Tenth

Measuring Broadband America Fixed Broadband Report

A Report on Consumer Fixed Broadband Performance in the United States

Federal Communications Commission

Office of Engineering and Technology

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1. Executive Summary

The Tenth Measuring Broadband America Fixed Broadband Report ("Tenth Report" or "Report") presents perspectives on empirical performance for data collected in September and October 2019[1] from fixed Internet Service Providers (ISPs), as part of the Federal Communication Commission's (FCC) Measuring Broadband America (MBA) program. This program is an ongoing, rigorous, nationwide study of consumer broadband performance in the United States. The goal of this program is to measure the network performance realized on a representative sample of service offerings and the residential broadband consumer demographic across the country.[2] This representative sample is referred to as the MBA 'panel'. Thousands of volunteer panelists are drawn from the subscriber bases of ISPs which collectively serve a large percentage of the residential marketplace.[3]

The initial Measuring Broadband America Fixed Broadband Report was published in August 2011,[4] and presented the first broad-scale study of directly measured consumer broadband performance throughout the United States. As part of an open data program, all methodologies used in the program are fully documented, and all data collected is published for public use without any restrictions. Including this current Report, ten reports have now been issued.[5] These reports provide a snapshot of fixed broadband Internet access service performance in the United States utilizing a comprehensive set of performance metrics. The resulting performance data is analyzed in a variety of ways that has evolved to make the information more understandable and useful.

A. MAJOR FINDINGS OF THE TENTH REPORT

The key findings of this report are:

- The maximum advertised download speeds amongst the service tiers offered by ISPs and measured by the FCC ranged from 24 Mbps to 940 Mbps for the period covered by this report.

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[1] The actual dates used for measurements for this Tenth Report were September 6 – October 3, 2019 (inclusive) plus October 8 – 9, 2019 (inclusive). An isolated server outage forced the exclusion of data from October 4 to 7 to avoid anomalous results.

[2] The sample is representative in that it aims to include those tiers that constitute the top 80% of the subscriber base per ISP. Some tiers accordingly are not included. As with any sample, budget and sample constitution constraints limit completeness of coverage.

[3] At the request of and with the assistance of the State of Hawaii Department of Commerce and Consumer Affairs (DCCA) the state of Hawaii was added to the MBA program in 2017. The ISPs whose performance were measured in the State of Hawaii were Hawaiian Telcom and Oceanic Time Warner Cable (which is now a part of Charter Spectrum).

[4] All reports can be found at https://www.fcc.gov/general/measuring-broadband-america.

[5] The First Report (2011) was based on measurements taken in March 2011, the Second Report (2012) on measurements taken in April 2012, and the Third (2013) through Ninth (2019) Reports on measurements taken in September of the year prior to the reports' release dates. In order to avoid confusion between the date of release of the report and the measurement dates we have shifted last year to numbering the reports. Thus, this year's report is termed the Tenth MBA Report instead of the 2020 MBA Report. Going forward we will continue with a numbered approach and the next report will be termed as the Eleventh Report.

- The weighted average advertised speed of the participating ISPs was 146.1 Mbps, representing an 8% increase from the previous year (Ninth Report) and over 100% increase from two years prior (Eighth Report).
- For most of the major broadband providers that were tested, measured download speeds were 100% or better than advertised speeds during the peak hours (7 p.m. to 11 p.m. local time).
- Ten ISPs were evaluated in this report. Of these Cincinnati Bell and Frontier employed multiple different broadband technologies across the USA. Overall 12 different ISP/technology configurations were evaluated in this report and eight performed at or better than their advertised speed during the peak hours. Only one performed below 90% for actual-to-advertised download speed during the peak hours.
- In addition to providing download and upload speed measurements of ISPs, this report also provides a measure of consistency of measured to advertised speeds of ISPs with the use of our "80/80" metric. The 80/80 metric measures the percentage of the advertised speed that at least 80% of subscribers experience at least 80% of the time over peak periods. Ten of the 12 ISP/technology configurations provide better than 75% of advertised speed to at least 80% of panelists for at least 80% of the time.

These and other findings are described in greater detail within this report.

B. SPEED PERFORMANCE METRICS

Speed (both download and upload) performance continues to be one of the key metrics reported by the MBA. The data presented includes ISP broadband performance as a median[6] of speeds experienced by panelists within a specific service tier. These reports mainly focus on common service tiers used by an ISP's subscribers.[7]

Additionally, consistent with previous Reports, we also compute average per-ISP performance by weighting the median speed for each service tier by the number of subscribers in that tier. Similarly, in calculating the composite average speed taking into account all ISPs in a specific year, the median speed of each ISP is used and weighted by the number of subscribers of that ISP as a fraction of the total number of subscribers across all ISPs.

In calculating these weighted medians, we draw on two sources for determining the number of subscribers per service tier. ISPs may voluntarily contribute subscription demographics per surveyed service tier as the most recent and authoritative data. Many ISPs have chosen to do so.[8] When such

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[6] We first determine the mean value over all the measurements for each individual panelist's "whitebox." (Panelists are sent "whiteboxes" that run pre-installed software on off-the-shelf routers that measure thirteen broadband performance metrics, including download speed, upload speed, and latency.) Then for each ISP's speed tiers, we choose the median of the set of mean values for all the panelists/whiteboxes. The median is that value separating the top half of values in a sample set with the lower half of values in that set; it can be thought of as the middle (*i.e.*, most typical) value in an ordered list of values. For calculations involving multiple speed tiers, we compute the weighted average of the medians for each tier. The weightings are based on the relative subscriber numbers for the individual tiers.

[7] Only tiers that contribute to the top 80% of an ISPs total subscribership are included in this report.

[8] The ISPs that provided SamKnows, the FCC's contractor supporting the MBA program, with weights for each of their tiers were: Cincinnati Bell, CenturyLink, Charter, Comcast, Cox Frontier, Optimum, and Windstream.

information has not been provided by an ISP, we instead rely on the FCC's Form 477 data.[9] All facilities-based broadband providers are required to file data with the FCC twice a year (Form 477) regarding deployment of broadband services, including subscriber counts. For this report, we used the June 2019 Form 477 data. It should be noted that the Form 477 subscriber data values generally lag the reporting month, and therefore, there are likely to be small inaccuracies in the tier ratios. It is for this reason that we encourage ISPs to provide us with subscriber numbers for the measurement month.

As in our previous reports, we found that for most ISPs the actual speeds experienced by subscribers either nearly met or exceeded advertised service tier speeds. However, since we started our MBA program, consumers have changed their Internet usage habits. In 2011, consumers mainly browsed the web and downloaded files; thus, we reported mean broadband speeds since these statistics were likely to closely mirror user experience. By contrast, in September-October 2019 (the measurement period for this report) consumer internet usage had become dominated by video consumption, with consumers regularly streaming video for entertainment and education.[10] Therefore, our network performance analytics have been expanded by using consistency in service metrics to better capture the shift in usage patterns. Both the median measured speed metric and consistency in service metrics help to better reflect the consumer's perception and usefulness of Internet access service.

Specifically, we use two kinds of metrics to reflect the consistency of service delivered to the consumer: First, we report the percentage of advertised speed experienced by at least 80% of panelists during at least 80% of the daily peak usage period ("80/80 consistent speed" measure). Second, we show the fraction of consumers who obtain median speeds greater than 95%, between 80% and 95%, and less than 80% of advertised speeds.

A. USE OF OTHER PERFORMANCE METRICS

Although download and upload speeds remain the network performance metric of greatest interest to the consumer, we also spotlight two other key network performance metrics in this report: latency and packet loss. These metrics can significantly affect the overall quality of Internet applications.

Latency is the time it takes for a data packet to travel across a network from one point on the network to another. High latencies may affect the perceived quality of some interactive services such as phone calls over the Internet, video chat and video conferencing, or online multiplayer games. All network access technologies have a minimum latency that is largely determined by the technology. There are many other factors that affect latency though, including the location of the server you're communicating with, the route taken to the server, and whether or not there is any congestion on that route. Technology-

[9] For an explanation of Form 477 filing requirements and required data see: https://transition.fcc.gov/form477/477inst.pdf (Last accessed 8/10/2020).

[10] "It is important to track the changing mix of devices and connections and growth in multidevice ownership as it affects traffic patterns. Video devices, in particular, can have a multiplier effect on traffic. An Internet-enabled HD television that draws couple - three hours of content per day from the Internet would generate as much Internet traffic as an entire household today, on an average. Video effect of the devices on traffic is more pronounced because of the introduction of Ultra-High-Definition (UHD), or 4K, video streaming. This technology has such an effect because the bit rate for 4K video at about 15 to 18 Mbps is more than double the HD video bit rate and nine times more than Standard-Definition (SD) video bit rate. We estimate that by 2023, two-thirds (66 percent) of the installed flat-panel TV sets will be UHD, up from 33 percent in 2018" *See Cisco Annual Internet Report (2018-2023) White Paper* , https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html (Last accessed Aug. 8, 2020).

dependent latencies are typically small for terrestrial broadband services and are thus unlikely to affect the perceived quality of applications. Additionally, for certain applications the user experience is not necessarily affected by high latencies. As an example, when using entertainment video streaming applications, because the data can be cached prior to display, the user experience is likely to be unaffected by relatively high latencies

Packet loss measures the fraction of data packets sent that fail to be delivered to the intended destination. Packet loss may affect the perceived quality of applications that do not incorporate retransmission of lost packets, such as phone calls over the Internet, video chat, some online multiplayer games, and some video streaming. High packet loss also degrades the achievable throughput of download and streaming applications. However, packet loss of a few tenths of a percent are unlikely to significantly affect the perceived quality of most Internet applications and are common. During network congestion, both latency and packet loss typically increase.

The Internet continually evolves in its architecture, performance, and services. Accordingly, we will continue to adapt our measurement and analysis methodologies to further improve the collective understanding of performance characteristics of broadband Internet access. By doing so we aim to help the community of interest across the board, from consumers to technologists, service providers and regulators.

2. Summary of Key Findings

A. MOST POPULAR ADVERTISED SERVICE TIERS

A list of the ISP download and upload speed service tiers that were measured in this report are shown in Table 1. It should be noted that while upload and download speeds are measured independently and shown separately, they are typically offered by an ISP in a paired configuration. The service tiers that are included for reporting represent the top 80% (therefore 'most popular') of an ISP's set of tiers based on subscriber numbers. Taken in aggregate, these plans serve the majority of the subscription base of the participating ISPs.

Table 1: List of ISP service tiers whose broadband performance was measured in this report

Tech-nology	Company	Speed Tiers (Download)									Speed Tiers (Upload)					
DSL	**CenturyLink**	1.5	3	7	8*	10	12	20	25*	40	0.512*	0.768	0.896	2	5	10*
	Cincinnati Bell DSL	5	30*								0.768	3*				
	Frontier DSL	3	6	12	24*						0.768	1	1.5*			
	Windstream	3	6	10	12*	15*	25	50*	100*		0.768*	1	1.5	4*		
Cable	**Altice Optimum**	100	200	300*							35					
	Charter	100	200	400							10	20				
	Comcast	60	150	250							5	10				
	Cox	30	100*	150*	300						3	10	30			
	Mediacom	60	100	200							5	10	20			
Fiber	**Cincinnati Bell Fiber**	50	250	500							10	100	125			
	Frontier Fiber	50	75	100	150	200					50	75	100	150	200	
	Verizon Fiber	50*	75	100	940**						50*	75	100	880**		

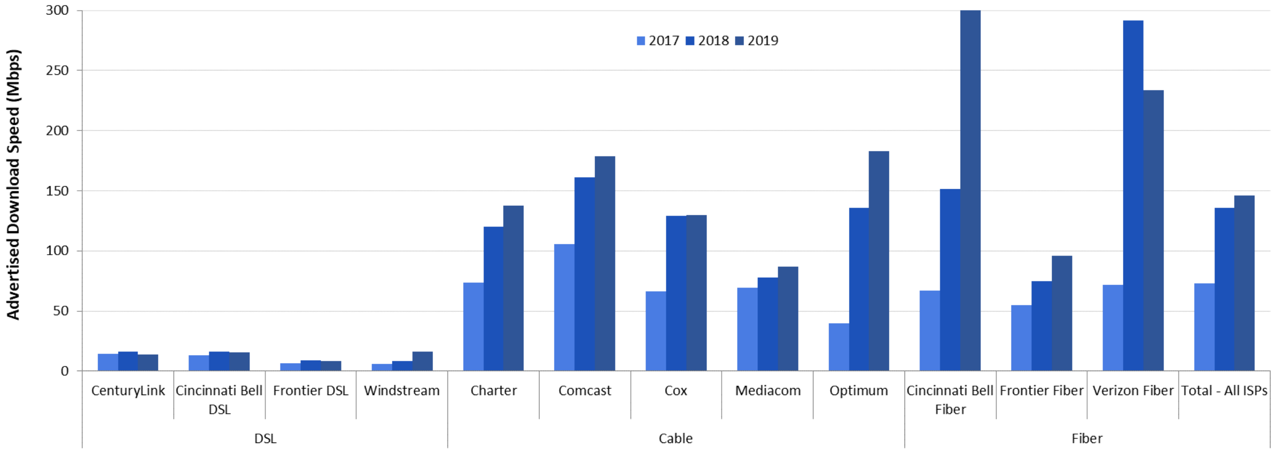
*Tiers that lack sufficient panelists to meet the program's target sample size.

** Although Verizon Fiber's 940/880 Mbps service tier was amongst the top 80% of Verizon's offered tiers by subscription numbers, it is not included in the report charts because technical methodologies for measuring high speed rates near Gigabit and above have not yet been established for the MBA program.

Chart 1.1 (below) displays the weighted (by subscriber numbers) mean of the top 80% advertised download speed tiers for each participating ISP for the last three years (September 2017 to September-October 2019) grouped by the access technology used to offer the broadband Internet access service (DSL, cable, or fiber). It should be noted that this chart does not reflect the actual performance of the ISPs and only provides the weighted average of the ISP's advertised speeds. In September-October 2019, the weighted average advertised download speed was 146.1 Mbps among the measured ISPs, which represents a 100% increase from 2017 and a 8% increase compared to the average in September-October 2018 which was 135.7 Mbps.[11]

[11] Please note that this average for September-October 2018 and September 2017 represents the average advertised download speed with AT&T tiers removed. We did this to have a fairer comparison between the years since AT&T is no longer an active participant in the MBA program. The actual weighted average advertised download speed (with AT&T included) for September-October 2018, as reported in the Ninth MBA Report is 123.3 Mbps.

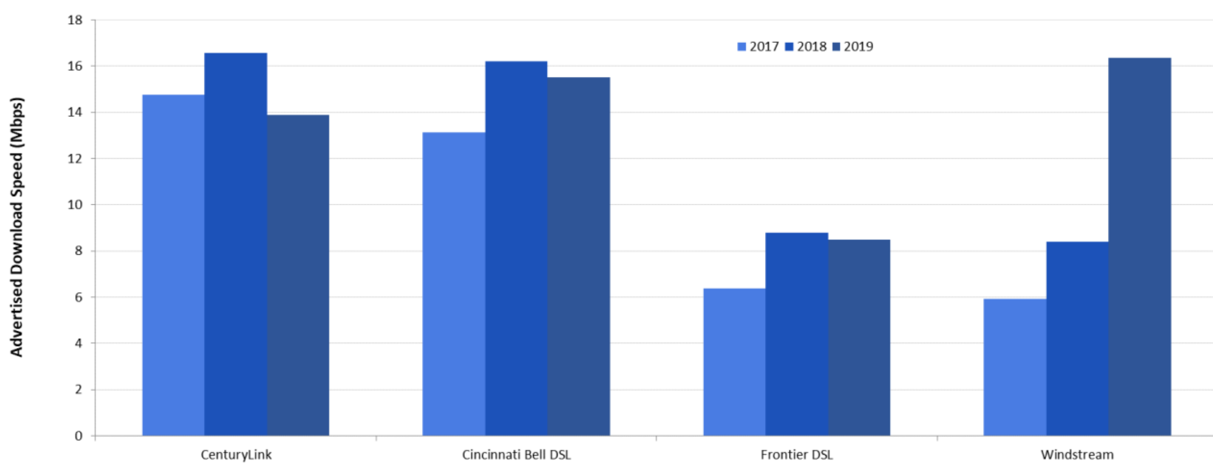
Chart 1.1: Weighted average advertised download speed among the top 80% service tiers offered by each ISP



All of the ISPs, except Verizon, showed higher weighted-averages of advertised speeds in September-October 2019 as compared to September 2018. Verizon-fiber showed a slight decrease in 2019 compared to 2018 which was not due to any reduction in the service speed offerings but arose from changes in weighting due to relative shifts in subscriber numbers on the advertised tiers from 2018 to 2019.

It can be seen from Chart 1.1 that the DSL speeds lag far behind the speed of other technologies. In order to better compare the DSL speed offerings by the various ISPs we have added a separate Chart 1.2 drawn to a scale that makes their relative speeds more discernable.

Chart 2.2: Weighted average advertised download speed among the DSL ISPs



Among participating broadband ISPs, only Cincinnati Bell, Frontier, and Verizon use fiber as the access technology for a substantial number of their customers and their maximum speed offerings range from 200 Mbps to 940 Mbps. A key difference between the fiber vendors and other technology vendors is that (with the exception of Cincinnati Bell), most fiber vendors advertise generally symmetric upload and download speeds. This is in sharp contrast to the asymmetric offerings for all the other technologies, where the upload advertised speeds are typically 5 to 10 times below the download advertised speeds.

As can be seen in Chart 1.1, there is considerable difference between the offered average weighted speed tier by technology. Chart 2 plots the weighted average of the top 80% ISP tiers by technology for the last three years.[12] As can be seen in this chart, most technologies showed increases in the set of advertised download speeds by ISPs. For the September-October 2019 period, the weighted mean advertised speeds for DSL technology was 13 Mbps which lagged considerably behind the weighted mean advertised download speeds for cable and fiber technologies, which were 155 Mbps and 208 Mbps, respectively. Fiber technology showed the greatest increase in speed offerings in 2019 compared to 2017 with a weighted mean going up from 70 Mbps to 208 Mbps representing a nearly 200% increase. This year's (2019) average advertised speed for fiber, however, showed a slight decrease by 17% from last year's (2018) speed. DSL technology speed increased from 11 Mbps to 13 Mbps from 2017 to 2019, a 16% increase overall (though it did show a small 1% decrease in speed this year compared to last year). In comparison, cable technology showed an 12% increase from 2018 to 2019 and an overall 83% increase from 2017 to 2019

Chart 2: Weighted average advertised download speed among the top 80% service tiers based on technology.

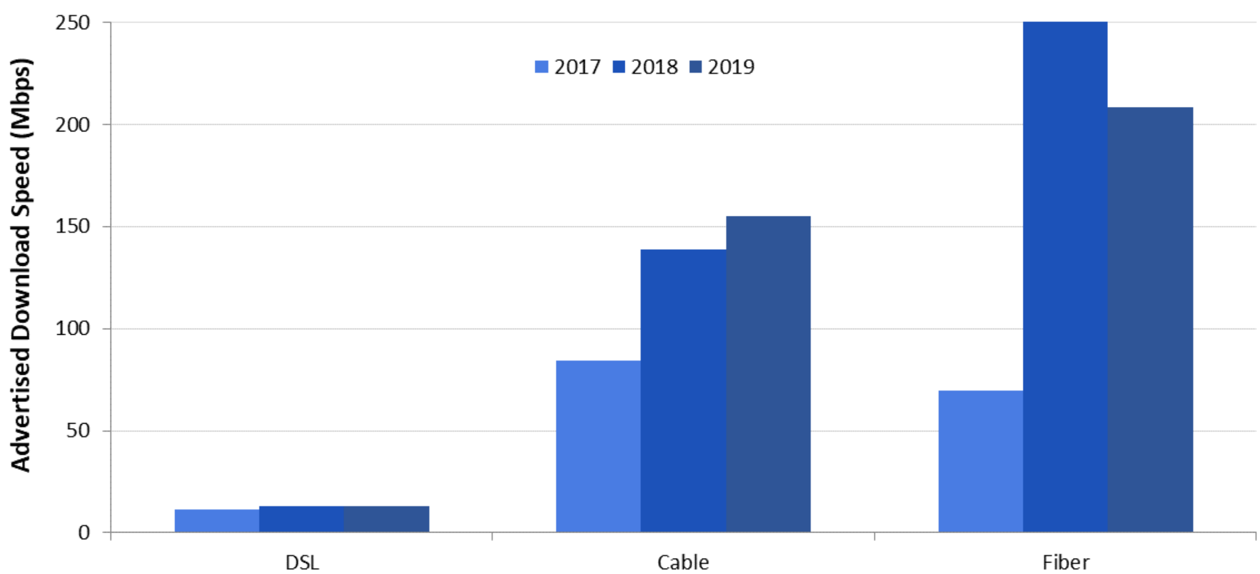


Chart 3 plots the migration of panelists to a higher service tier based on their access technology.[13] Specifically, the horizontal axis of Chart 3 partitions the September 2018 panelists by the advertised download speed of the service tier to which they were subscribed. For each such set of panelists who

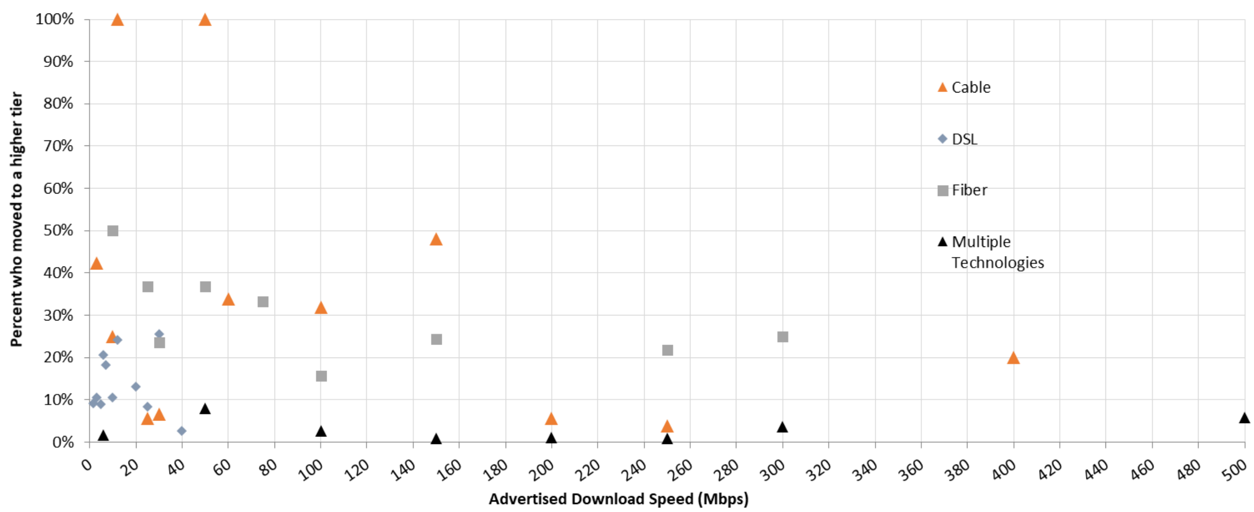
[12] Since AT&T is no longer actively participating in the Measuring Broadband America program, we have removed it from previous years' results in Charts 1 and 2. This allows a proper comparison to be made between the results for this year as compared to previous years. It should also be noted that although AT&T IPBB had been characterized in previous reports as a DSL technology it actually included a mix of ADSL2+, VDSL2, G.Fast and Ethernet technologies delivered over a hybrid of fiber optic and copper facilities.

