Measuring Broadband America

A Report on Consumer Wireline Broadband Performance in the U.S.

FCC's Office of Engineering and Technology and
Consumer and Governmental Affairs Bureau

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Executive Summary

To make informed choices about purchasing and using broadband, consumers need to have access to basic information about broadband performance. Will a particular offering allow me to browse the web quickly and easily? Will it enable me to use new applications that help me maintain my health, search for a job, or take courses online? What should I look for in a provider if I want to watch high definition online video or play online video games? Does a given speed tier have sufficient upload capacity to enable video conferencing? Will a higher speed, higher priced service improve my Internet experience? Can I get by with a lower priced service? And does the speed a provider advertises match the actual speed I will receive at my home? To help answer these questions, this Report presents the results of the first rigorous, nationwide study of actual home broadband performance in the United States.

Currently, information that would allow consumers to answer these questions is not readily available in a consistent and easily understandable form, and studies show that consumers' awareness of their broadband service and its characteristics is limited. A recent FCC survey found that 80 percent of consumers did not know what speed they purchased from their Internet Service Provider (ISP),[1] and during the course of the study outlined below, we found that a more modest but still sizable 49 percent of consumer volunteers inaccurately reported the advertised broadband speed they believed they had purchased from their ISP. Another study conducted in 2010 found that 13 percent of consumers who have broadband in the home do not know whether they purchased a basic or premium service.[2]

This lack of consumer awareness of basic elements of broadband performance led to the recommendation in the National Broadband Plan (NBP), released last year, that the Commission undertake several initiatives to help improve the availability of information for consumers.[3]

As part of the NBP, in March of 2010 the FCC made available a consumer-initiated online test of broadband speed.[4] The purpose of the Consumer Broadband Test is to give consumers additional information about the quality of their broadband connections across their chosen ISPs' networks and to increase awareness about the importance of broadband quality in accessing content and services over the Internet. The Consumer Broadband Test has gathered data about how well the Internet is functioning, both generally and for specific ISPs at specific times. But the results of the software-based Consumer Broadband Test do not always capture the baseline connection quality provided by the consumer's broadband service: the core connectivity between an ISP and its subscribers, rather than between the rest of the Internet and those subscribers. For instance, results of software-based tests can vary depending on the end user's computer, the type of connection between the end user's computer and the ISP's network (*e.g.*, the use of an in-home WiFi router may affect test results), the number of end user devices connected to a broadband service, and the physical distance of the end user from the testing server. Additionally, there is no standard testing methodology for software-based broadband performance tests, and the Consumer Broadband Test therefore uses two

alternative testing methodologies, which also affects the results.[5] In order to assess the speed claims made by ISPs, and to see how particular activities – such as browsing the web or watching streaming video – are impacted by different speeds, we decided to complement the more general Consumer Broadband Test with more consistent tests of the speed of broadband delivered to American homes.

The Commission has opened a public inquiry into the availability of information regarding broadband performance. Specifically, the Commission has issued a Notice of Inquiry on the topic of general consumer information and disclosure requirements,[6] which sought comment on the types of information that consumers need to make informed choices. In April 2011, the Commission also issued a Public Notice seeking input on the particular types of information that are most useful to consumers in assessing which broadband services to purchase, and in particular which technical parameters have the most significant effects on common consumer uses for broadband.[7]

This Report responds to another NBP recommendation: that the Commission obtain and publicly release detailed and accurate measurements of consumer broadband performance on a national level.[8] Such measurements can help inform consumers and create a mechanism for checking ISP broadband performance claims and for comparing ISPs in meaningful ways.

This Report presents results of the first nationwide performance study of residential wireline (or "fixed," as opposed to mobile) broadband service in the United States using measurement technology deployed in the consumer's home, focusing on three technologies—digital subscriber line (DSL), cable, and fiber-to-the-home.[9] The study examined service offerings from 13 of the largest broadband providers[10]—which collectively account for approximately 86 percent of all U.S. wireline broadband connections—using automated, direct measurements of broadband performance delivered to the homes of thousands of volunteer broadband subscribers during March 2011.[11] This Report focuses on major findings of this study, while a separate Appendix provides a detailed description of the process by which the measurements were made and describes each test that was performed. In addition, the Commission is making available the following resources: electronic copies of the charts included in the Report; data sets for each of the charts in the Report; resources regarding the underlying methodology by which the data was collected and calculated; tabular results for each test performed and data sets for recorded data for March 2011; and the complete raw bulk data set for all tests run during the testing period.[12]

The results contained in this Report will enable consumers to compare the actual performance of different broadband offerings with a new level of detail and accuracy. In addition, the methodology developed in this study can serve as a tool to help broadband providers, including those that did not participate in this process, measure and disclose accurate information regarding the performance of their broadband services. The Appendix and the complete raw bulk data set will be useful to the research community in examining performance characteristics of broadband services in the United States, and in encouraging the development of new broadband performance testing methodologies in the future. We hope that

independent investigation of this data set will provide additional insights into consumer broadband services.

