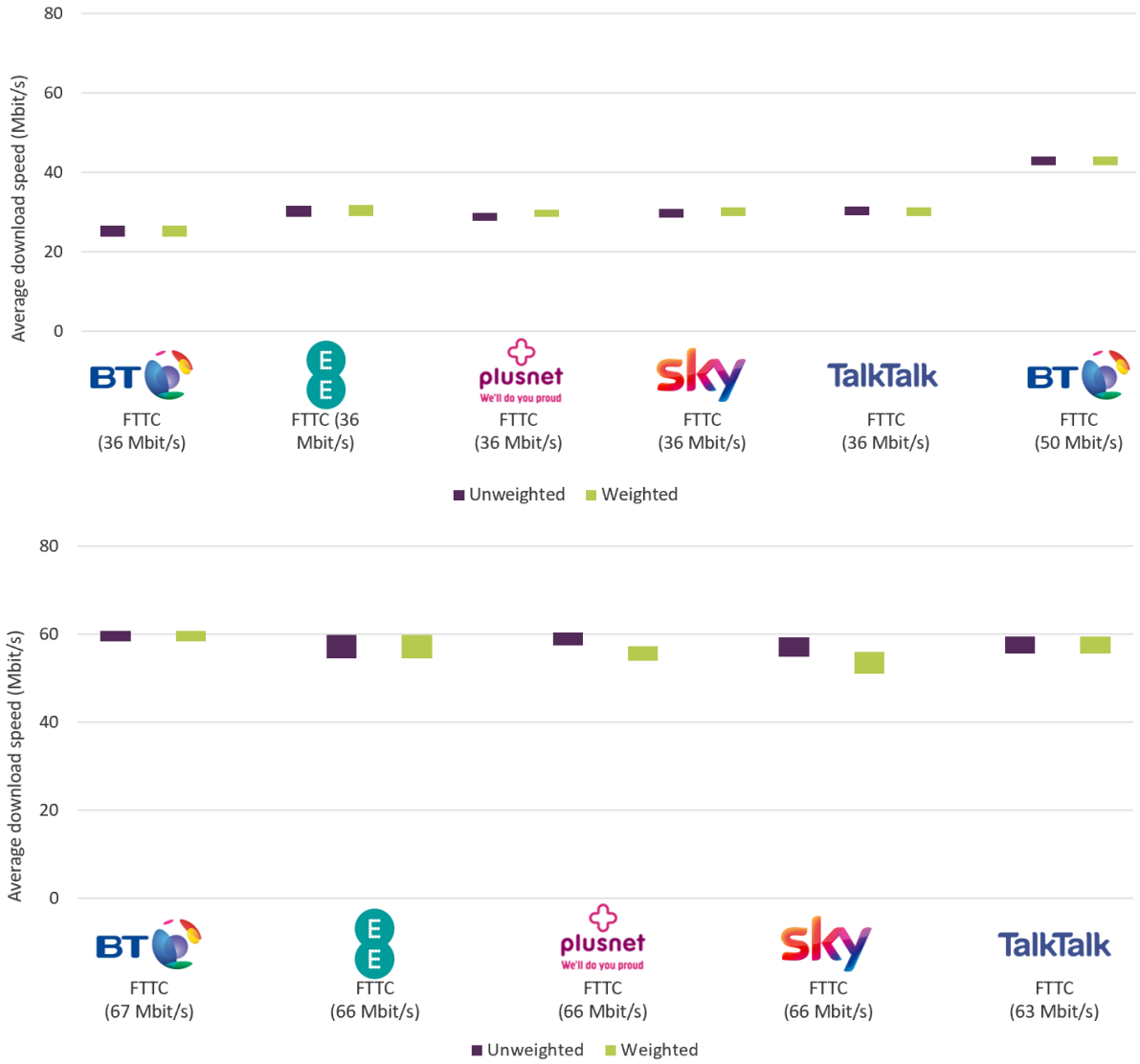


Figure 3.12: Average minimum download speeds for FTTC ISP packages: weighted and unweighted data



Source: SamKnows measurement data for all ISP panel members with a connection in November 2018.
Panel base: BT 36 Mbit/s 94; BT 50 Mbit/s 115; EE 36 Mbit/s 88; Plusnet 36 Mbit/s 176; Sky 36 Mbit/s 197; TalkTalk 36 Mbit/s 175; BT 67 Mbit/s 307; EE 66 Mbit/s 79; Plusnet 66 Mbit/s 196; Sky 66 Mbit/s 118; TalkTalk 63 Mbit/s 140
Notes: (1) Data have been normalised to the UK profile by max attainable line speed (FTTC) to ensure that operators can be compared on a like-for-like basis; (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.

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 2.5k and in open countryside). This grouping enables us to compare rural and urban areas over time.

Annex 4: Glossary

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).

Backhaul: The links by which data are transmitted from a local telephone exchange back to the core or backbone of the operator's network.

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 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 ISP 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 consumers' copper telephone lines are connected to enable telephone calls to be switched, and where network equipment is installed which enables consumers' 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'.

ISP: Internet service provider. A company that provides access to the internet.

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.

Modem synchronisation speed: The maximum download speed that a line can support according to the way the line is configured by a customer's ISP.

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.

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).