[13] Where several technologies are plotted at the same point in the chart, this is identified as "Multiple Technologies."

also participated in the September-October 2019 collection of data,[14] the vertical axis of Chart 3 displays the percentage of panelists that migrated by September-October 2019 to a service tier with a higher advertised download speed. There are two ways that such a migration could occur: (1) if a panelist changed their broadband plan during the intervening year to a service tier with a higher advertised download speed, or (2) if a panelist did not change their broadband plan but the panelist's ISP increased the advertised download speed of the panelist's subscribed plan.[15]

Chart 3 shows that the percentage of panelists subscribed in September-October 2018 who moved to higher tiers in September-October 2019 was between 3% to 26% for DSL subscribers, 4% to 100% for cable subscribers and 16% to 50% for fiber subscribers. In addition, 1% to 8% subscribers migrated to a higher speed tier using a different technology from what they had in September 2018.

Chart 3: Consumer migration to higher advertised download speeds



B. MEDIAN DOWNLOAD SPEEDS

Advertised download speeds may differ from the speeds that subscribers actually experience. Some ISPs more consistently meet network service objectives than others or meet them unevenly across their geographic coverage area. Also, speeds experienced by a consumer may vary during the day if the aggregate user demand during busy hours causes network congestion. Unless stated otherwise, all actual speeds were measured only during peak usage periods, which we define as 7 p.m. to 11 p.m. local time.

To compute the average ISP performance, we determine the ratio of the median speed for each tier to the advertised tier speed and then calculate the weighted average of these based on the subscriber count per tier. Subscriber counts for the weightings were provided from the ISPs themselves or, if unavailable, from FCC Form 477 data.

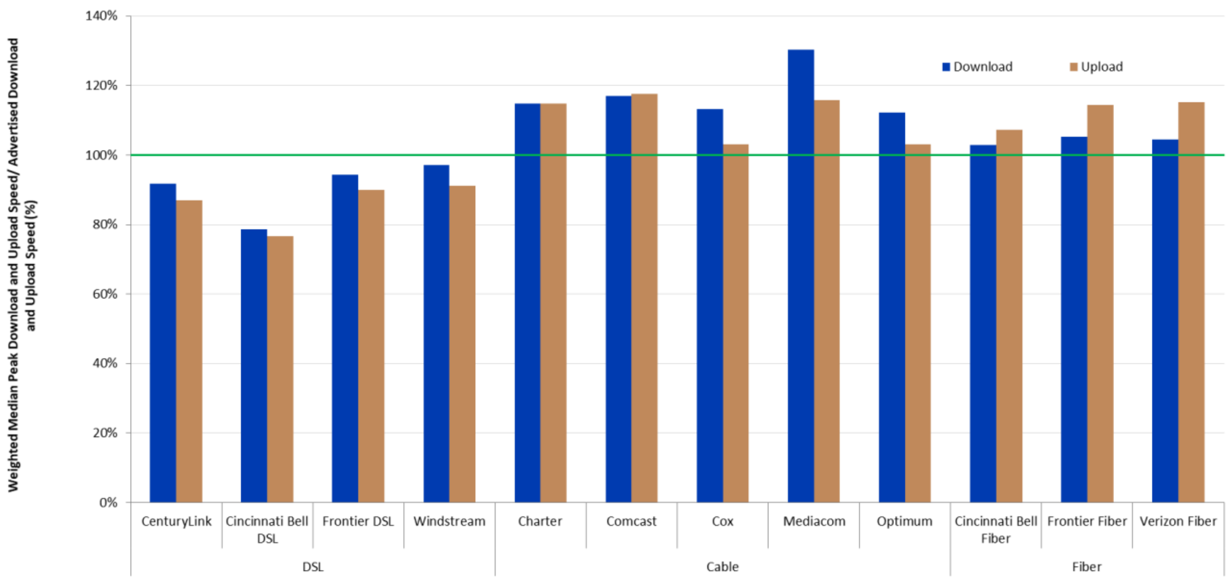
Chart 4 shows the ratio of the measured median download and upload speeds experienced by an ISP's subscribers to that ISP's advertised download and upload speeds weighted by the subscribership numbers for the tiers. The actual speeds experienced by most ISPs' subscribers are close to or exceed the

[14] Of the 5,855 panelists who participated in the September 2018 collection of data, 4,246 panelists continued to participate in the September-October 2019 collection of data.

[15] We do not attempt here to distinguish between these two cases.

advertised speeds. However, DSL broadband ISPs continue to advertise "up-to" speeds that on average exceed the actual speeds experienced by their subscribers. Out of the 12 ISP/technology configurations shown, 8 met or exceeded their advertised download speed and three more reached at least 90% of their advertised download speed. Only Cincinnati-DSL (at 79%) performed below 90% of its advertised download speed.

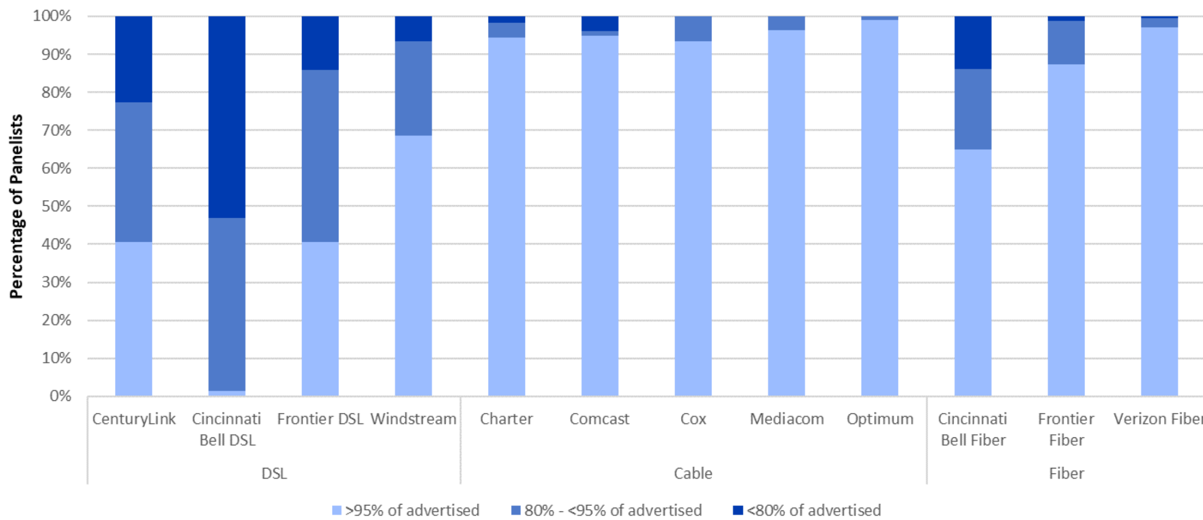
Chart 4: The ratio of weighted median speed (download and upload) to advertised speed for each ISP.



C. VARIATIONS IN SPEEDS

As discussed earlier, actual speeds experienced by individual consumers may vary by location and time of day. Chart 5 shows, for each ISP, the percentage of panelists who experienced a median download speed (averaged over the peak usage period during our measurement period) that was greater than 95%, between 80% and 95%, or less than 80% of the advertised download speed.

Chart 5: The percentage of consumers whose median download speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised download speed



ISPs using DSL technology had between 2% to 69% of their subscribers getting greater than or equal to 95% of their advertised download speeds during peak hours. ISPs using cable technology and fiber technology had between 93%-99% and between 65%-97%, respectively, of their subscribers getting equal to or better than 95% of their advertised download speeds.

Though the median download speeds experienced by most ISPs' subscribers nearly met or exceeded the advertised download speeds, there are some customers of each ISP for whom the median download speed fell significantly short of the advertised download speed. Relatively few subscribers of cable service experienced this. The best performing ISPs, when measured by this metric, are Charter, Comcast, Cox, Mediacom, Optimum, Frontier-Fiber and Verizon-Fiber; more than 80% of their panelists were able to attain an actual median download speed of at least 95% of the advertised download speed.

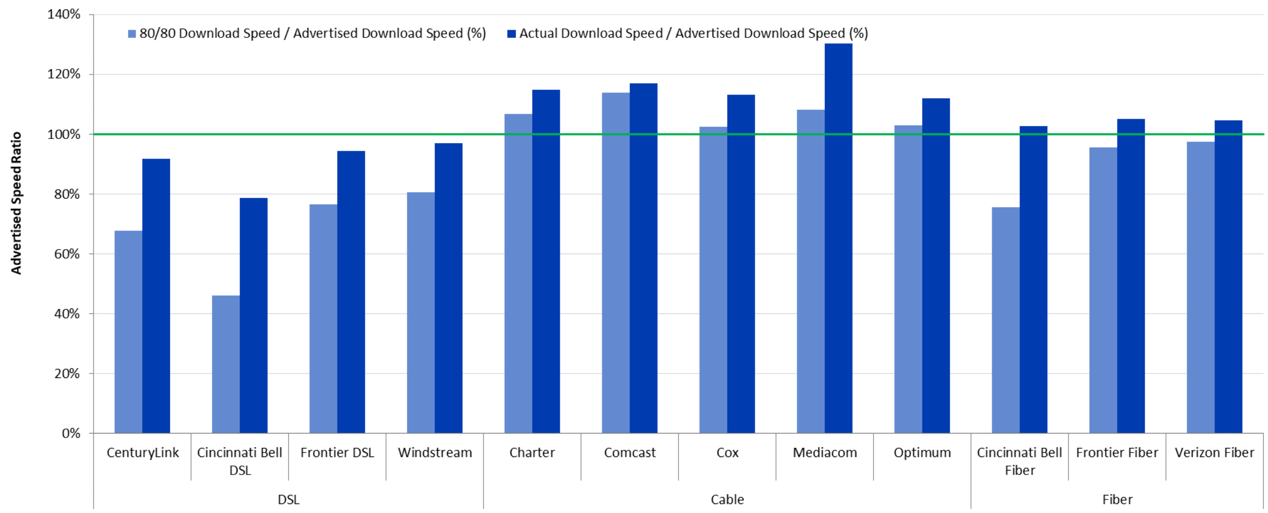
In addition to variations based on a subscriber's location, speeds experienced by a consumer may fluctuate during the day. This is typically caused by increased traffic demand and the resulting stress on different parts of the network infrastructure. To examine this aspect of performance, we use the term "80/80 consistent speed." This metric is designed to assess temporal and spatial variations in measured values of a user's download speed.[16] While consistency of speed is in itself an intrinsically valuable service characteristic, its impact on consumers will hinge on variations in usage patterns and needs. As an example, a good consistency of speed measure is likely to indicate a higher quality of service experience for internet users consuming video content.

Chart 6 summarizes, for each ISP, the ratio of 80/80 consistent median download speed to advertised download speed, and, for comparison, the ratio of median download speed to advertised download speed shown previously in Chart 4. The ratio of 80/80 consistent median download speed to advertised download speed is less than the ratio of median download speed to advertised download speed for all participating ISPs due to congestion periods when median download speeds are lower than the overall average. When the difference between the two ratios is small, the median download speed is fairly insensitive to both geography and time. When the difference between the two ratios is large, there is a

[16] For a detailed definition and discussion of this metric, please refer to the Technical Appendix.

greater variability in median download speed, either across a set of different locations or across different times during the peak usage period at the same location.

Chart 6: The ratio of 80/80 consistent median download speed to advertised download speed.



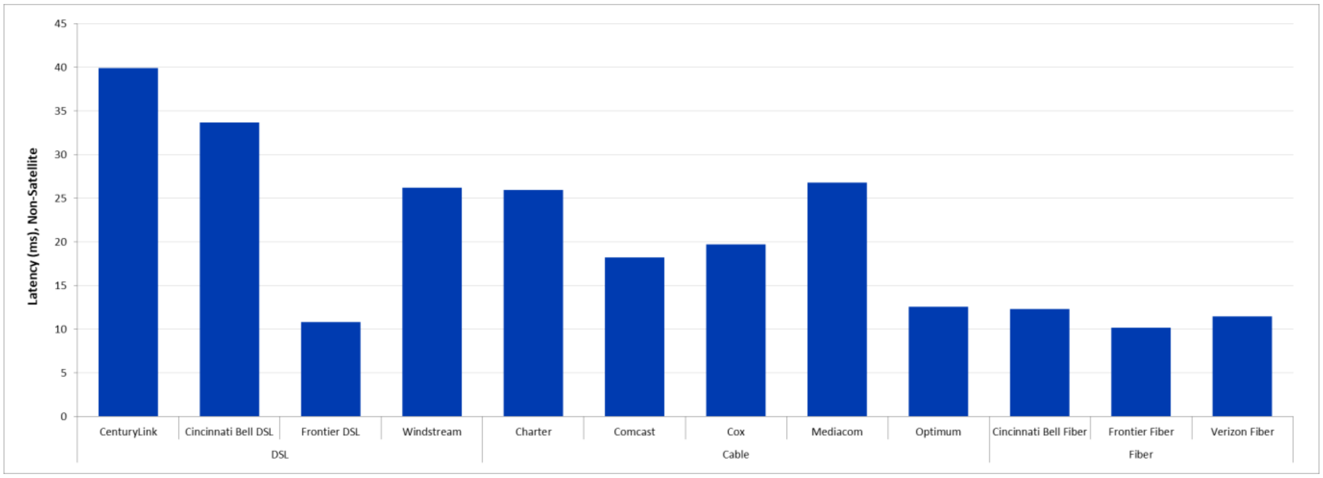
Customers of Charter, Comcast, Cox, Mediacom and Optimumexperienced median download speeds that were very consistent; *i.e.*, they provided greater than 100% of the advertised speed during peak usage period to more than 80% of panelists for more than 80% of the time. As can be seen in Chart 6 cable and fiber ISPs performed better than DSL ISPs with respect to their 80/80 consistent speeds. For example, for September-October 2019, the 80/80 consistent download speed for Cincinnati Bell DSL was 46% of the advertised speed.

D. LATENCY

The latency between any two points in the network is the time it takes for a packet to travel from one point to the other. It has a fixed component that depends on the distance, the transmission speed, and transmission technology between the source and destination, and a variable component due to queuing delay that increases as the network path congests with traffic. The MBA program measures latency by measuring the round-trip time between the consumer's home and the closest measurement server.

Chart 7 shows the median latency for each participating ISP. In general, higher-speed service tiers have lower latency, as it takes less time to transmit each packet. The median latencies ranged from 10 ms to 27 ms in our measurements (with the exception of CenturyLink DSL and Cincinnati Bell DSL which had median latencies of 40 ms and 34 ms, respectively).

Chart 7: Latency by ISP



DSL latencies (between 11 ms to 40 ms) were slightly higher than those for cable (13 ms to 27 ms). Fiber ISPs showed the lowest latencies (10 ms to 12 ms). The differences in median latencies among terrestrial-based broadband services are relatively small and are unlikely to affect the perceived quality of highly interactive applications.

E. PACKET LOSS

Packet loss is the percentage of packets that are sent by a source but not received at the intended destination. The most common causes of packet loss are congestion leading to buffer overflows or active queue management along the network path. Alternatively, high latency might lead to a packet being counted as lost if it does not arrive within a specified window. A small amount of packet loss is expected, and indeed packet loss is commonly used by some Internet protocols such as TCP to infer Internet congestion and to adjust the sending rate to mitigate the offered load, thus lessening the contribution to congestion and the risk of lost packets. The MBA program uses an active UDP-based packet loss measurement method and considers a packet lost if it is not returned within 3 seconds.

Chart 8 shows the average peak-period packet loss for each participating ISP, grouped into bins. We have broken the packet loss performance into three bands, allowing a more granular view of the packet loss performance of the ISP network. The breakpoints for the three bins used to classify packet loss have been chosen with an eye towards balancing commonly accepted packet loss thresholds for specific services and provider packet loss Service Level Agreements (SLAs) for enterprise services, as consumer offerings are not typically accompanied by SLAs. Specifically, the 1% standard for packet loss is commonly accepted as the point at which highly interactive applications such as VoIP experience significant degradation in quality according to industry publications and international (ITU) standards.[17] The 0.4% breakpoint was chosen as middle ground between the highly desirable performance of 0% packet loss described in many documents (for Voice over Internet Protocol (VoIP)) and the 1% unacceptable limit on the high side. The specific value of 0.4% is also generally supported by major ISP SLAs for network performance. Indeed,

[17] See: http://www.itu.int/dms_pubrec/itu-r/rec/m/r-rec-m.1079-2-200306-i!!msw-e.doc.

most SLAs support 0.1% to 0.3% packet loss guarantees,[18] but these are generally for enterprise level services which entail business-critical applications that require some service guarantees.

Chart 8: Percentage of consumers whose peak-period packet loss was less than 0.4%, between 0.4% to 1%, and greater than 1%.

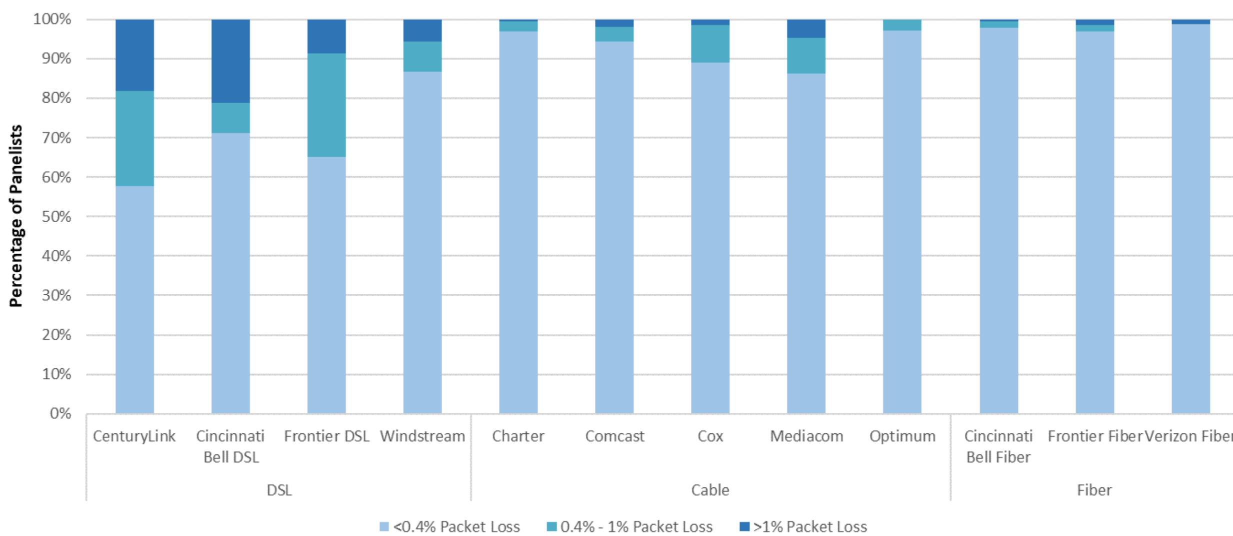


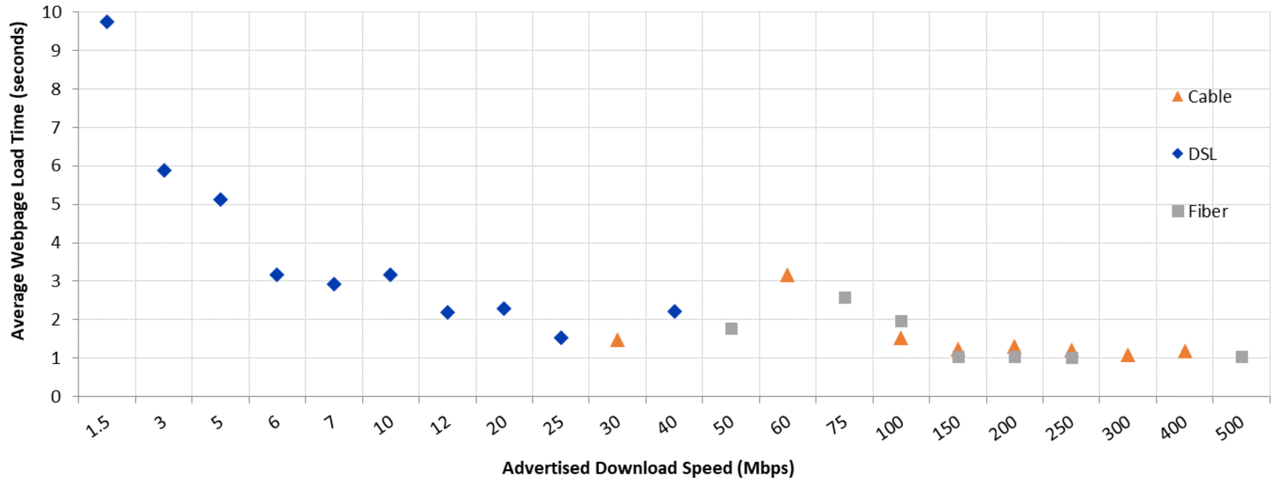
Chart 8 shows that ISPs using fiber technology have the lowest packet loss, and that ISPs using DSL technology tend to have the highest packet loss. As shown in this chart, 6% to 21% of DSL subscribers experience 1% or greater packet loss. The corresponding numbers for cable and fiber are 0% to 5% and 0% to 1.5%, respectively. Within a given technology class, packet loss also varies among ISPs.

F. WEB BROWSING PERFORMANCE

The MBA program also conducts a specific test to gauge web browsing performance. The web browsing test accesses nine popular websites that include text and images, but not streaming video. The time required to download a webpage depends on many factors, including the consumer's in-home network, the download speed within an ISP's network, the web server's speed, congestion in other networks outside the consumer's ISP's network (if any), and the time required to look up the network address of the webserver. Only some of these factors are under control of the consumer's ISP. Chart 9 displays the average webpage download time as a function of the advertised download speed. As shown by this chart, webpage download time decreases as download speed increases, from about 9.8 seconds at 1.5 Mbps download speed to about 1.5 seconds for 25 Mbps download speed. Subscribers to service tiers exceeding 25 Mbps experience slightly smaller webpage download times decreasing to 1 – 1.25 seconds at 150 Mbps. Beyond 150 Mbps, the webpage download times decrease only by minor amounts. These download times assume that only a single user is using the Internet connection when the webpage is downloaded, and does not account for more common scenarios, where multiple users within a household are simultaneously using the Internet connection for viewing web pages, as well as other applications such as real-time gaming or video streaming.

[18] See: https://www.voip-info.org/wiki/view/QoS and http://www.ciscopress.com/articles/article.asp?p=357102.

Chart 9: Average webpage download time, by advertised download speed.