Unless explicitly stated otherwise, all of the findings in this Report reflect performance during the peak consumer usage hours of weekdays from 7:00 pm - 11:00 pm local time. We focus on this period of time since it is during such "busy periods" that consumer usage of broadband services is greatest and it is also during this period that the greatest performance degradation occurs.

Throughout this Report we use the term "advertised speed" to refer to the speed ISPs use to advertise and market a particular broadband service, *e.g.*, "1.5 Mbps[13] DSL" versus "7 Mbps DSL." Generally ISPs do not expressly guarantee advertised speeds, but rather may describe an advertised speed as an "up to" speed, suggesting that consumers can expect to experience performance up to the advertised speed, with actual performance varying based upon network conditions and other factors.

We also use the term "sustained speed" throughout this Report. Broadband Internet access service is "bursty" in nature. On a short time scale, broadband speeds or information rates may vary widely, at times approaching or even exceeding advertised speeds and at other times—due to network congestion—slowing to rates which may be well below advertised speeds. In this Report, to provide an estimate of long-term average broadband performance, we define sustained speed as speed averaged over a period of several seconds (note that sustained speed does *not* necessarily mean that actual speed stays above the sustained speed average for the entire period).[14]

Based on the foregoing, the major findings of this study include the following:

- Actual versus advertised speeds. For most participating broadband providers, actual download speeds are substantially closer to advertised speeds than was found in data from early 2009 and discussed in a subsequent FCC white paper, though performance can vary significantly by technology and specific provider.[15]
- Sustained download speeds. The average[16] actual sustained download speed during the peak period was calculated as a percentage of the ISP's advertised speed. This calculation was done for different speed tiers offered by each ISP.
    - *Results by technology*:
        - On average, during peak periods DSL-based services delivered download speeds that were 82 percent of advertised speeds, cable-based services delivered 93 percent of advertised speeds, and fiber-to-the-home services delivered 114 percent of advertised speeds.[17]
        - Peak period speeds decreased from 24-hour average speeds[18] by .4 percent for fiber-to-the-home services, 5.5 percent for DSL-based services, and 7.3 percent for cable-based services.

- *Results by ISP*. Peak period download speeds varied from a high of 114 percent of advertised speed to a low of 54 percent of advertised speed.
    - Only three ISPs had speed decreases of 10 percent or greater during the peak period (as compared to 24-hour average speeds).

- Sustained upload speeds. Peak period performance results for upload speeds were similar to or better than those for download speeds.
    - Upload speeds were not significantly affected during peak periods, showing an average decrease of only 0.7 percent from the 24-hour average speed.
        - *Results by technology*: On average, DSL-based services delivered 95 percent of advertised upload speeds, cable-based services delivered 108 percent, and fiber-to-the-home services delivered 112 percent.
        - *Results by ISP*: Upload speeds among ISPs ranged from a low of 85 percent of advertised speed to a high of 125 percent of advertised speed.

- Latency. Latency is the time it takes for a packet of data to travel from one designated point to another in a network. Since many communication protocols depend upon an acknowledgement that packets were received successfully, or otherwise involve transmission of data packets back and forth along a path in the network, latency is often measured by round-trip time. Round-trip time is the time it takes a packet to travel from one end point to another, and for an acknowledgement of successful transit to be received back. In our tests, latency is defined as the round-trip time from the consumer's home to the closest[19] server used for speed measurement within the provider's network.
    - During peak periods, latency increased across all technologies by 6.5 percent, which represents a modest drop in performance.
        - *Results by technology*.
            - Latency was lowest in fiber-to-the-home services, and this finding was true across all fiber-to-the-home speed tiers.
            - Fiber-to-the-home services provided 17 milliseconds (ms) round-trip latency on average, while cable-based services averaged 28 ms, and DSL-based services averaged 44 ms.
        - *Results by ISP*. The highest average round-trip latency among ISPs was 75 ms, while the lowest average latency was 14 ms.