3. Methodology

A. PARTICIPANTS

Ten ISPs actively participated in the Fixed MBA program in September-October 2019.[19] They were:

- CenturyLink
- Charter Communications
- Cincinnati Bell
- Comcast
- Cox Communications
- Frontier Communications Company
- Mediacom Communications Corporation
- Optimum
- Verizon
- Windstream Communications

The methodologies and assumptions underlying the measurements described in this Report are reviewed at meetings that are open to all interested parties and documented in public ex parte letters filed in the GN Docket No. 12-264. Policy decisions regarding the MBA program were discussed at these meetings prior to adoption, and involved issues such as inclusion of tiers, test periods, mitigation of operational issues affecting the measurement infrastructure, and terms-of-use notifications to panelists. Participation in the MBA program is open and voluntary. Participants include members of academia, consumer equipment vendors, telecommunications vendors, network service providers, consumer policy groups, as well as our contractor for this project, SamKnows. In 2019-2020, participants at these meetings (collectively and informally referred to as "the broadband collaborative"), included all eleven participating ISPs and the following additional organizations:

- Level 3 Communications ("Level 3"), now part of CenturyLink
- Massachusetts Institute of Technology ("MIT")
- Measurement Lab (M-Lab)
- StackPath
- NCTA – The Internet & Television Association ("NCTA")
- New America Foundation
- Princeton University
- United States Telecom Association ("US Telecom")
- University of California - Santa Cruz

Participants have contributed in important ways to the integrity of this program and have provided valuable input to FCC decisions for this program. Initial proposals for test metrics and testing platforms were discussed and critiqued within the broadband collaborative. M-Lab and Level 3 contributed their core network testing infrastructure, and both parties continue to provide invaluable assistance in helping to define and implement the FCC testing platform. We thank all the participants for their continued contributions to the MBA program.

[19] While Hawaiian Telcom participated in the Fixed MBA program, we did not report on it since we did not have sufficient number of panelists on Hawaiian Telcom tiers to have a statistically valid dataset.

B. MEASUREMENT PROCESS

The measurements that provided the underlying data for this report were conducted between MBA measurement clients and MBA measurement servers. The measurement clients (*i.e.*, whiteboxes) were situated in the homes of 6,006 panelists each of whom received service from one of the 11 evaluated ISPs. The evaluated ISPs collectively accounted for over 80% of U.S. residential broadband Internet connections. After the measurement data was processed (as described in greater detail in the Technical Appendix), test results from 3,075 panelists were used in this report.

The measurement servers used by the MBA program were hosted by StackPath, M-Lab, and Level 3 Communications, and were located in thirteen cities (often with multiple locations within each city) across the United States near a point of interconnection between the ISP's network and the network on which the measurement server resided.

The measurement clients collected data throughout the year, and this data is available as described below. However, only data collected from September 6 – October 3, 2019 (inclusive) plus October 8 – 9, 2019 (inclusive), referred to throughout this report as the "September-October 2019" reporting period, were used to generate the charts in this Report.[20]

Broadband performance varies with the time of day. At peak hours, more people tend to use their broadband Internet connections, giving rise to a greater potential for network congestion and degraded user performance. Unless otherwise stated, this Report focuses on performance during peak usage period, which is defined as weeknights between 7:00 p.m. to 11:00 p.m. local time at the subscriber's location. Focusing on peak usage period provides the most useful information because it demonstrates what performance users can expect when the Internet in their local area experiences the highest demand from users.

Our methodology focuses on the network performance of each of the participating ISPs. The metrics discussed in this Report are derived from active measurements, *i.e.*, test-generated traffic flowing between a measurement client, located within the modem/router within a panelist's home, and a measurement server, located outside the ISP's network. For each panelist, the tests automatically choose the measurement server that has the lowest latency to the measurement client. Thus, the metrics measure performance along the path followed by the measurement traffic within each ISP's network, through a point of interconnection between the ISP's network and the network on which the chosen measurement server is located. However, the service performance that a consumer experiences could differ from our measured values for several reasons.

First, as noted, in the course of each test instance we measure performance only to a single measurement server rather than to multiple servers. This is consistent with the approach chosen by most network measurement tools. As a point of comparison, the average web page may load its content from a multiplicity of end points.

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[20] This proposed time period avoids the dates in early September when parts of North Carolina and Florida were affected by Hurricanes Florence and Michael. It also avoided the increased traffic resulting from latest iOS release which also took place in early September. Omitting dates during these periods was done consistent with the FCC's data collection policy for fixed MBA data. *See* FCC, Measuring Fixed Broadband, Data Collection Policy, https://www.fcc.gov/general/measuring-broadband-america-measuring-fixed-broadband (explaining that the FCC has developed policies to deal with impairments in the data collection process with potential impact for the validity of the data collected).

In addition, bottlenecks or congestion points in the full path traversed by consumer application traffic might also impact a consumer's perception of Internet service performance. These bottlenecks may exist at various points: within the ISP's network, beyond its network (depending on the network topology encountered *en route* to the traffic destination), in the consumer's home, on the Wi-Fi used to access the in-home access router, or from a shortfall of capacity at the far end point being accessed by the application. The MBA tests explore how a service performs from the point at which a fixed ISP's Internet service is delivered to the home on fixed infrastructure (deliberately excluding Wi-Fi, due to the many confounding factors associated with it) to the point at which the test servers are located. As MBA tests are designed to focus on the access to the ISP's network, they will not include phenomena at most interconnection points or transit networks that consumer traffic may traverse.

To the extent possible[21] the MBA focuses on performance within an ISP's network. It should be noted that the overall performance a consumer experiences with their service can also be affected by congestion such as may arise at other points in the path potentially taken by consumer traffic (*e.g.*, in-home Wi-Fi, peering points, transit networks, *etc.*) but this does not get reflected in MBA measurements.

A consumer's home network, rather than the ISP's network, may be the bottleneck with respect to network congestion. We measure the performance of the ISP's service delivered to the consumer's home network, but this service is often shared simultaneously among multiple users and applications within the home. In-home networks, which typically include Wi-Fi, may not have sufficient capacities to support peak loads.[22]

In addition, consumers' experience of ISP performance is manifested through the set of applications they utilize. The overall performance of an application depends not only on the network performance (*i.e.*, raw speed, latency, or packet loss), but also on the application's architecture and implementation and on the operating system and hardware on which it runs. While network performance is considered in this Report, application performance is generally not.

C. MEASUREMENT TESTS AND PERFORMANCE METRICS

This Report is based on the following measurement tests:

- Download speed: This test measures the download speed of each whitebox over a 10-second period, once per hour during peak hours (7 p.m. to 11 p.m.) and once during each of the following periods: midnight to 6 a.m., 6 a.m. to noon, and noon to 6 p.m. The download speed measurement results from each whitebox are then averaged across the measurement month;

[21] The MBA program uses test servers that are both neutral (*i.e.*, operated by third parties that are not ISP-operated or owned) and located as close as practical, in terms of network topology, to the boundaries of the ISP networks under study. As described earlier in this section, a maximum of two interconnection points and one transit network may be on the test path. If there is congestion on such paths to the test server, it may impact the measurement, but the cases where it does so are detectable by the test approach followed by the MBA program, which uses consistent longitudinal measurements, comparisons with control servers located on-net and trend analyses of averaged results. Details of the methodology used in the MBA program are given in the Technical Appendix to this report.

[22] Independent research, drawing on the FCC's MBA test platform, suggests that home networks are a significant source of end-to-end service congestion. *See* Srikanth Sundaresan et al., *Home Network or Access Link? Locating Last-Mile Downstream Throughput Bottlenecks*, PAM 2016 - Passive and Active Measurement Conference, at 111-123 (Mar. 2016). Numerous instances of research supported by the fixed MBA test platform are described at https://www.fcc.gov/general/mba-assisted-research-studies.

and the median value for these average speeds across the entire set of whiteboxes on a given tier is used to determine the *median measured download speed* for that tier. The overall ISP download speed is computed as the weighted median for each service tier, using the subscriber counts for the tiers as weights.

- Upload speed: This test measures the upload speed of each whitebox over a 10-second period, which is the same measurement interval as the download speed. The upload speed measured in the last five seconds of the 10-second interval is retained, the results of each whitebox are then averaged over the measurement period, and the median value for the average speed taken over the entire set of whiteboxes is used to determine the *median upload speed* for a service tier. The ISP upload speed is computed in the same manner as the download speed.
- Latency and packet loss: These tests measure the round-trip times for approximately 2,000 packets per hour sent at randomly distributed intervals. Response times less than three seconds are used to determine the mean latency. If the whitebox does not receive a response within three seconds, the packet is counted as lost.
- Web browsing: The web browsing test measures the total time it takes to request and receive webpages, including the text and images, from nine popular websites and is performed once every hour. The measurement includes the time required to translate the web server name (URL) into the webserver's network (IP) address.

This Report focuses on three key performance metrics of interest to consumers of broadband Internet access service, as they are likely to influence how well a wide range of consumer applications work: download and upload speed, latency, and packet loss. Download and upload speeds are also the primary network performance characteristic advertised by ISPs. However, as discussed above, the performance observed by a user in any given circumstance depends not only on the actual speed of the ISP's network, but also on the performance of other parts of the Internet and on that of the application itself.

The standard speed tests use TCP with 8 concurrent TCP sessions. In 2017 we also introduced a less-data intensive throughput test, which both generated less traffic and ran less frequently and thereby provided less strain on consumer accounts that are data-capped. The Lightweight tests are used exclusively to provide broadband performance results for satellite ISPs. The Technical Appendix to this Report describes each test in more detail, including additional tests not contained in this Report.

D. AVAILABILITY OF DATA

The MBA panel sample used in the reporting period is validated (i.e., upload and download tiers of the whiteboxes are verified with providers) and the measurement results are carefully inspected to eliminate misleading outliers. This leads to a 'validated data set' that accompanies each report. The Validated Data Set[23] on which this Report is based, as well as the full results of all tests, are available at http://www.fcc.gov/measuring-broadband-america. For interested parties, as tests are run 24x7x365, we also provide raw data (referred to as such because cross-checks are not done except in the test period used for the report, thus subscriber tier changes may be missed) for the reference month and other months. Previous reports of the MBA program, as well as the data used to produce them, are also available there.

Both the Commission and SamKnows, the Commission's contractor for this program, recognize that, while the methodology descriptions included in this document provide an overview of the project, interested

[23] The September-October 2019 data set was validated to remove anomalies that would have produced errors in the Report. This data validation process is described in the Technical Appendix.

parties may be willing to contribute to the project by reviewing the software used in the testing. SamKnows welcomes review of its software and technical platform, consistent with the Commission's goals of openness and transparency for this program.[24]

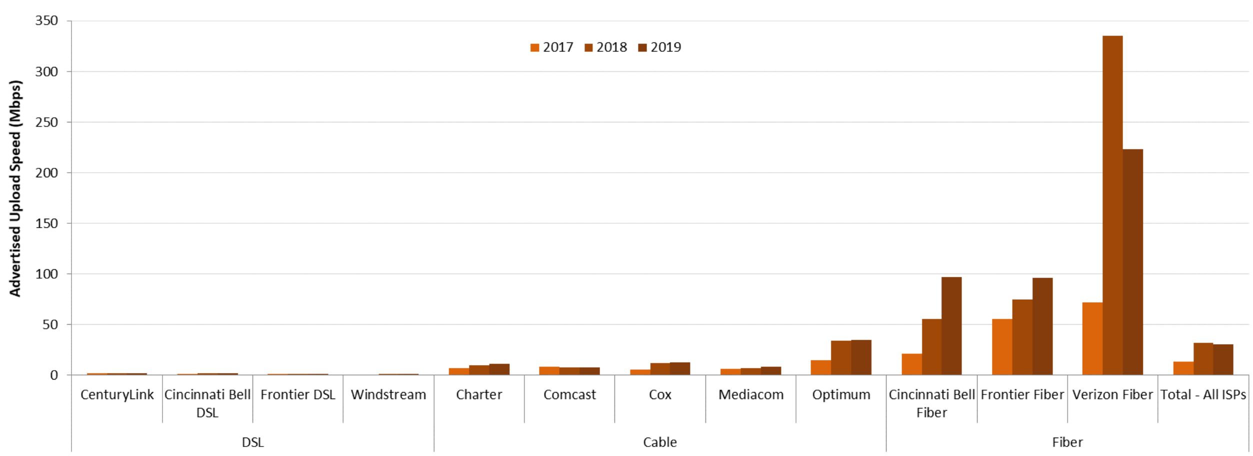
[24] The software that was used for the MBA program will be made available for noncommercial purposes. To apply for noncommercial review of the code, interested parties may contact SamKnows directly at team@samknows.com, with the subject heading "Academic Code Review."

4. Test Results

A. MOST POPULAR ADVERTISED SERVICE TIERS

Chart 1 above summarizes the weighted average of the advertised download speeds[25] for each participating ISP, for the last 3 years (September 2017 to September-October 2019) where the weighting is based upon the number of subscribers to each tier, grouped by the access technology used to offer the broadband Internet access service (DSL, cable, or fiber). Only the top 80% tiers (by subscriber number) of each ISP were included. Chart 10 below shows the corresponding weighted average of the advertised upload speeds among the measured ISPs. The computed weighted average of the advertised upload speed of all the ISPs is 30.5 Mbps representing a 133% increase compared to 13.1 Mbps in 2017. However, the computed average weighted upload speed decreased slightly this year by 4% over the previous year's value of 31.9 Mbps.[26]

Chart 10.1: Weighted average advertised upload speed among the top 80% service tiers offered by each ISP.



Due to the relatively high upload speeds for optical technology, it is difficult to discern the variations in speed for both DSL and cable technologies when drawn to the same scale. Separate Charts 10.1 and 10.2 are included here that provide the weighted-average upload speeds for ISPs using DSL and cable technologies, respectively.

Chart 10.2: Weighted average advertised upload speed offered by ISPs using DSL technology.

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[25] Measured service tiers were tiers which constituted the top 80% of an ISP's broadband subscriber base.

[26] Please note that this average for Sept-Oct 2018 represents the average advertised upload speed with AT&T tiers removed. We did this to have a fairer comparison between the years since AT&T is no longer an active participant in the MBA program. The actual weighted average upload speed for September-October 2018, as reported in the Ninth MBA Report, is 27.4 Mbps.

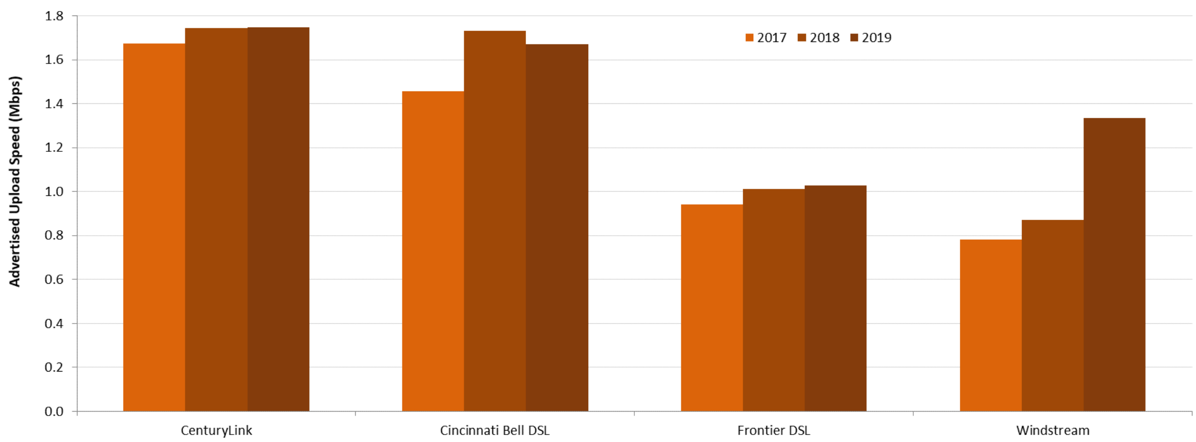


Chart 10.3: Weighted average advertised upload speed offered by ISPs using Cable technology.

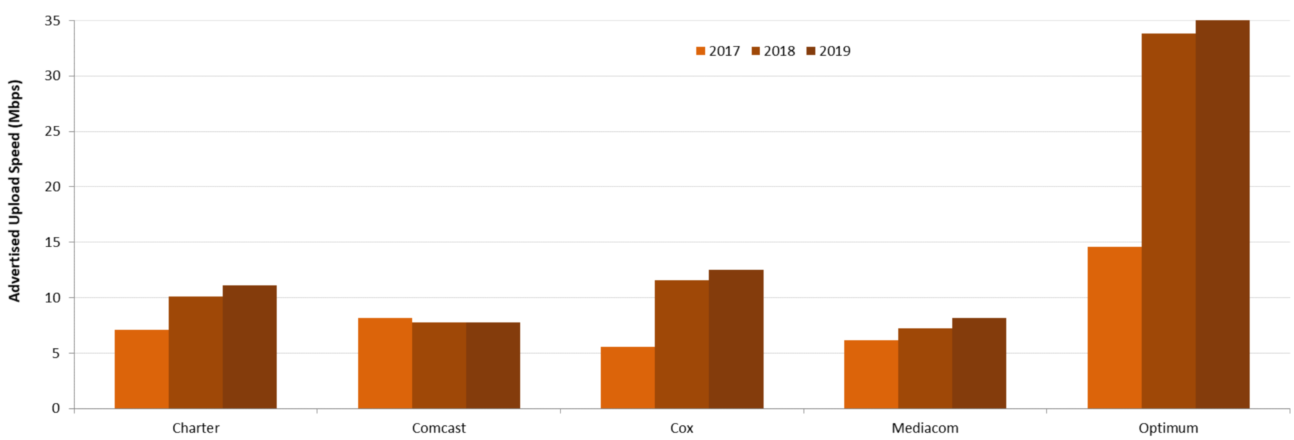
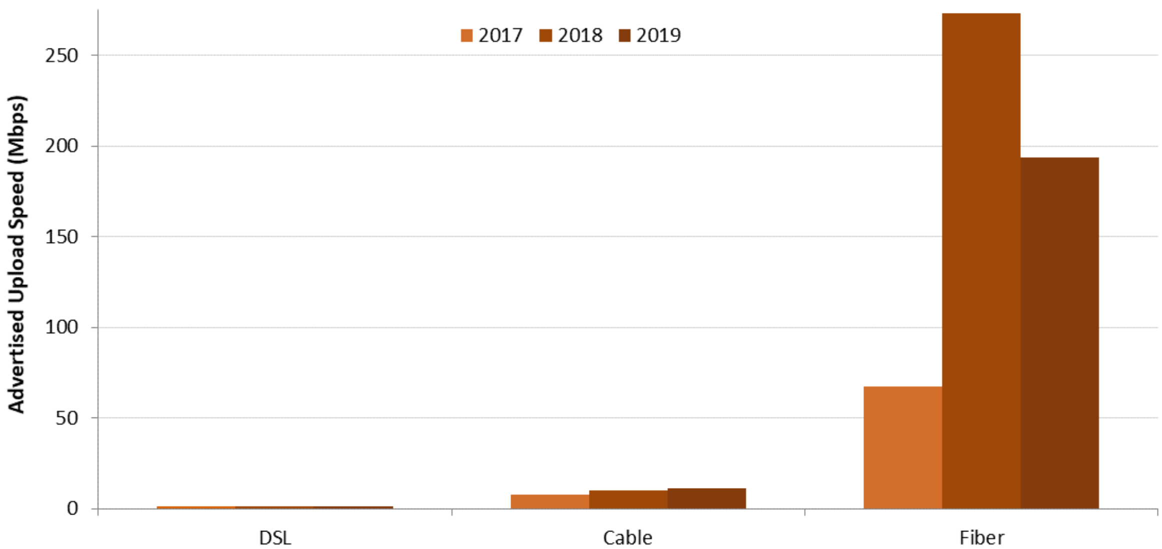


Chart 11 compares the weighted average of the advertised upload speeds by technology for the last 3 years (September 2017 to September-October 2019). As can be seen in this chart, all technologies showed increased rates in 2019 as compared to 2017. However, the rates of increase were not the same for all technologies. The rate of increase in the weighted average of Fiber technology was 189% compared to DSL and Cable which were 11% and 43%, respectively. Comparing the 2019 results with the previous year's (2018) results, we see an increase of offered upload speeds in DSL by 6% to 1.5 Mbps and an increase in cable of 9% to 11 Mbps. However, Fiber upload speed decreased by 29% in 2019 as compared with 2018. This drop in fiber upload speed is due to relative shifts in the number of subscribers to the tiers rather than lowering of offered upload tier speeds. Despite this drop, the advertised fiber upload speeds (194 Mbps) were still far higher than for other technologies.

Observing both the download and upload speeds, it is clear that fiber service tiers are generally symmetric in their actual upload and download speeds. This results from the fact that fiber technology has significantly more capacity than other technologies and it can be engineered to have symmetric upload and download speeds. For other technologies with more limited capacity, higher capacity is usually allocated to download speeds than to upload speeds, typically in ratios ranging from 5:1 to 10:1. This resulting asymmetry in download/upload speeds is reflective of actual usage because consumers typically download significantly more data than they upload.

Chart 11: Weighted average advertised upload speed among the top 80% service tiers based on technology.



B. OBSERVED MEDIAN DOWNLOAD AND UPLOAD SPEEDS

Chart 4 (in Section 2.B) shows the ratio in September-October 2019 of the weighted median of both download and upload speeds of each ISP's subscribers to advertised speeds. Charts 12.1 and 12.2 below show the same ratios separately for download speed and for upload speed. The median download speeds of most ISPs' subscribers have been close to, or have exceeded, the advertised speeds. Exceptions to this were the following DSL providers: CenturyLink, Cincinnati Bell DSL, Frontier DSL and Windstream with respective ratios of 92%, 79%, 94% and 97%.

Chart 12.1: The ratio of median download speed to advertised download speed.

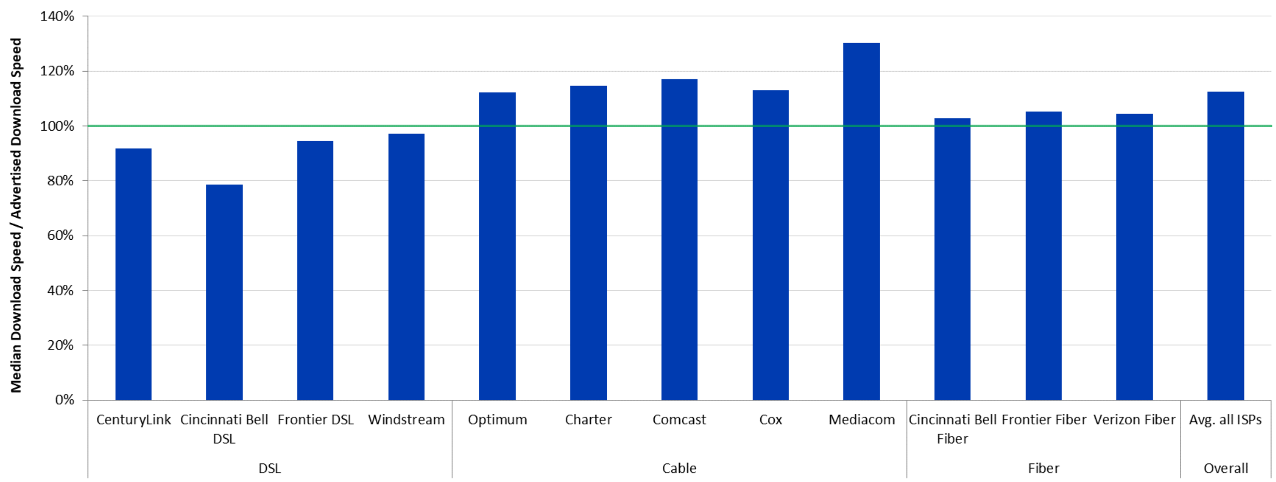
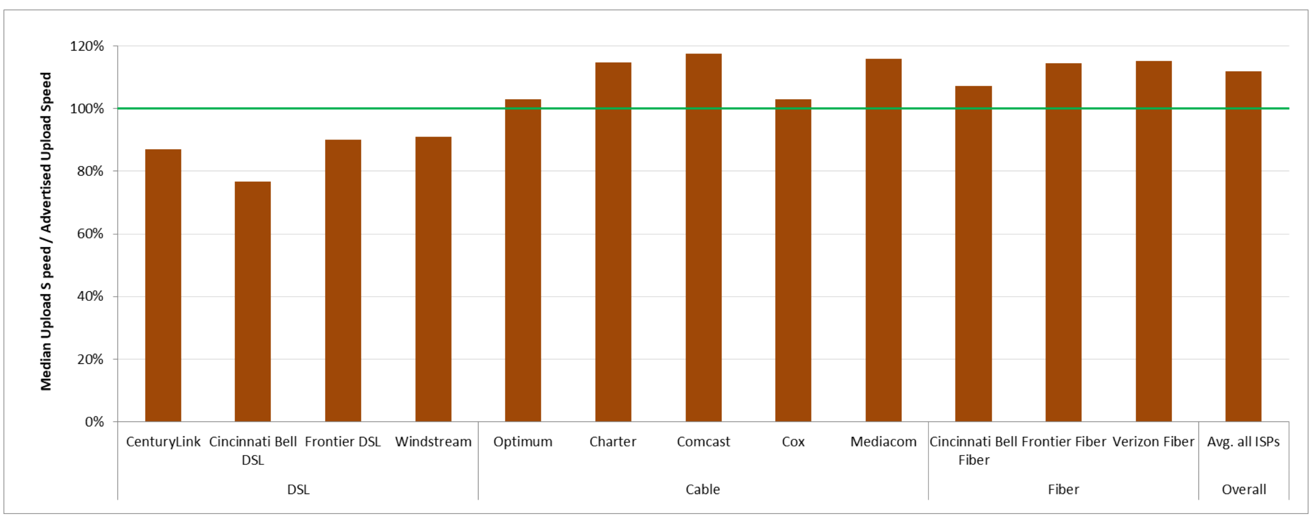


Chart 12.2 shows the median upload speed as a percentage of the advertised speed. As was the case with download speeds most ISPs met or exceeded the advertised rates except for a number of DSL providers: CenturyLink, Cincinnati Bell DSL, Frontier DSL and Windstream which had respective ratios of 87%, 77%, 90%, and 91%.

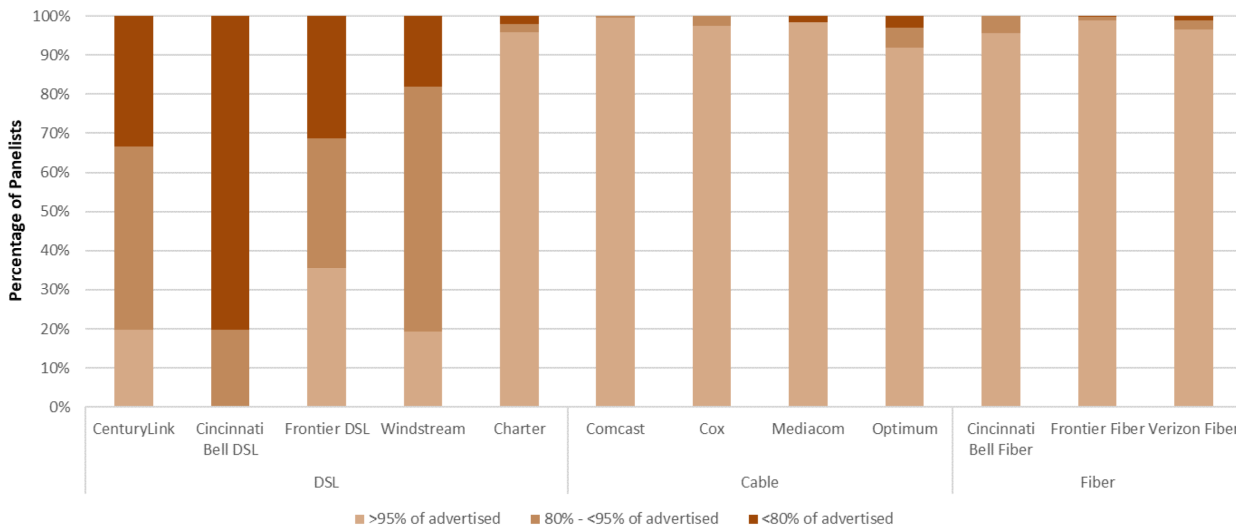
Chart 12.2: The ratio of median upload speed to advertised upload speed.



C. VARIATIONS IN SPEEDS

Median speeds experienced by consumers may vary based on location and time of day as the network architectures and traffic patterns may differ. Chart 5 in Section 2 above showed, for each ISP, the percentage of consumers (across the ISP's service territory) who experienced a median download speed over the peak usage period that was either greater than 95%, between 80% and 95%, or less than 80% of the advertised download speed. Chart 13 below shows the corresponding percentage of consumers whose median upload speed fell in each of these ranges. ISPs using DSL technology had only between 0% to 36% of their subscribers getting greater than or equal to 95% of their advertised upload speeds during peak hours. In contrast, ISPs using cable or fiber technology had between 92% - 100% of their subscribers getting equal to or better than 95% of their advertised upload speeds.

Chart 13: The percentage of consumers whose median upload speed was (a) greater than 95%, (b) between 80% and 95%, or (c) less than 80% of the advertised upload speed.



Though the median upload speeds experienced by most subscribers were close to or exceeded the advertised upload speeds there were some subscribers, for each ISP, whose median upload speed fell significantly short of the advertised upload speed. This issue was most prevalent for ISPs using DSL technology. On the other hand, ISPs using cable and fiber technology generally showed very good consistency based on this metric.

We can learn more about the variation in network performance by separately examining variations across geography and across time. We start by examining the variation across geography within each participating ISP's service territory. For each ISP, we first calculate the ratio of the median download speed (over the peak usage period) to the advertised download speed for each panelist subscribing to that ISP. We then examine the distribution of this ratio across the ISP's service territory.

Charts 14.1 and 14.2 show the complementary cumulative distribution of the ratio of median download speed (over the peak usage period) to advertised download speed for each participating ISP. For each ratio of actual to advertised download speed on the horizontal axis, the curves show the percentage of panelists subscribing to each ISP that experienced at least this ratio.[27] For example, the Cincinnati Bell fiber curve in Chart 14.1 shows that 90% of its subscribers experienced a median download speed exceeding 76% of the advertised download speed, while 70% experienced a median download speed exceeding 92% of the advertised download speed, and 50% experienced a median download speed exceeding 107% of the advertised download speed.

[27] In Reports prior to the 2015 MBA Report, for each ratio of actual to advertised download speed on the horizontal axis, the cumulative distribution function curves showed the percentage of measurements, rather than panelists subscribing to each ISP, that experienced at least this ratio. The methodology used since then, *i.e.*, using panelists subscribing to each ISP, more accurately illustrates ISP performance from a consumer's point of view.

Chart 14.1: Complementary cumulative distribution of the ratio of median download speed to advertised download speed.

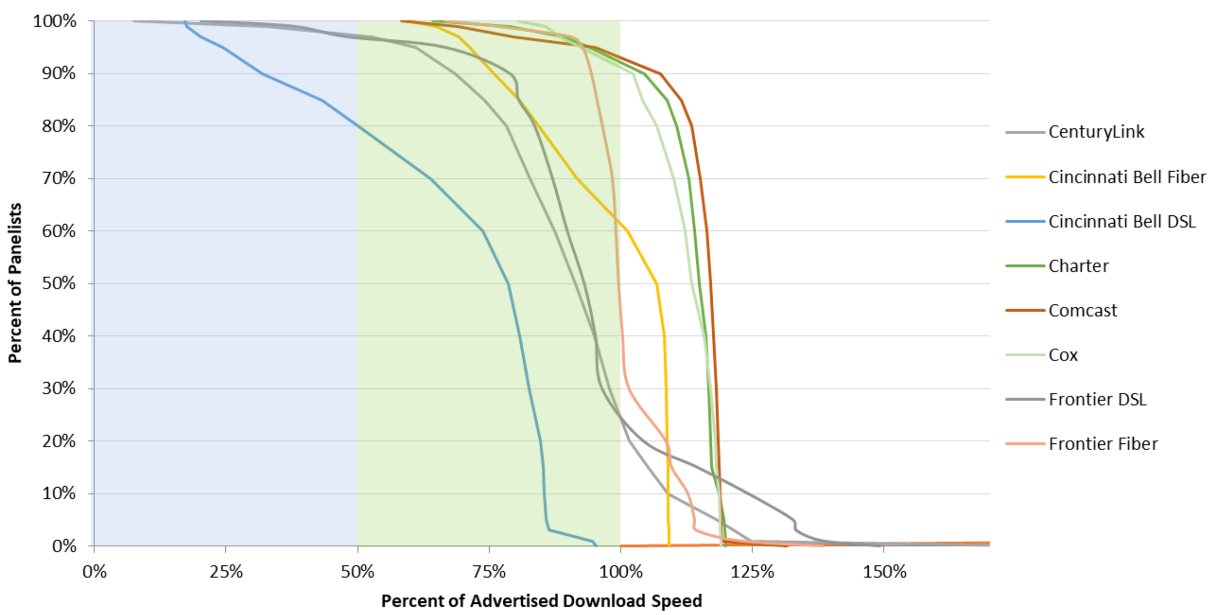
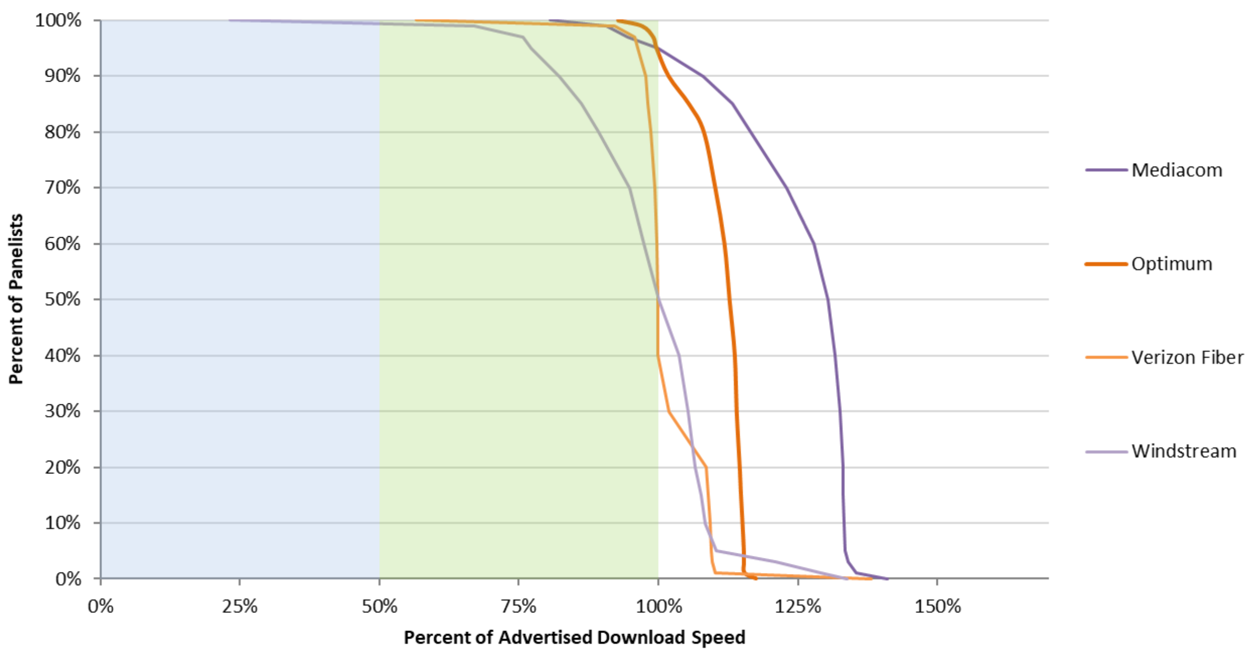
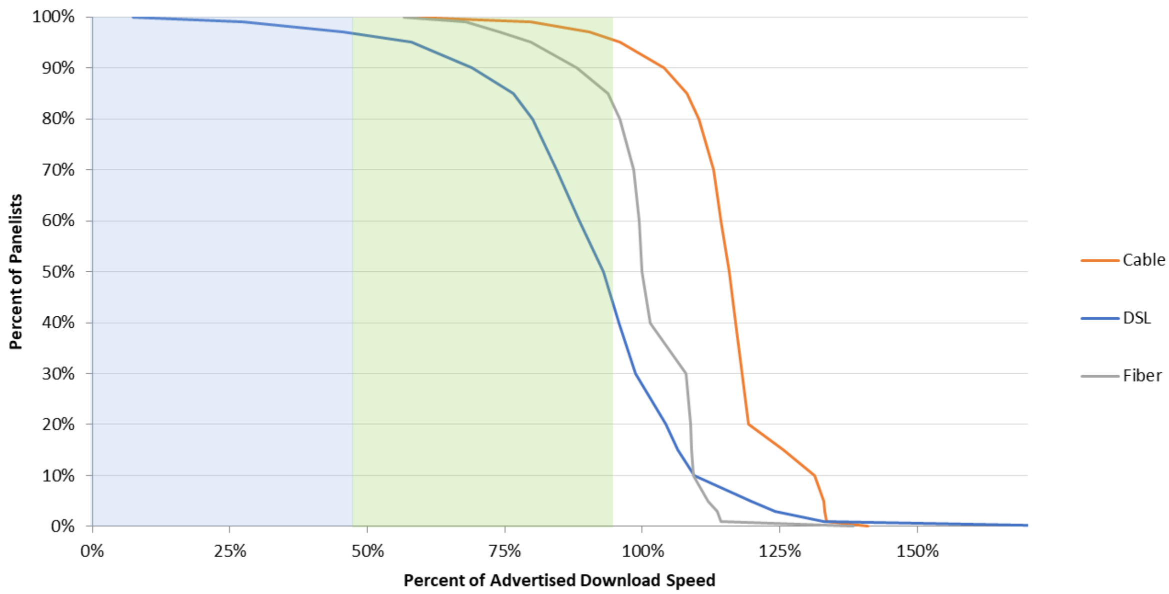


Chart 14.2: Complementary cumulative distribution of the ratio of median download speed to advertised download speed (continued).



The curves for cable-based broadband and fiber-based broadband are steeper than those for DSL-based broadband. This can be seen more clearly in Chart 14.3, which plots aggregate curves for each technology. Approximately 90% of subscribers to cable and 50% of subscribers to fiber-based technologies experience median download speeds exceeding the advertised download speed. In contrast, less than 30% of subscribers to DSL-based services experience median download speeds exceeding the advertised download speed.[28]

Chart 14.3: Complementary cumulative distribution of the ratio of median download speed to advertised download speed, by technology.



Charts 14.4 to 14.6 show the complementary cumulative distribution of the ratio of median upload speed (over the peak usage period) to advertised upload speed for each participating ISP (Charts 14.4 and 14.5) and by access technology (Chart 14.6).

[28] The speed achievable by DSL depends on the distance between the subscriber and the central office. Thus, the complementary cumulative distribution function will fall slowly unless the broadband ISP adjusts its advertised rate based on the subscriber's location. (Chart 16 illustrates that the performance during non-busy hours is similar to the busy hour, making congestion less likely as an explanation.)

Chart 14.4: Complementary cumulative distribution of the ratio of median upload speed to advertised upload speed.

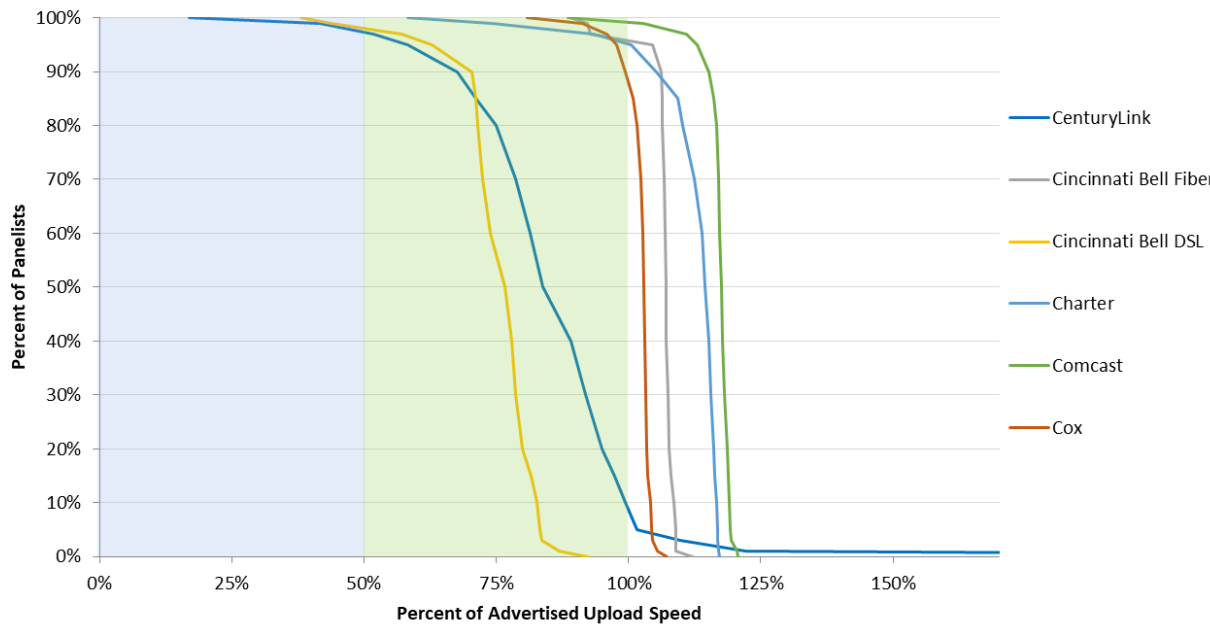


Chart 14.5: Complementary cumulative distribution of the ratio of median upload speed to advertised upload speed (continued).

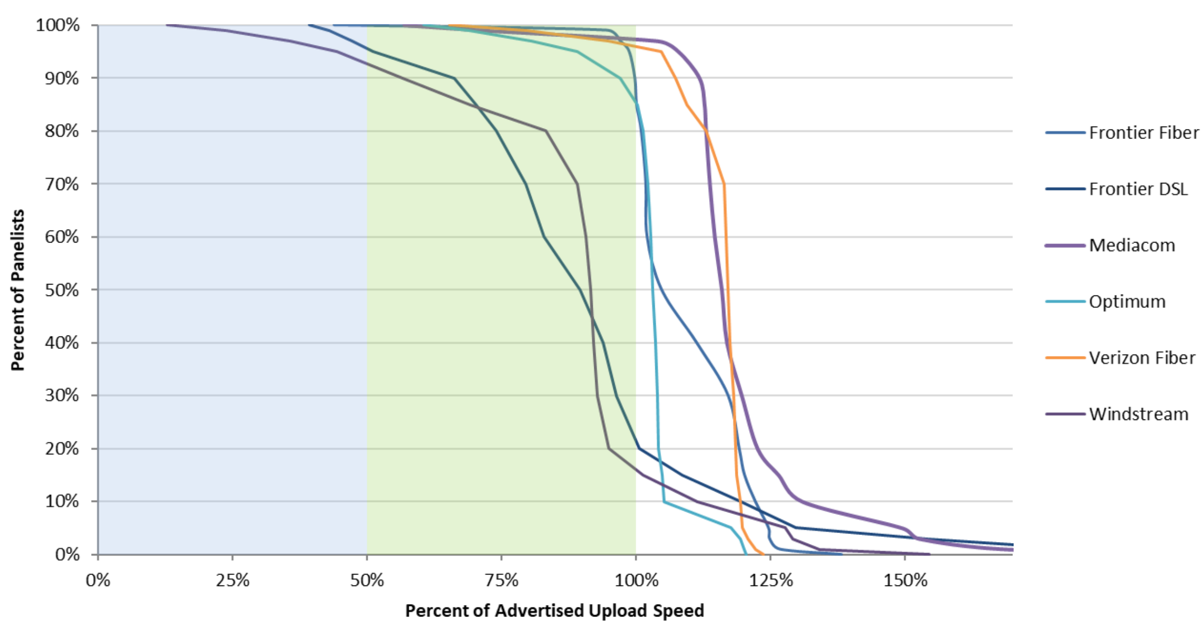
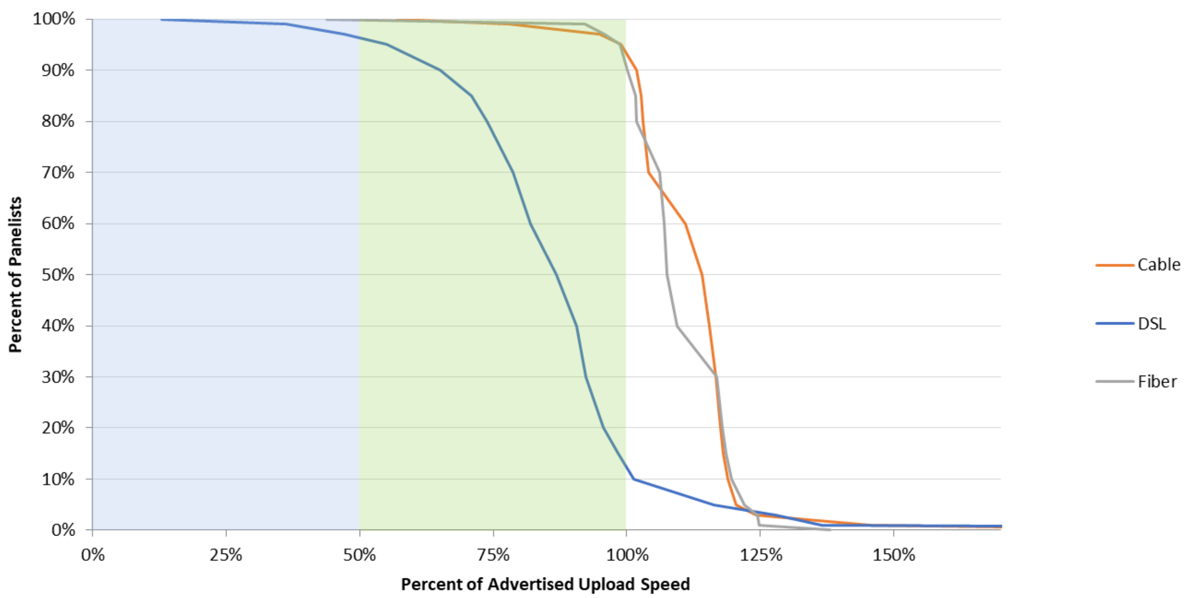


Chart 14.6: Complementary cumulative distribution of the ratio of median upload speed to advertised upload speed, by technology.



All actual speeds discussed above were measured during peak usage periods. In contrast, Charts 15.1 and 15.2 below compare the ratio of actual download and upload speeds to advertised download and upload speeds during peak and off-peak times. Charts 15.1 and 15.2 show that most ISP subscribers experience only a slight degradation from off-peak to peak hour performance.

Chart 15.1: The ratio of weighted median download speed to advertised download speed, peak hours versus off-peak hours.

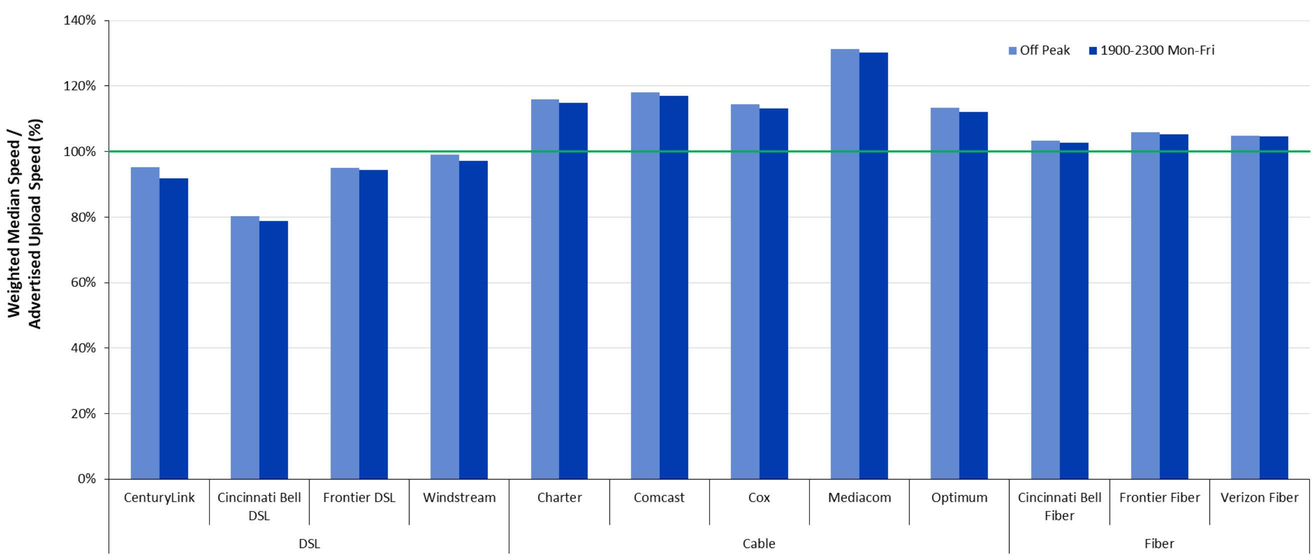


Chart 15.2: The ratio of weighted median upload speed to advertised upload speed, peak versus off-peak.

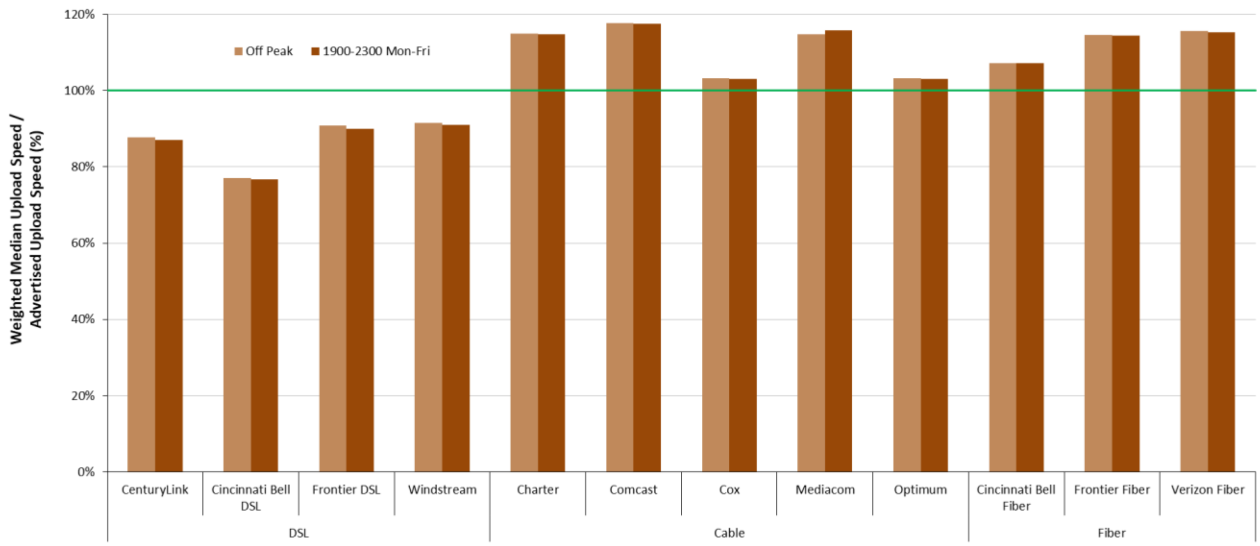
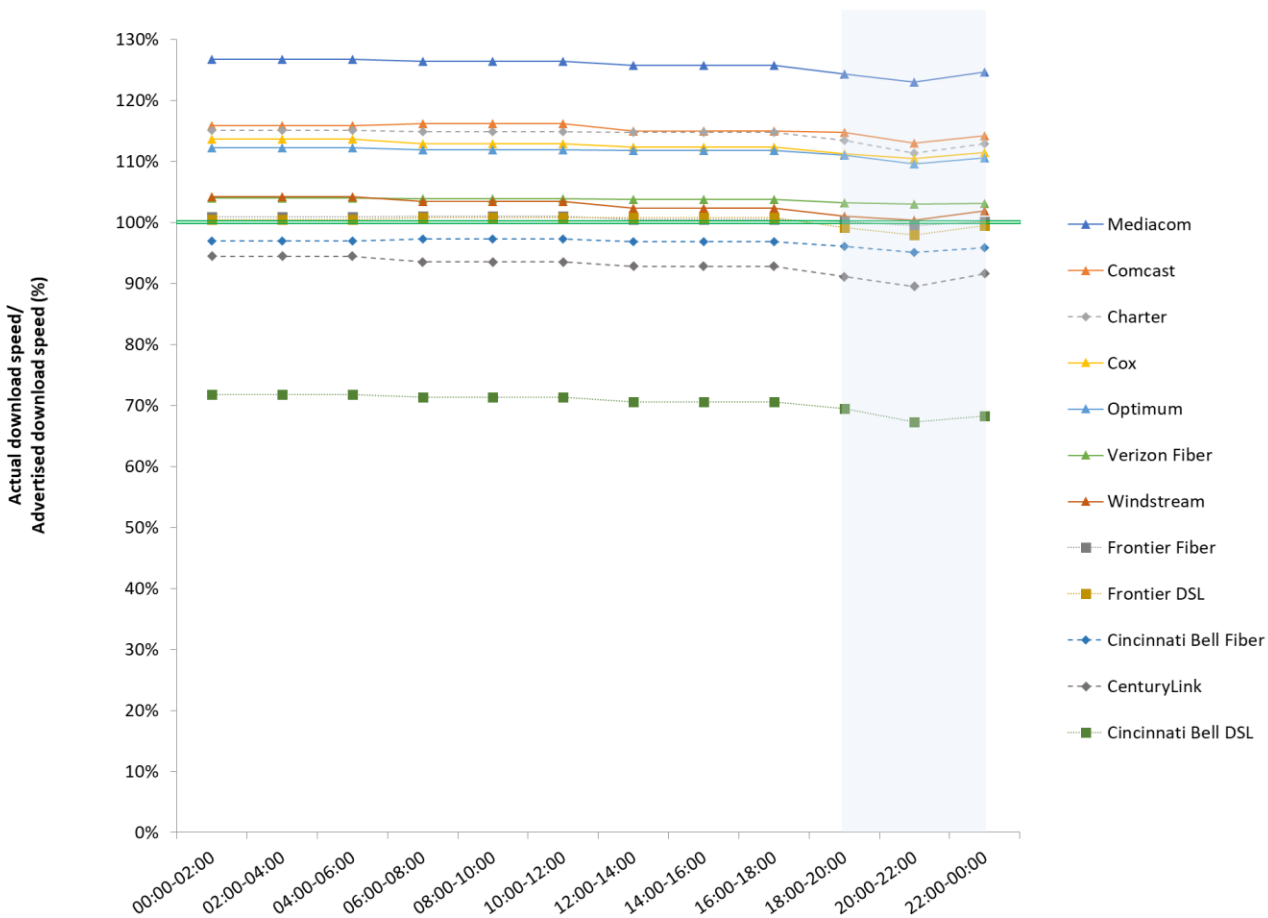


Chart 16 below shows the actual download speed to advertised speed ratio in each two-hour time block during weekdays for each ISP. The ratio is lowest during the busiest four-hour time block (7:00 p.m. to 11:00 p.m.).

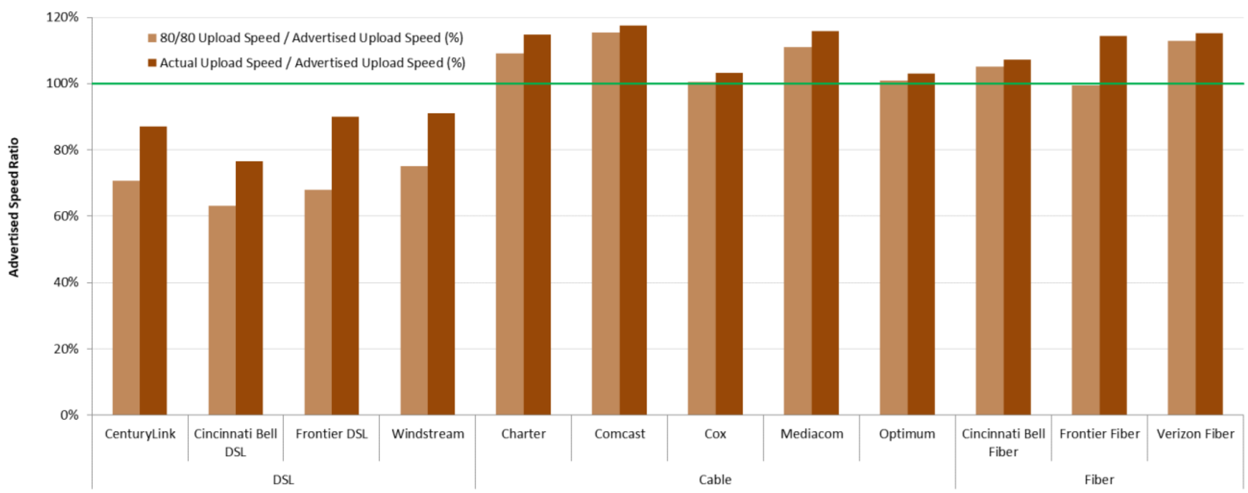
Chart 16: The ratio of median download speed to advertised download speed, Monday-to-Friday, two-hour time blocks, terrestrial ISPs.



For each ISP, Chart 6 (in Section 2.C) showed the ratio of the 80/80 consistent median download speed to advertised download speed, and for comparison, Chart 4 showed the ratio of median download speed to advertised download speed.

Chart 17.1 illustrates information concerning 80/80 consistent upload speeds. While all the upload 80/80 speeds were slightly lower than the median speed the differences were more marked in DSL. Charts 6 and 17.1 make it clear that cable and fiber technologies behaved more consistently than DSL technology both for download as well as upload speeds.

Chart 17.1: The ratio of 80/80 consistent upload speed to advertised upload speed.



Charts 17.2 and 17.3 below illustrate similar consistency metrics for 70/70 consistent download and upload speeds, *i.e.*, the minimum download or upload speed (as a percentage of the advertised download or upload speed) experienced by at least 70% of panelists during at least 70% of the peak usage period. The ratios for 70/70 consistent speeds as a percentage of the advertised speed are higher than the corresponding ratios for 80/80 consistent speeds. In fact, for many ISPs, the 70/70 consistent download or upload speed is close to the median download or upload speed. Once again, ISPs using DSL technology showed a considerably smaller value for the 70/70 download and upload speeds as compared to the download and upload median speeds, respectively.

Chart 17.2: The ratio of 70/70 consistent download speed to advertised download speed.

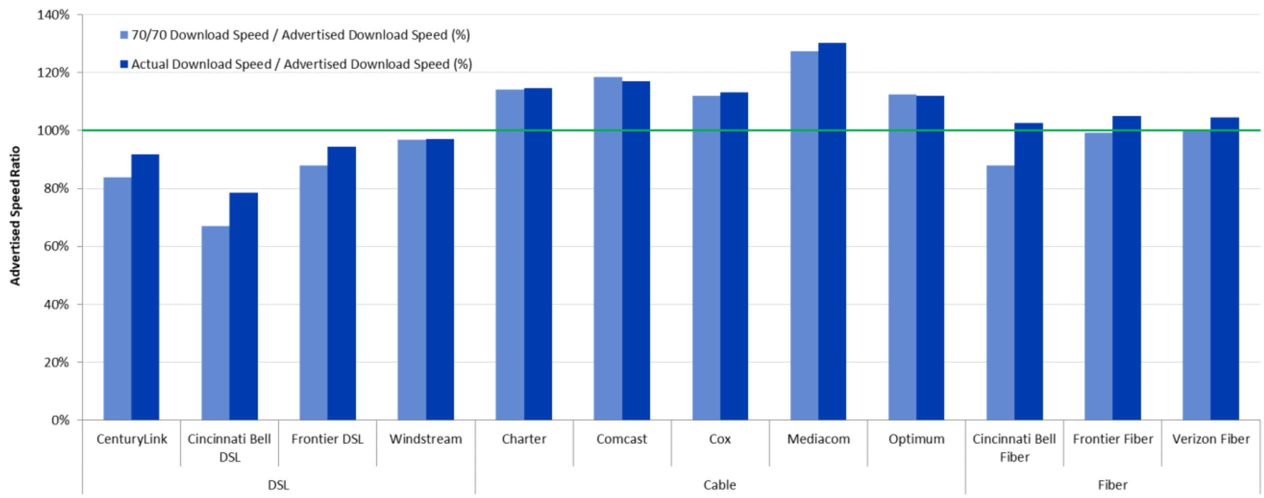
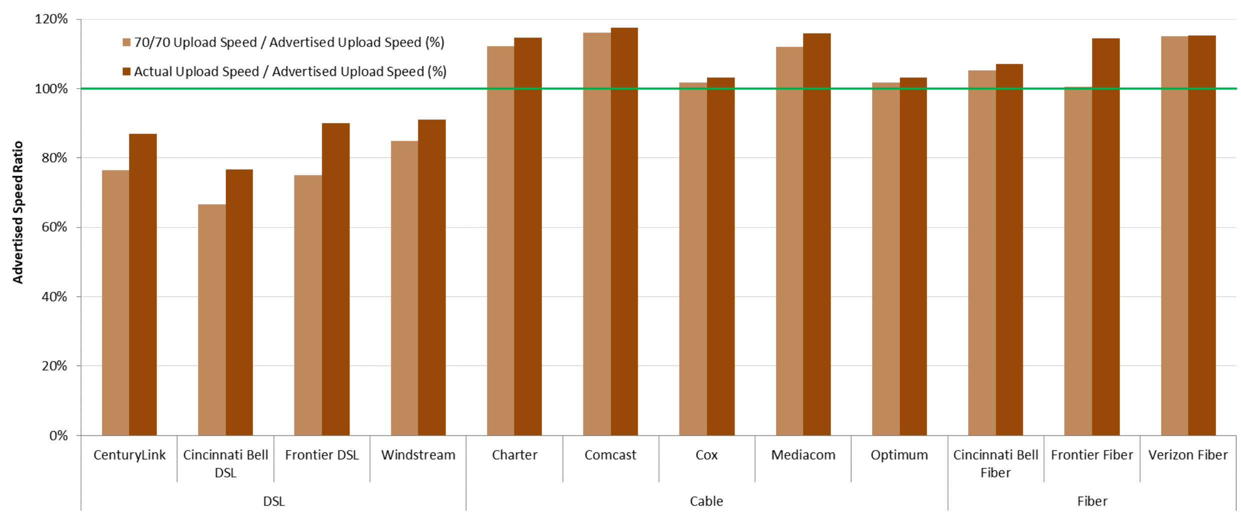


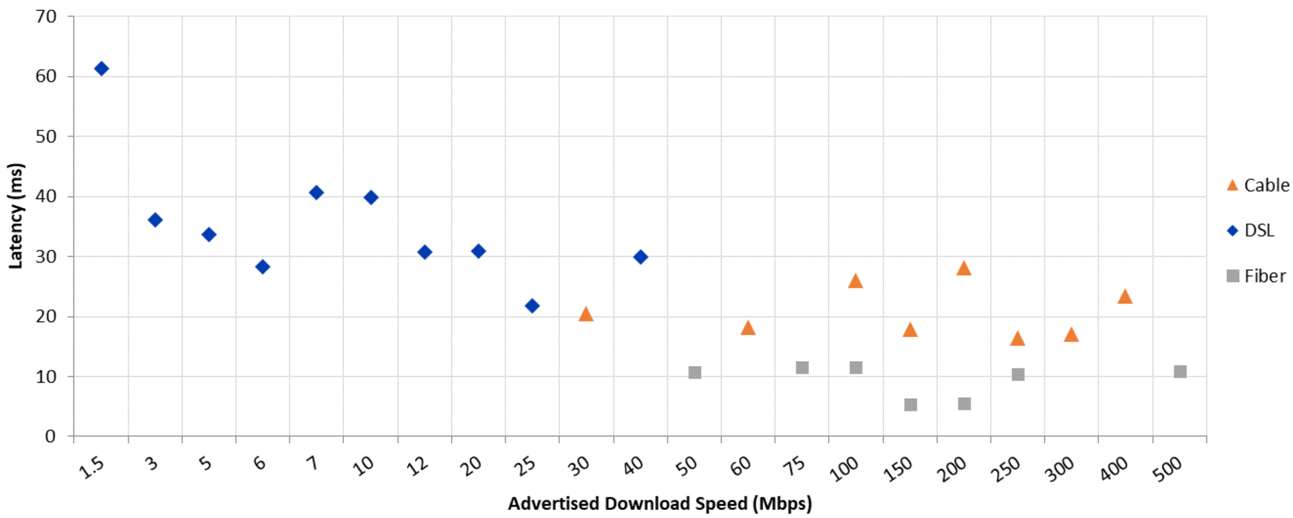
Chart 17.3: The ratio of 70/70 consistent upload speed to advertised upload speed.



D. LATENCY

Chart 18 below shows the weighted median latencies, by technology and by advertised download speed for terrestrial technologies. For all terrestrial technologies, latency varied little with advertised download speed. DSL service typically had higher latencies, and lower latency was better correlated with advertised download speed, than with either cable or fiber. Cable latencies ranged between 16ms to 28ms, fiber latencies between 5ms to 11ms, and DSL between 21ms to 61ms.

Chart 18: Latency for Terrestrial ISPs, by technology, and by advertised download speed.



5. Additional Test Results

A. Actual Speed, by Service Tier

As shown in Charts 19.1-19.8, peak usage period performance varied by service tier among participating ISPs during the September-October 2019 period. On average, during peak periods, the ratio of median download speed to advertised download speed for all ISPs was 79% or better, and 90% or better for most ISPs. However, the ratio of median download speed to advertised download speed varies among service tiers. Out of the 37 speed tiers that were measured a large majority (32) showed that they at least achieved 90% of the advertised speed and 23 of the 37 tiers either met or exceeded the advertised speed.

Chart 19.1: The ratio of median download speed to advertised download speed, by ISP (1-5 Mbps).

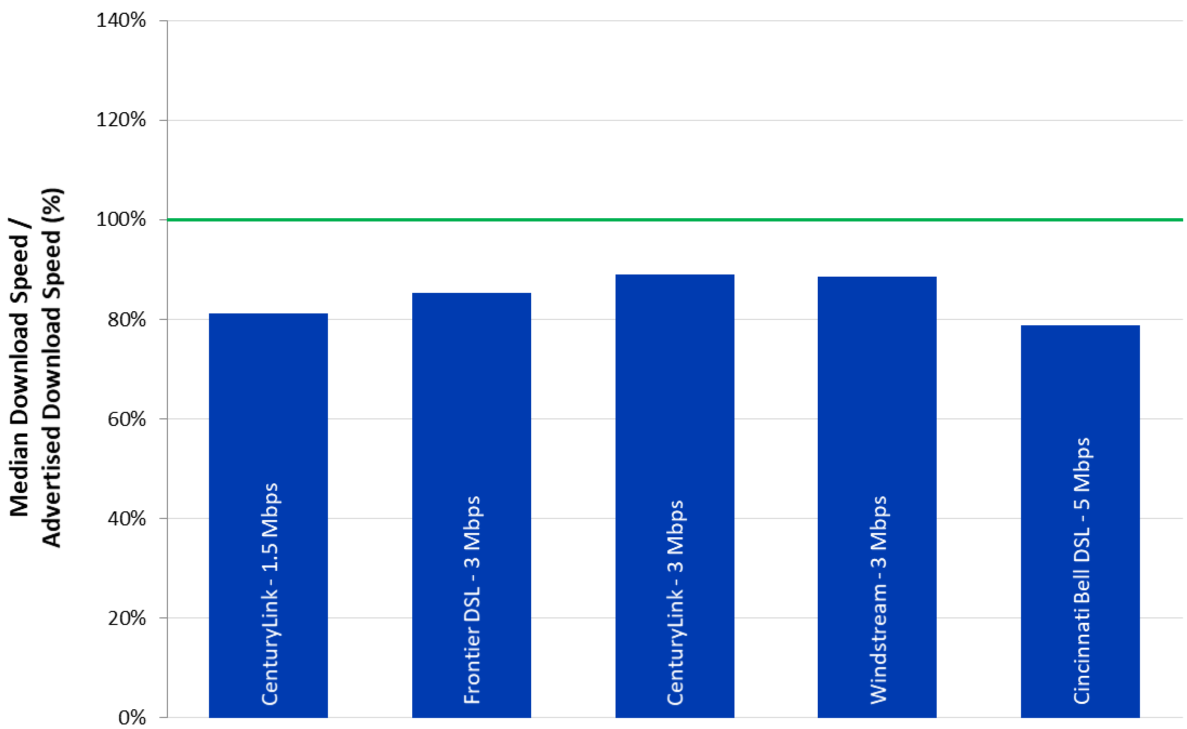


Chart 19.2: The ratio of median download speed to advertised download speed, by ISP (6-10 Mbps).

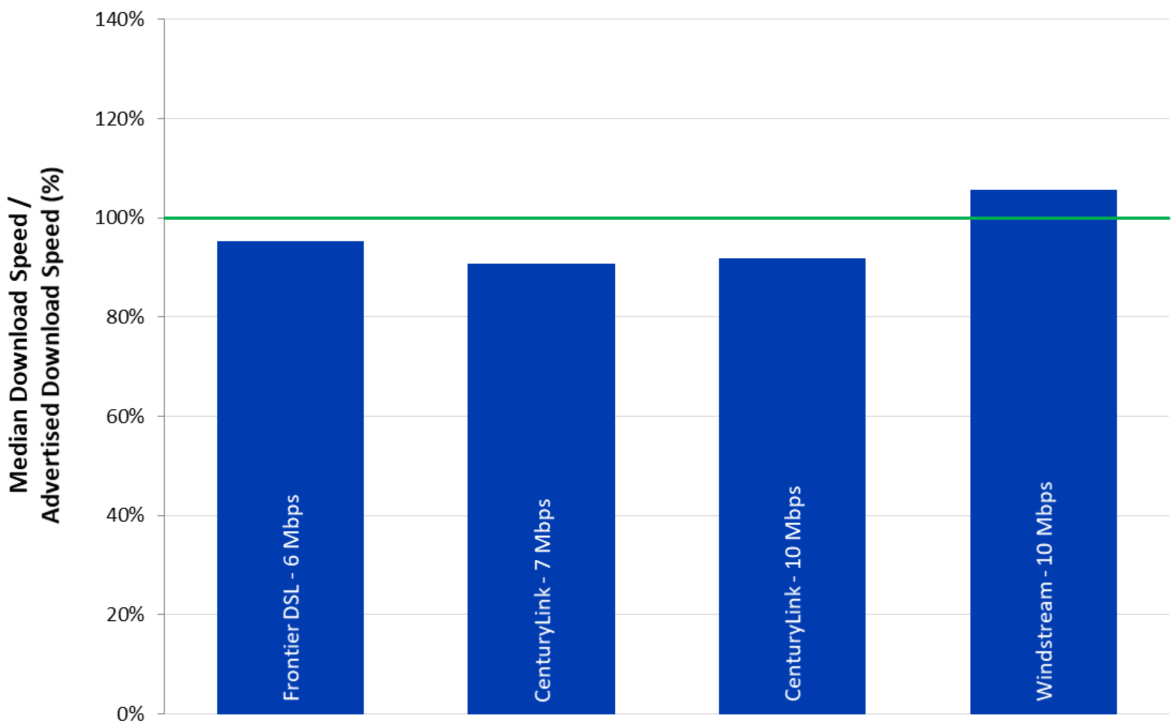


Chart 19.3: The ratio of median download speed to advertised download speed, by ISP (12-25 Mbps).

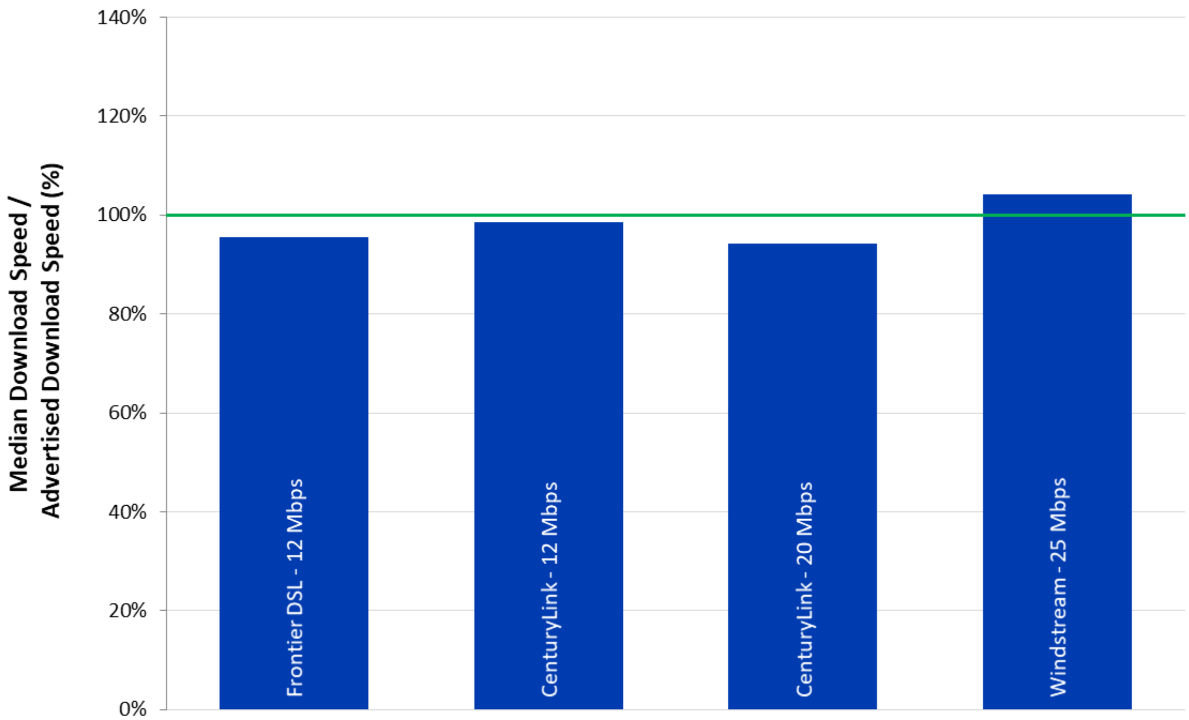


Chart 19.4: The ratio of median download speed to advertised download speed, by ISP (30-60 Mbps).

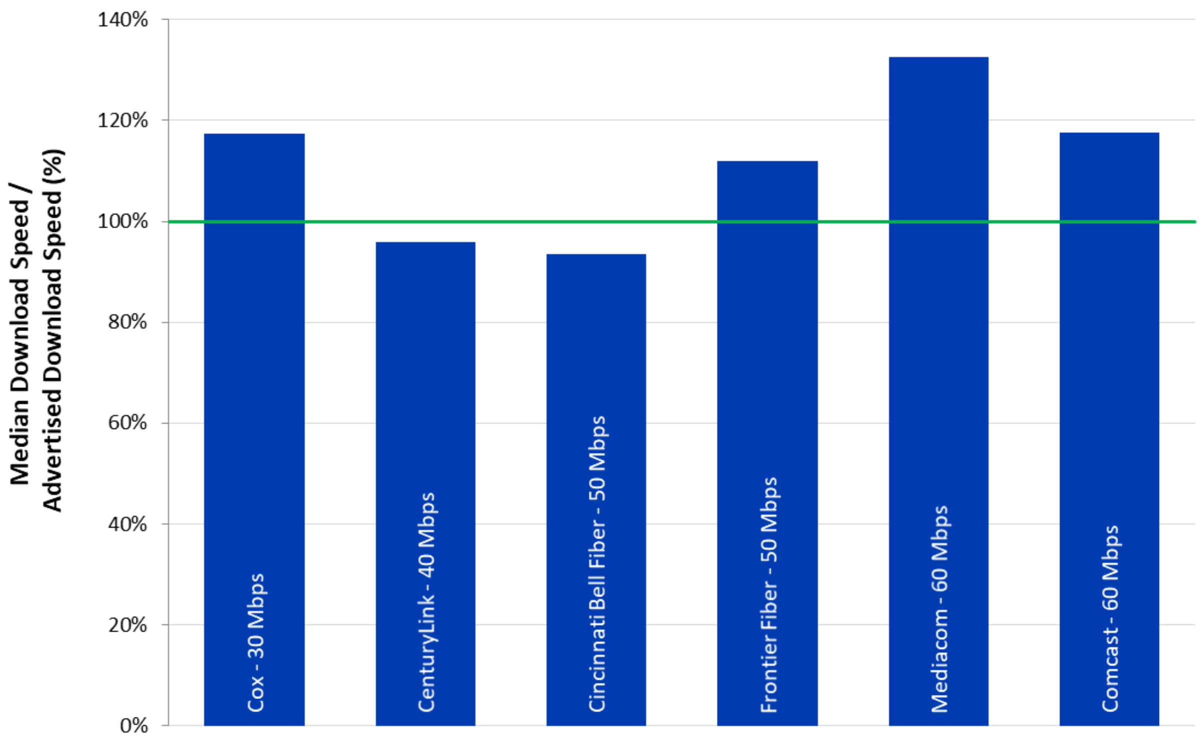


Chart 19.5: The ratio of median download speed to advertised download speed, by ISP (75-100Mbps).

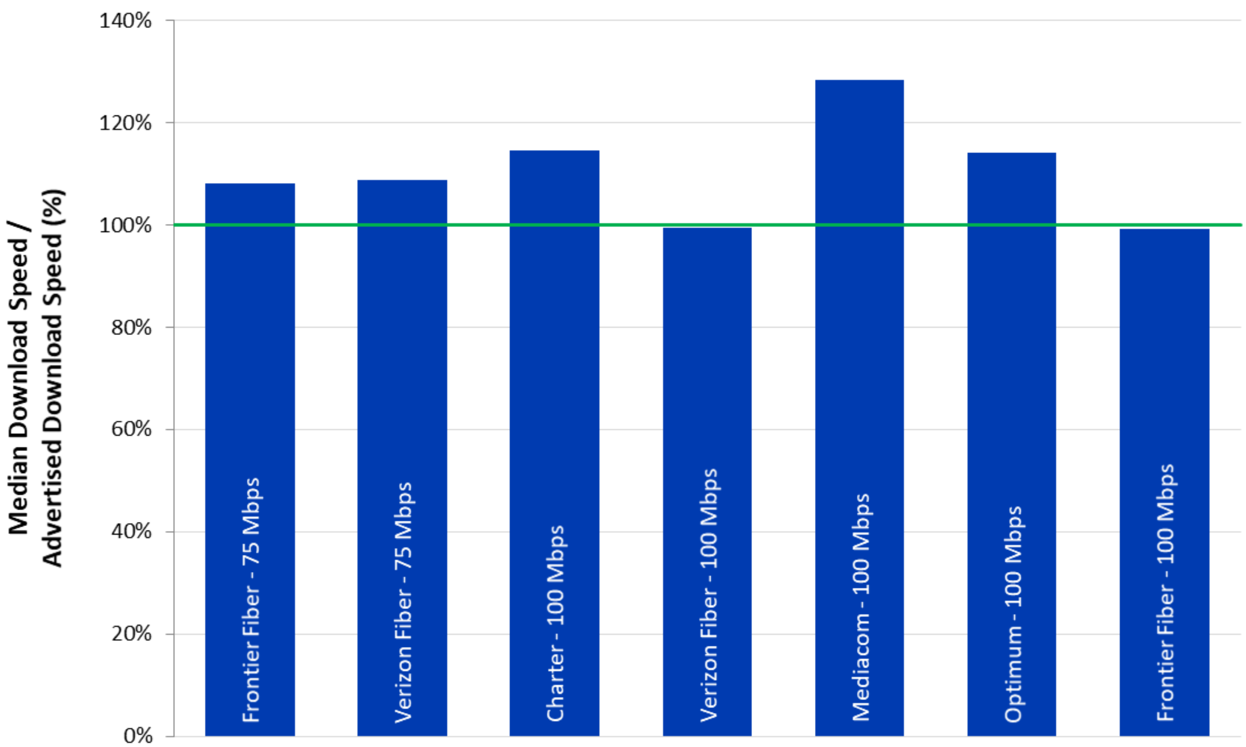


Chart 19.6: The ratio of median download speed to advertised download speed, by ISP (150-200 Mbps).

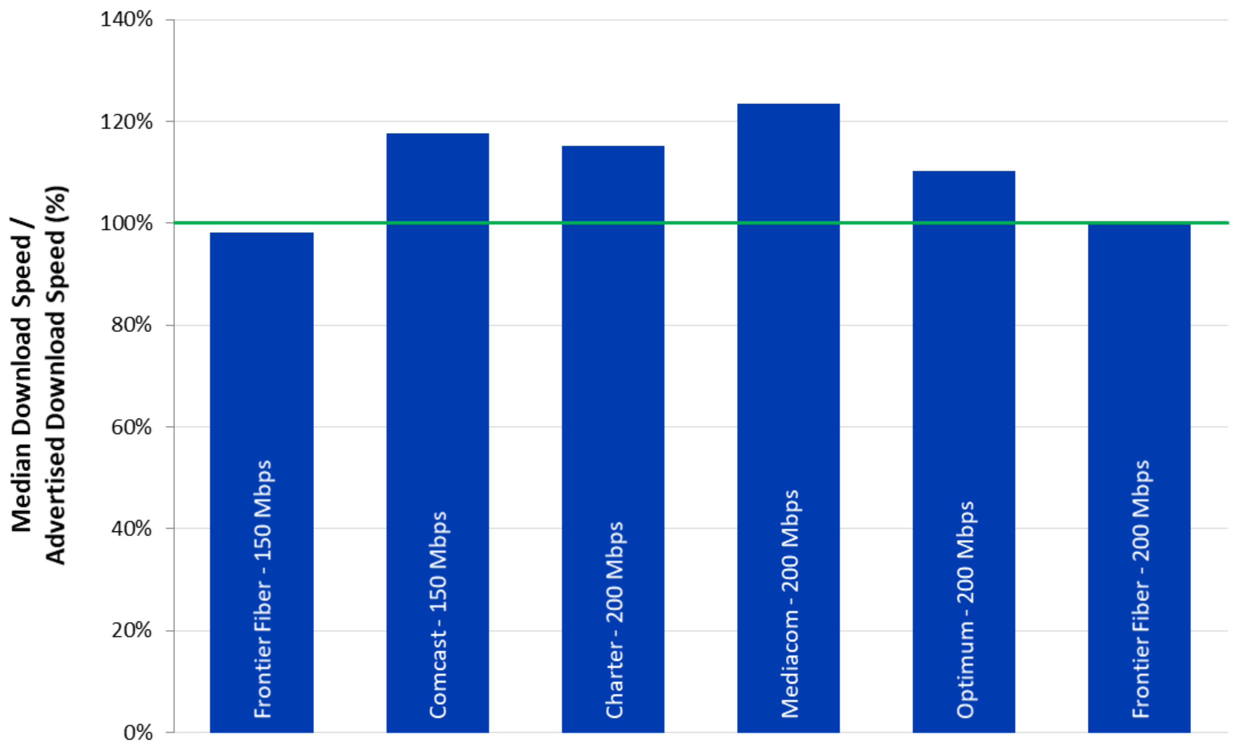
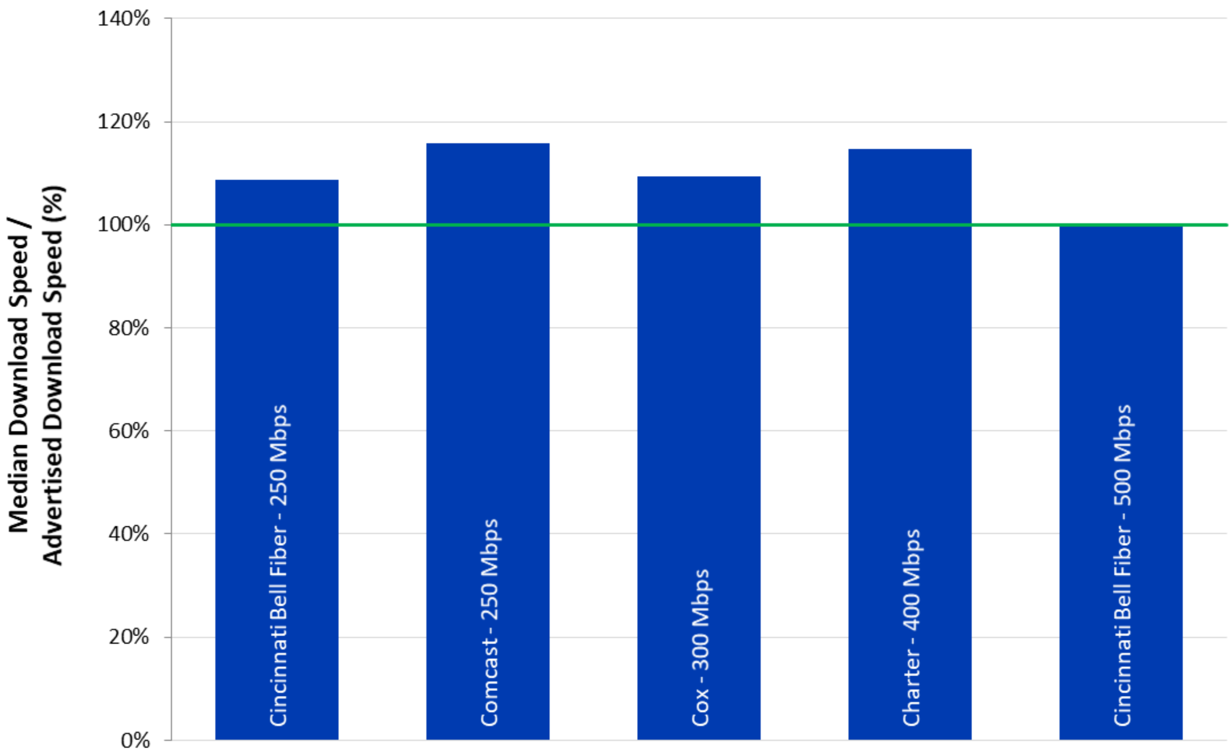


Chart 19.7: The ratio of median download speed to advertised download speed, by ISP (250-500 Mbps).



Charts 20.1 – 20.6 depict the ratio of median upload speeds to advertised upload speeds for each ISP by service tier. Out of the 30 upload speed tiers that were measured a large majority (25) showed that they at least achieved 90% of the advertised upload speed, and 21 of the 30 tiers either met or exceeded the advertised upload speed.

Chart 20.1: The ratio of median upload speed to advertised upload speed, by ISP (0.768 - 1 Mbps).

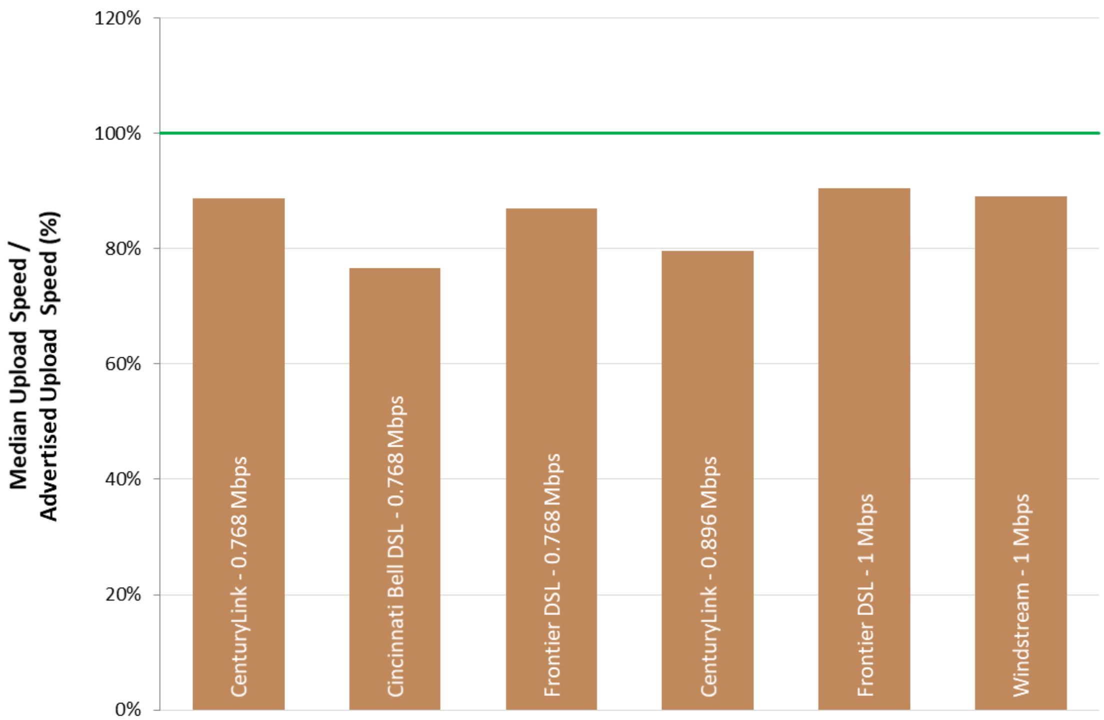


Chart 20.2: The ratio of median upload speed to advertised upload speed, by ISP (1.5-5 Mbps).

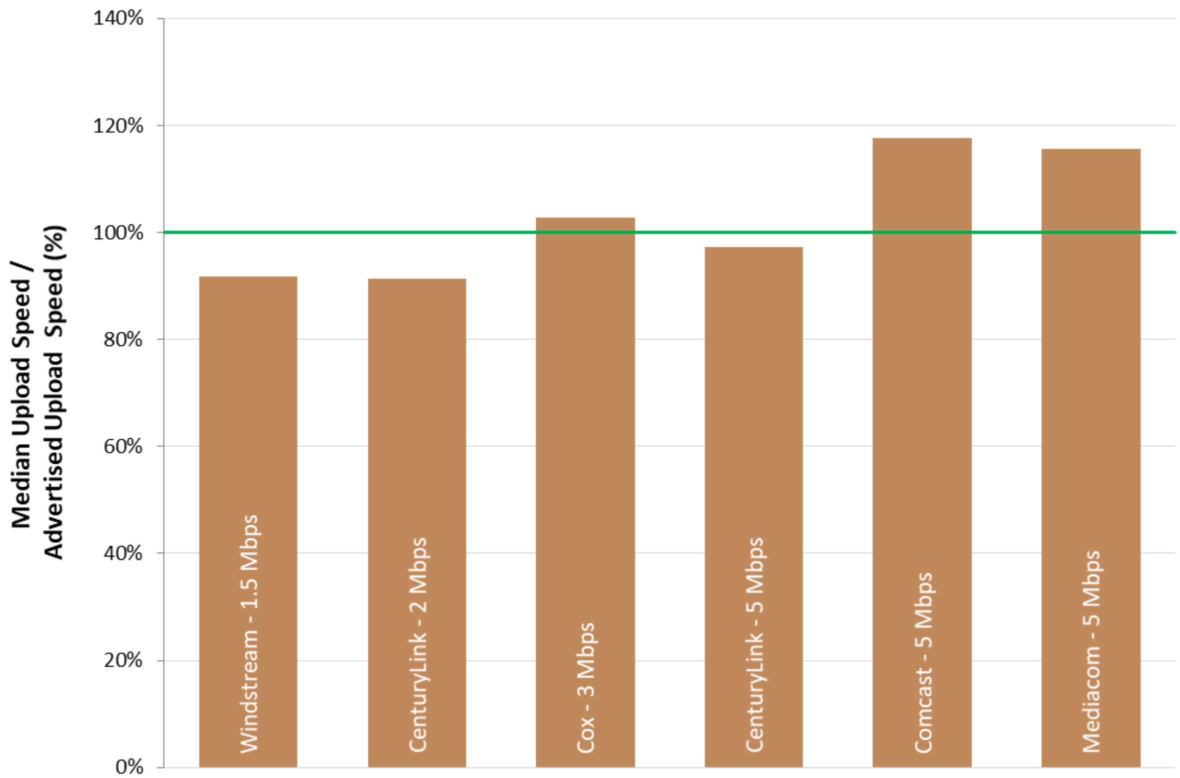


Chart 20.3: The ratio of median upload speed to advertised upload speed, by ISP (10 -20 Mbps).

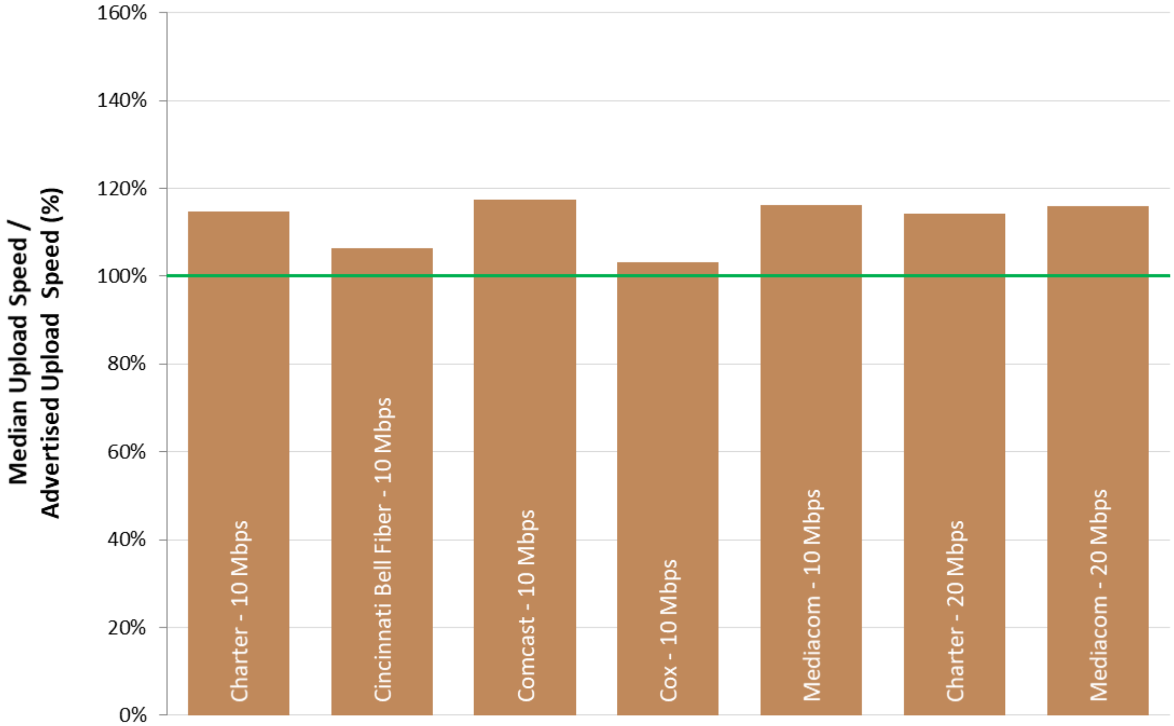


Chart 20.4: The ratio of median upload speed to advertised upload speed, by ISP (30-75 Mbps).

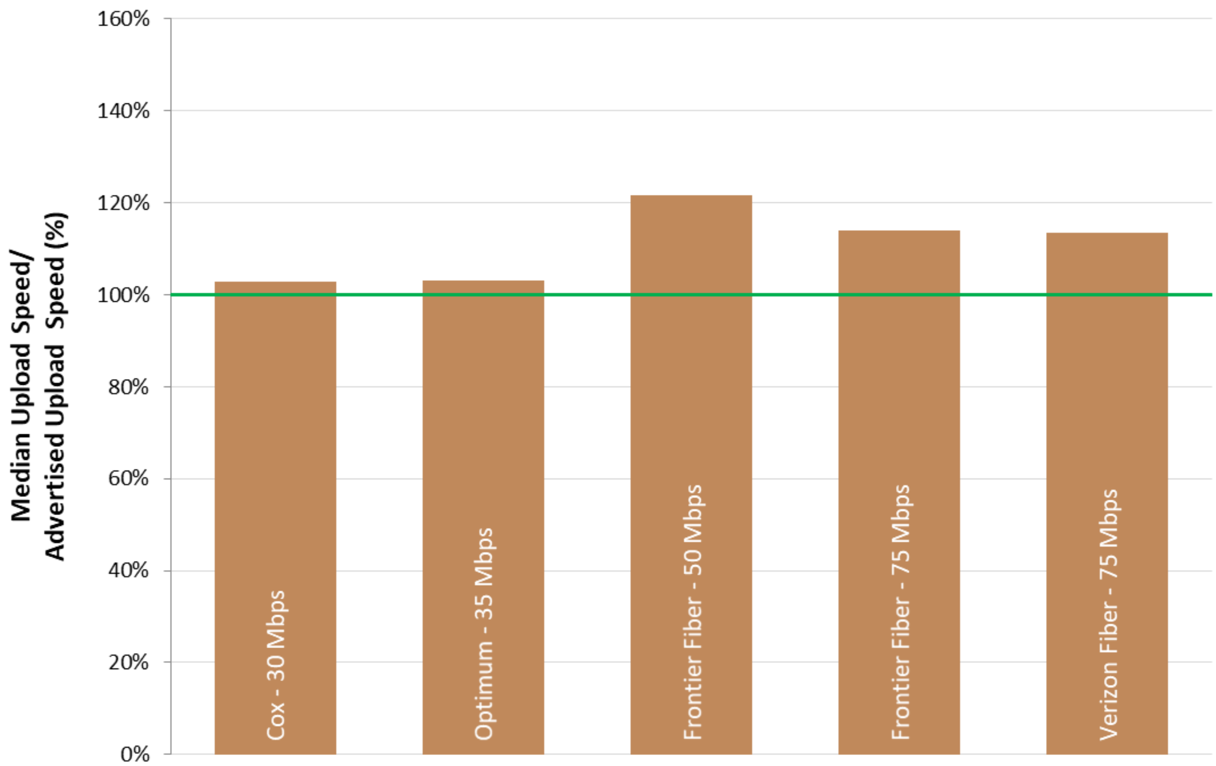


Chart 20.5: The ratio of median upload speed to advertised upload speed, by ISP (100–200 Mbps).

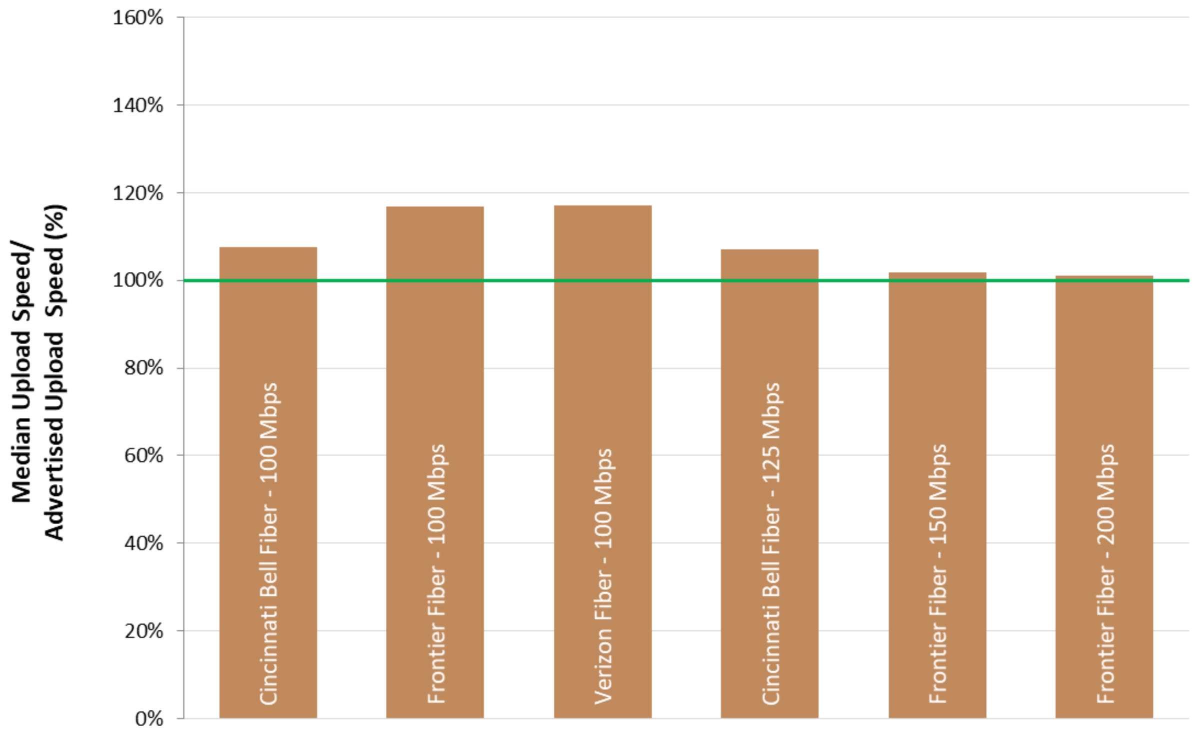


Table 2 lists the advertised download service tiers included in this study. For each tier, an ISP's advertised download speed is compared with the median of the measured download speed results. As we noted in the past reports, the download speeds listed here are based on national averages and may not represent the performance experienced by any particular consumer at any given time or place.

Table 2: Peak period median download speed, sorted by actual download speed

ISP	Advertised Download Speed (Mbps)	Download Median Speed (Mbps)	Actual Speed / Advertised Speed (%)
CenturyLink	1.5	1.22	81.26%
Frontier DSL	3	2.56	85.23%
CenturyLink	3	2.67	88.97%
Windstream	3	2.66	88.54%
Cincinnati Bell DSL	5	3.94	78.71%
Frontier DSL	6	5.72	95.36%
CenturyLink	7	6.35	90.71%

CenturyLink	10	9.17	91.75%
Windstream	10	10.57	105.71%
Frontier DSL	12	11.47	95.54%
CenturyLink	12	11.83	98.57%
CenturyLink	20	18.86	94.31%
Windstream	25	26.02	104.07%
Cox	30	35.22	117.39%
CenturyLink	40	38.37	95.92%
Cincinnati Bell Fiber	50	46.76	93.52%
Frontier Fiber	50	55.98	111.97%
Mediacom	60	79.53	132.55%
Comcast	60	70.61	117.69%
Frontier Fiber	75	81.03	108.04%
Verizon Fiber	75	81.65	108.87%
Charter	100	114.58	114.58%
Verizon Fiber	100	99.53	99.53%
Mediacom	100	128.36	128.36%
Optimum	100	114.21	114.21%
Frontier Fiber	100	99.10	99.10%
Frontier Fiber	150	147.23	98.15%
Comcast	150	176.36	117.57%
Charter	200	230.37	115.18%
Mediacom	200	246.89	123.45%
Optimum	200	220.63	110.32%
Frontier Fiber	200	200.07	100.04%
Cincinnati Bell Fiber	250	271.85	108.74%
Comcast	250	289.35	115.74%
Cox	300	327.92	109.31%
Charter	400	458.87	114.72%
Cincinnati Bell Fiber	500	499.15	99.83%

E. VARIATIONS IN SPEED

In Section 3.C above, we present speed consistency metrics for each ISP based on test results averaged across all service tiers. In this section, we provide detailed speed consistency results for each ISP's individual service tiers. Consistency of speed is important for services such as video streaming. A significant reduction in speed for more than a few seconds can force a reduction in video resolution or an intermittent loss of service.

Charts 21.1 – 21.3 below show the percentage of consumers that achieved greater than 95%, between 85% and 95%, or less than 80% of the advertised download speed for each ISP speed tier. Consistent with past performance, ISPs using DSL technology frequently fail to deliver advertised service rates. ISPs quote a single 'up-to' speed, but the actual speed of DSL depends on the distance between the subscriber and the serving central office.

Cable companies, in general, showed a high consistency of speed.

Chart 21.1: The percentage of consumers whose median download speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised download speed, by service tier (DSL).

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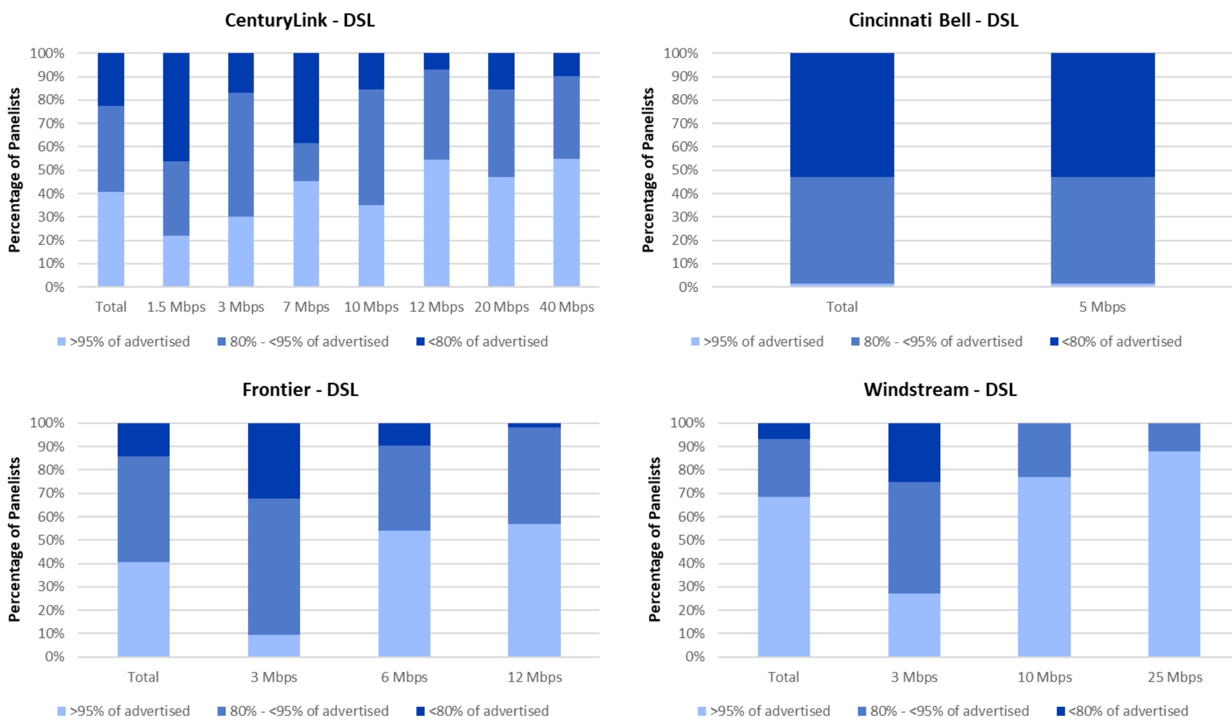


Chart 21.2: The percentage of consumers whose median download speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised download speed (cable).

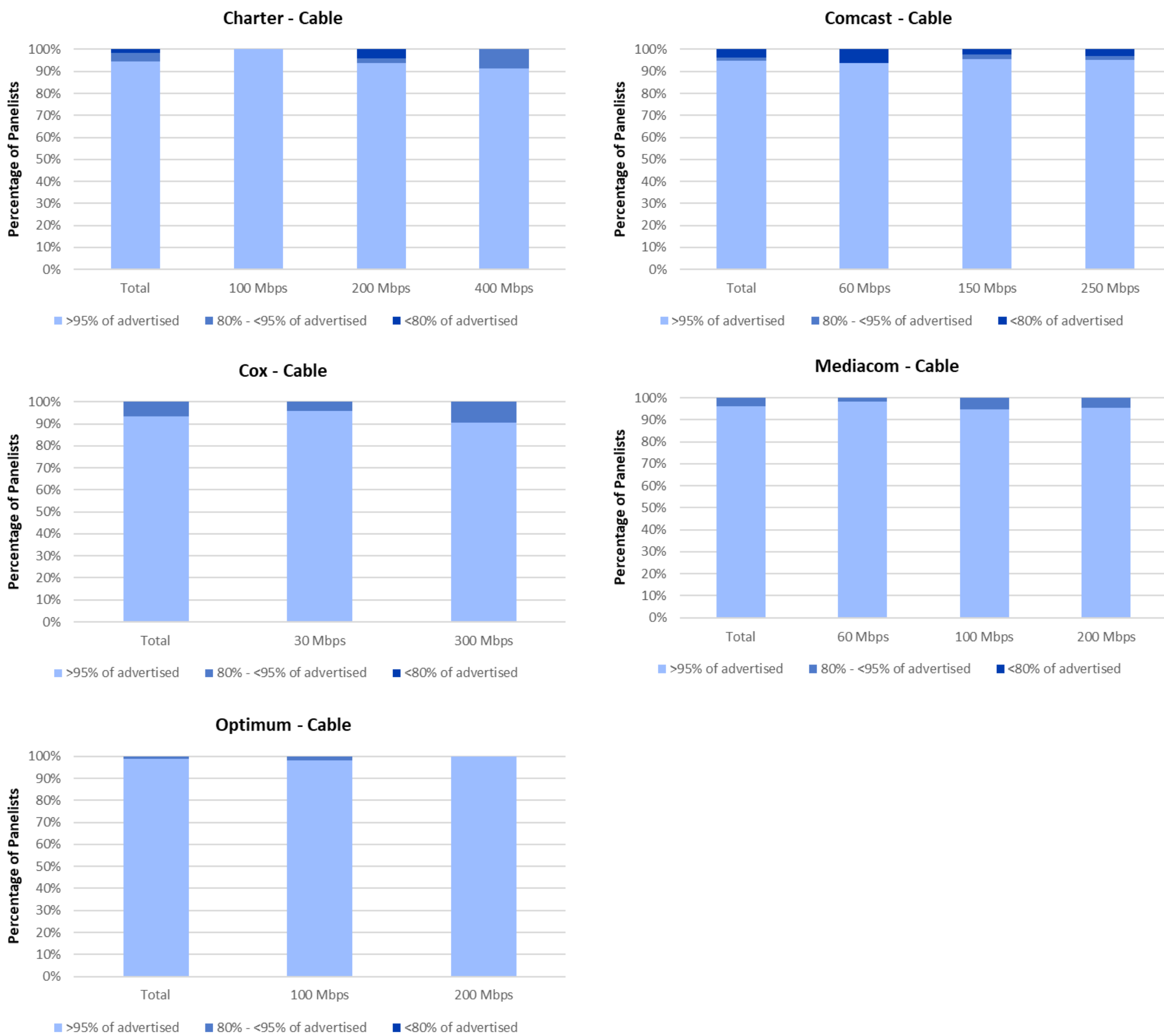
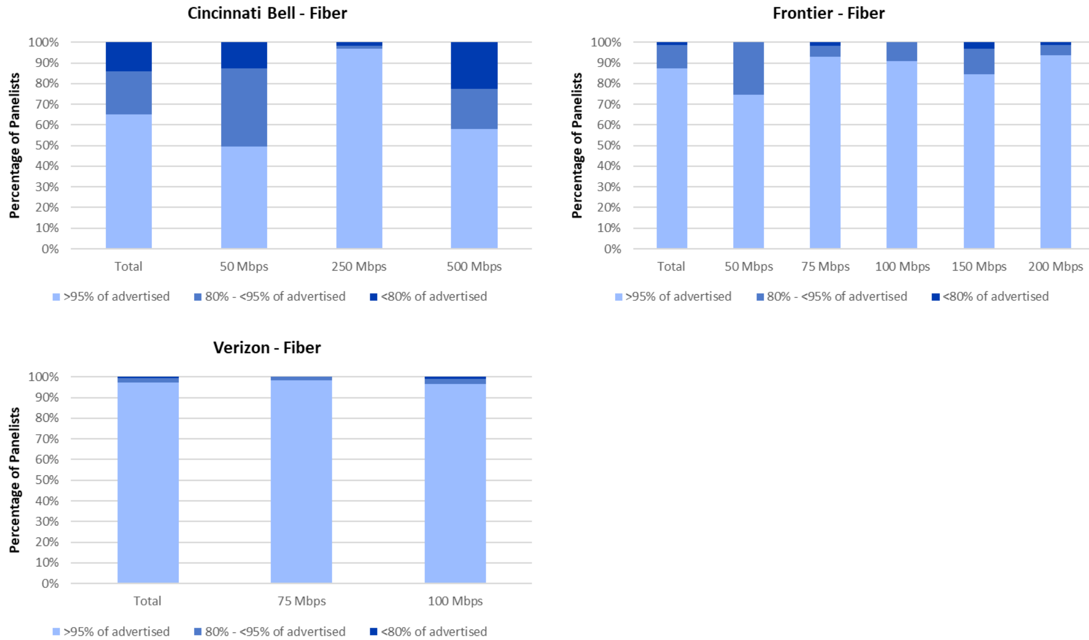


Chart 21.3: The percentage of consumers whose median download speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised download speed (fiber).



Similarly, Charts 22.1 to 22.3 show the percentage of consumers that achieved greater than 95%, between 85% and 95%, or less than 80% of the advertised upload speed for each ISP speed tier.

Chart 22.1: The percentage of consumers whose median upload speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised upload speed (DSL).

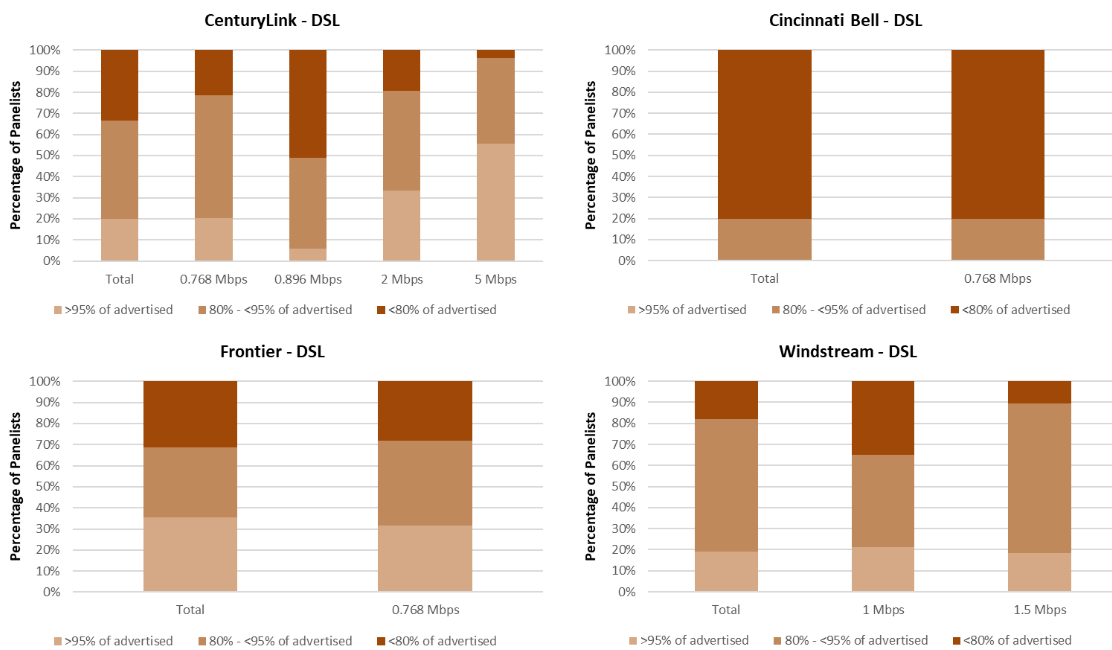
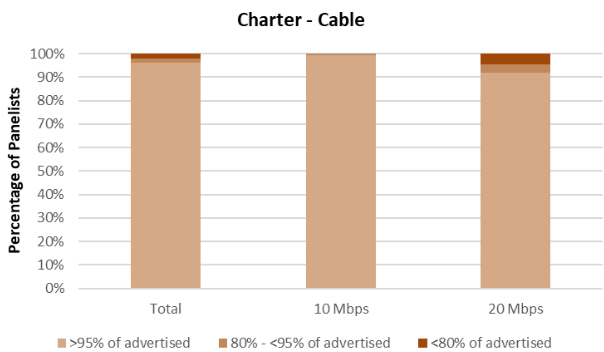
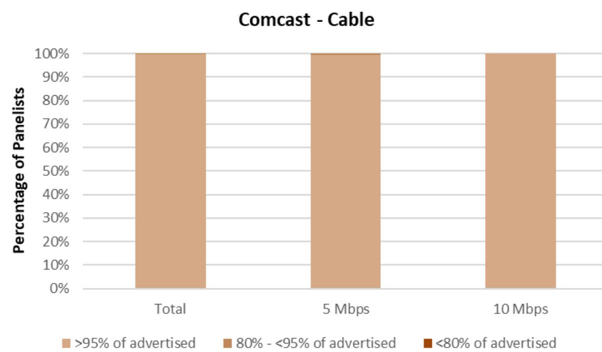
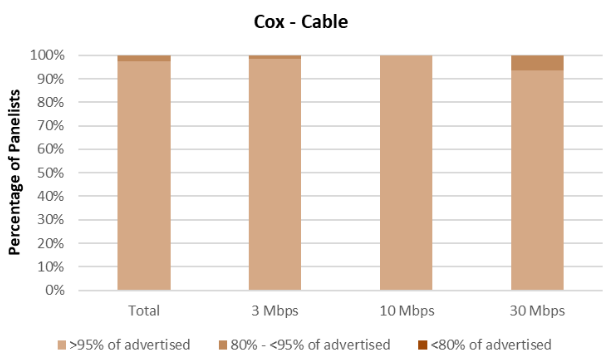
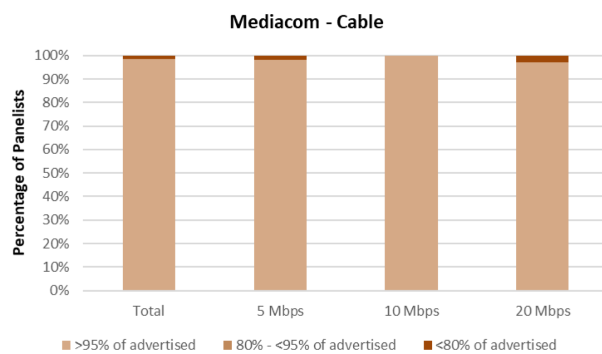


Chart 22.2: The percentage of consumers whose median upload speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised upload speed (cable).









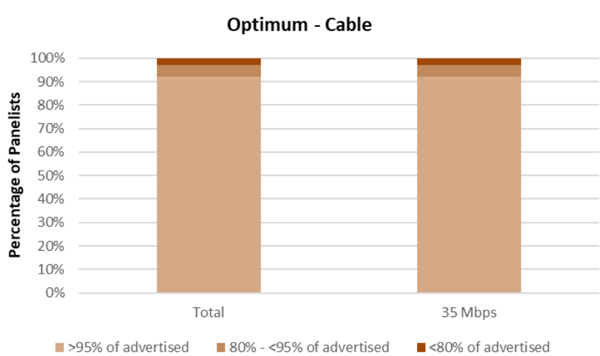
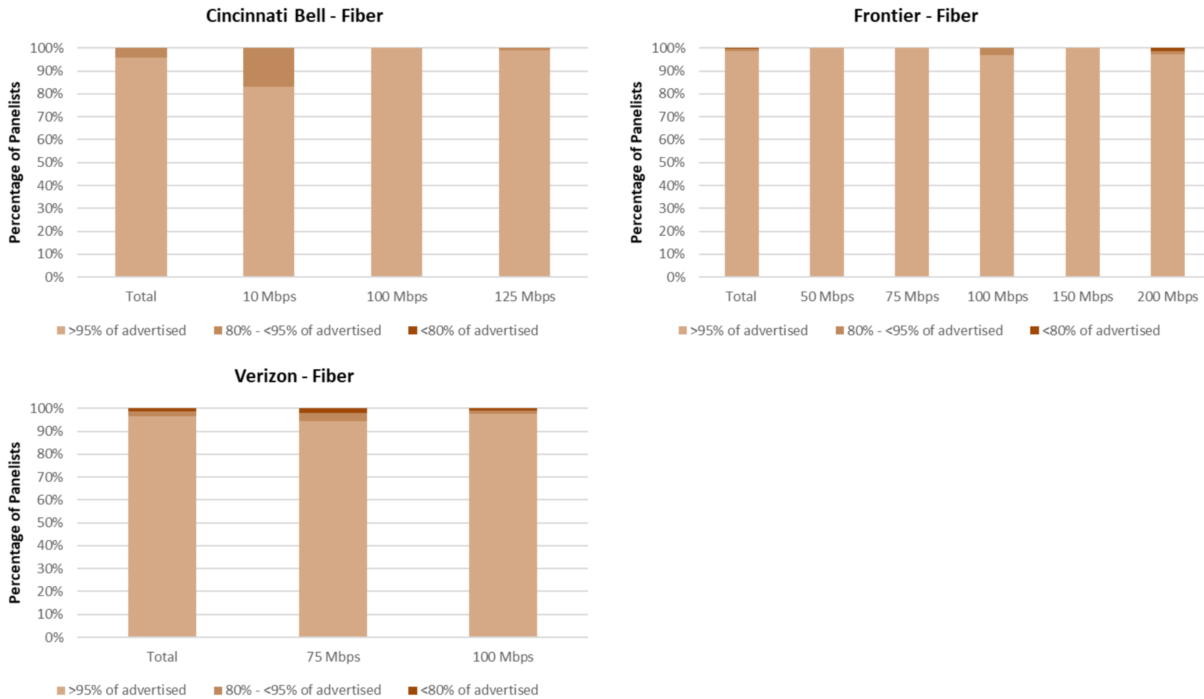


Chart 22.3: The percentage of consumers whose median upload speed was greater than 95%, between 80% and 95%, or less than 80% of the advertised upload speed (fiber).



In Section 3.C above, we present complementary cumulative distributions for each ISP based on test results across all service tiers. Below, we provide tables showing selected points on these distributions by each individual ISP. In general, DSL technology showed performance between 25% and 77% of advertised speed for at least 95% of their subscribers. Among cable-based companies, the average download speeds that at least 95% of their subscribers received were between 92% and 100% of advertised rates. Fiber-based services provided a range from 71% to 96% of advertised download speeds for at least 95% of subscribers.

Table 3: Complementary cumulative distribution of the ratio of median download speed to advertised download speed by ISP.

ISP	20%	50%	70%	80%	90%	95%
CenturyLink	101.5%	91.3%	82.7%	78.2%	68.6%	60.9%
Cincinnati Bell Fiber	108.8%	106.8%	91.7%	84.4%	75.9%	71.3%
Cincinnati Bell DSL	84.7%	78.7%	63.9%	50.1%	31.9%	24.5%
Charter	117.0%	115.0%	113.0%	110.6%	104.5%	94.1%
Comcast	118.5%	117.1%	115.0%	113.5%	107.5%	95.1%
Cox	117.9%	113.5%	110.0%	106.8%	102.4%	92.4%
Frontier Fiber	108.5%	99.5%	98.3%	96.4%	94.3%	92.7%

Frontier DSL	104.2%	93.0%	87.0%	83.6%	78.9%	66.6%
Mediacom	133.0%	130.3%	123.1%	116.5%	108.1%	99.8%
Optimum	114.6%	112.8%	110.2%	108.2%	101.9%	99.7%
Verizon Fiber	108.6%	99.9%	99.3%	98.6%	97.7%	96.3%
Windstream	106.6%	100.1%	94.9%	89.2%	82.2%	77.2%

Table 4: Complementary cumulative distribution of the ratio of median upload speed to advertised upload speed by ISP.

ISP	20%	50%	70%	80%
CenturyLink	94.9%	83.7%	78.6%	75.1%
Cincinnati Bell Fiber	107.6%	107.0%	106.7%	106.4%
Cincinnati Bell DSL	79.9%	76.7%	72.4%	71.5%
Charter	116.1%	114.5%	112.5%	110.3%
Comcast	118.6%	117.5%	117.1%	116.6%
Cox	103.4%	103.0%	102.3%	101.5%
Frontier Fiber	119.1%	104.7%	101.7%	100.9%
Frontier DSL	100.7%	89.7%	79.5%	74.0%
Mediacom	122.6%	115.9%	113.7%	113.0%
Optimum	104.1%	103.1%	102.2%	101.3%
Verizon Fiber	118.5%	117.0%	116.4%	113.0%
Windstream	94.9%	91.5%	89.1%	83.3%

F. WEB BROWSING PERFORMANCE, BY SERVICE TIER

Below, we provide the detailed results of the webpage download time for each individual service tier of each ISP. Generally, website loading time decreased steadily with increasing tier speed until a tier speed of 25 Mbps and does not change markedly above that speed.

Chart 23.1: Average webpage download time, by ISP (1.5-5 Mbps).

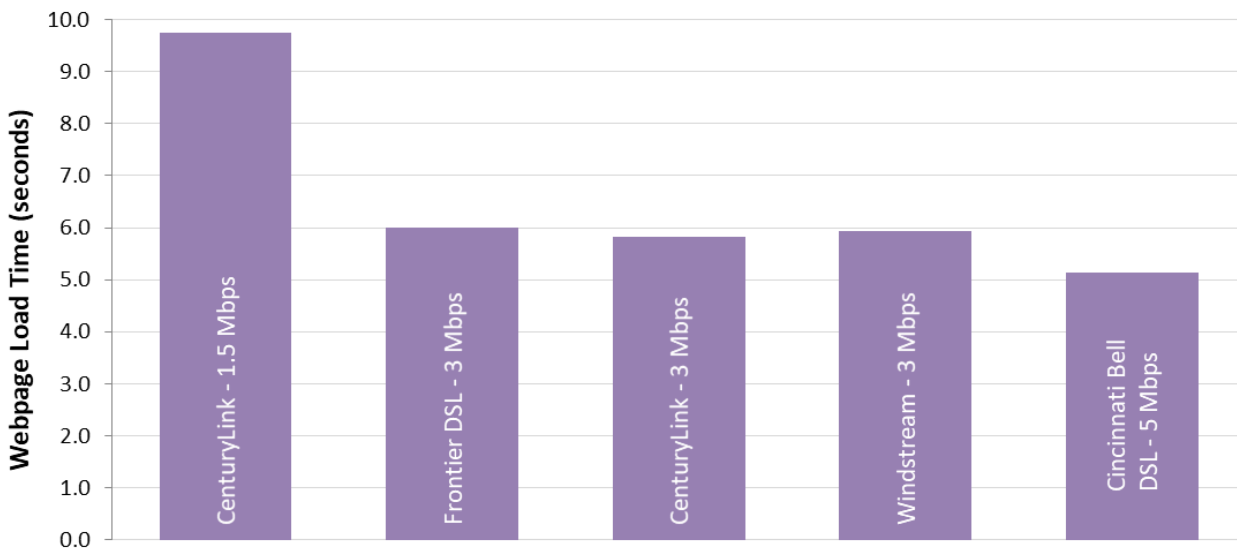


Chart 23.2: Average webpage download time, by ISP (6-10 Mbps).

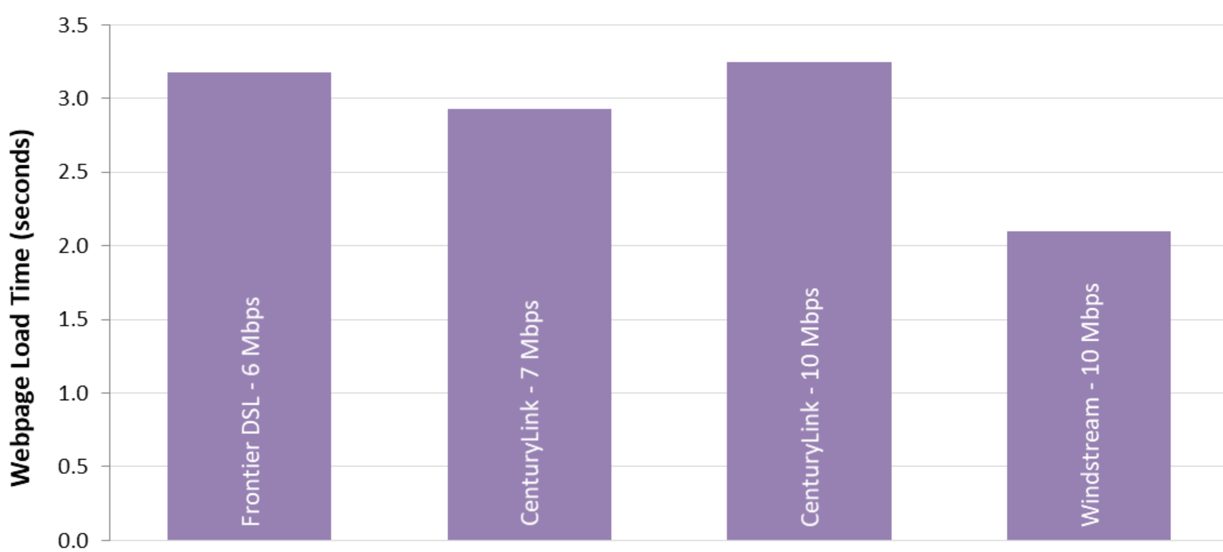


Chart 23.3: Average webpage download time, by ISP (12-25 Mbps).

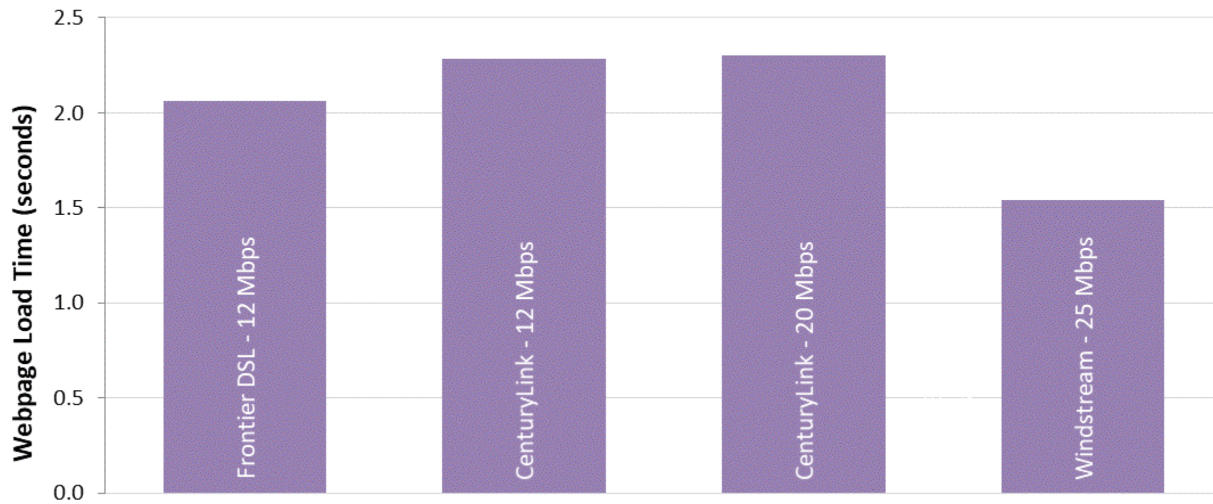


Chart 23.4: Average webpage download time, by ISP (30-60Mbps).

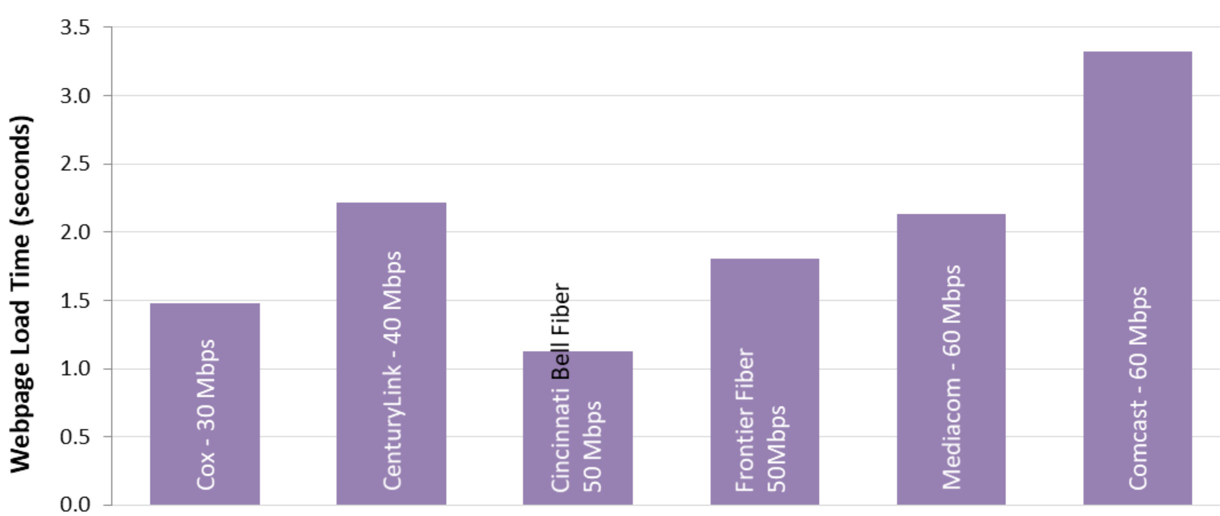


Chart 23.5: Average webpage download time, by ISP (75 - 100 Mbps).

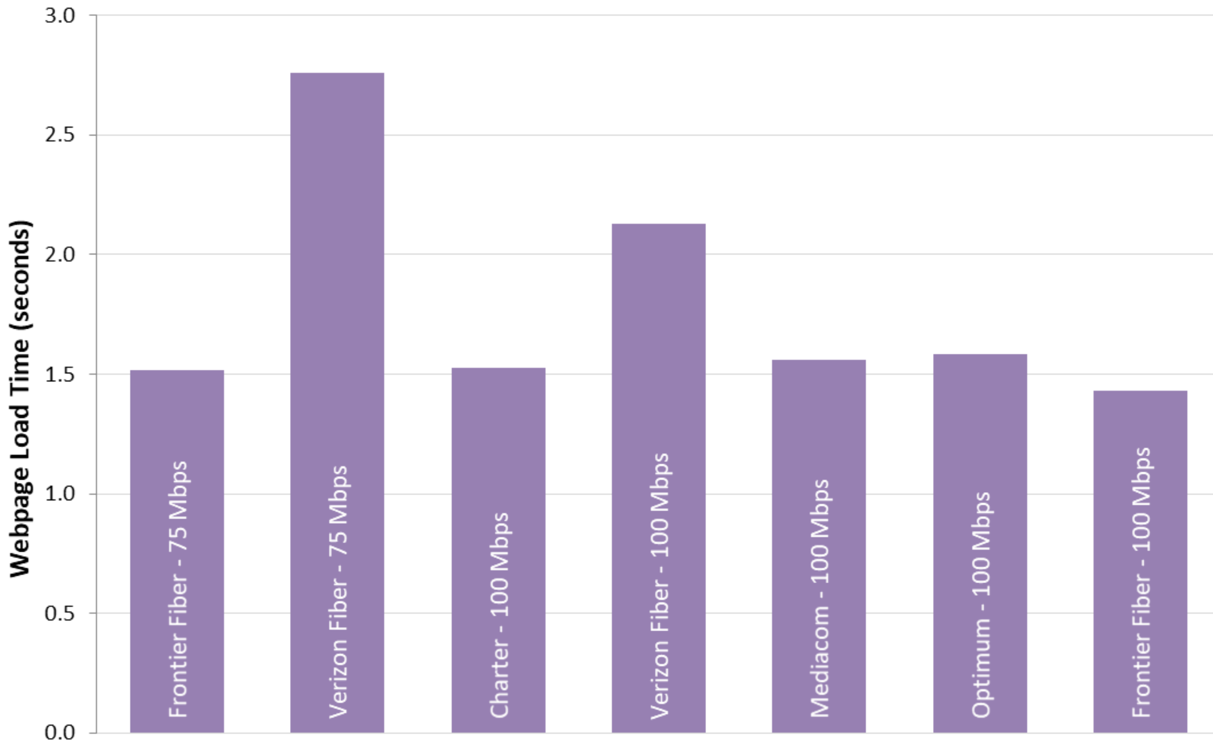


Chart 23.6: Average webpage download time, by ISP (150 - 200 Mbps).

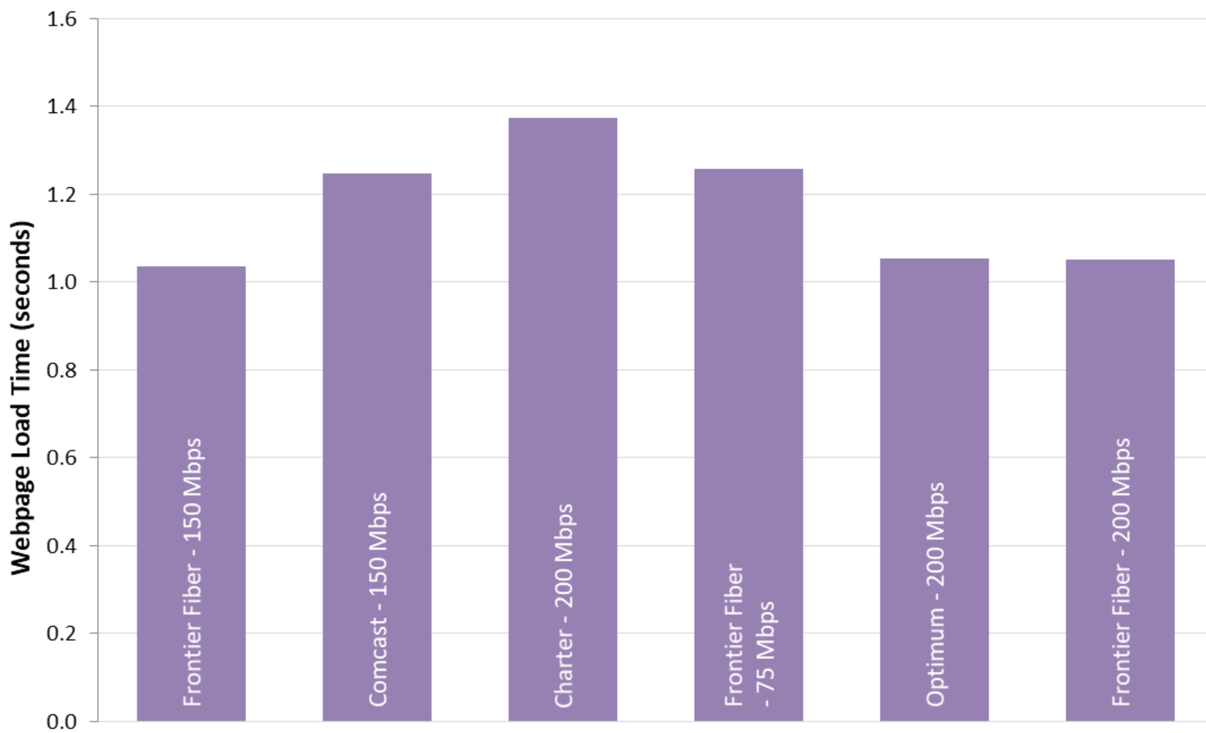


Chart 23.7: Average webpage download time, by ISP (250 - 500 Mbps).