- Effect of burst speed techniques. Some cable-based services offer burst speed techniques, marketed under names such as "PowerBoost," which temporarily allocate more bandwidth to a consumer's service. The effect of PowerBoost is temporary—it usually lasts less than 15 to 20 seconds—and may be reduced by other broadband activities occurring within the consumer household.[20] Burst speed is not equivalent to sustained speed. Sustained speed is a measure of long-term performance. Activities such as large file transfers, video streaming, and video chat require the transfer of large amounts of information over long periods of time. Sustained speed is a better measure of how well such activities may be supported. However, other activities such as web browsing or gaming often require the transfer of moderate amounts of information in a short interval of time. For example, a transfer of a web page typically begins with a consumer clicking on the page reference and ceases when the page is fully downloaded. Such services may benefit from burst speed techniques, which for a period of seconds will increase the transfer speed. The actual effect of burst speed depends on a number of factors explained more fully below.
    - Burst speed techniques increased short-term download performance by as much as 52 percent during peak periods for some offerings, and as little as 6 percent for other offerings.
- Web Browsing, Voice over Internet Protocol (VoIP), and Streaming Video
    - *Web browsing*. In specific tests designed to mimic basic web browsing—accessing a series of web pages, but not streaming video or using video chat sites or applications—performance increased with higher speeds, but only up to about 10 Mbps. Latency and other factors limited performance at the highest speed tiers. For these high speed tiers, consumers are unlikely to experience much if any improvement in basic web browsing from increased speed–*i.e.*, moving from a 10 Mbps broadband offering to a 25 Mbps offering.
    - *VoIP*. VoIP services, which can be used with a data rate as low as 100 kilobits per second (kbps) but require relatively low latency, were adequately supported by all of the service tiers discussed in this Report. However, VoIP quality may suffer during times when household bandwidth is shared by other services. The VoIP measurements utilized for this Report were not designed to detect such effects.
    - *Streaming Video*. Test results suggest that video streaming should work well across all technologies tested, provided that the consumer has selected a broadband service tier that matches the quality of streaming video desired. For example, standard video is currently commonly transmitted at speeds below 1 Mbps, while high quality streamed video might require 2 Mbps or more. Consumers should understand the requirements of the streaming video they want to use and ensure that

their chosen broadband service tier will meet those requirements, including when multiple members of a household simultaneously want to watch streaming video on separate devices.

This Report and the accompanying data sets provide a useful foundation for a more comprehensive and ongoing assessment of broadband speeds and reliability, and are a key step in our continuing effort to improve the availability of information regarding broadband performance in the U.S. We hope that broadband providers will adapt the methodology used in this project to develop their own broadband performance testing programs, to incorporate accurate performance measurement tools into their networks, and to improve their ongoing disclosures to consumers. In addition, the FCC plans to continue to study and acquire data on actual mobile broadband performance, which will help consumers, the FCC, and mobile broadband providers better understand actual performance, as the data from this project has done for fixed broadband.

This Report and associated supporting material can be found online as listed below:

Online Resources

- Report and Appendix: http://www.fcc.gov/measuring-broadband-america
- Electronic copies of charts included in Report: http://www.fcc.gov/measuring-broadband-america/charts
- Data sets for each of the charts in the Report: http://www.fcc.gov/validated-march-data-2011
- Resources regarding the underlying methodology by which the data was collected and calculated: http://www.fcc.gov/measuring-broadband-america/methodology
- Tabular results for each test performed and data sets for recorded data for March 2011: http://data.fcc.gov/download/measuring-broadband-america/statistical-averages-2011.xls
- Complete raw bulk data for all tests run during the testing period: http://www.fcc.gov/measuring-broadband-america/raw-bulk-data-2011

Methodology

The study detailed in this Report, which took place from February through June of 2011, represents the first comprehensive analysis of wireline broadband performance in the United States. The techniques used in the study, which are described in more detail below and in the Appendix, were developed through a collaborative process involving 13 major ISPs, academics and other researchers, consultants, and consumer organizations.

It is important to note some limitations in this effort. Only the most popular service tiers within an ISP's offerings were tested, even though some service providers may offer additional tiers.[21] In addition, the data collected is only analyzed at the national level, and does not permit meaningful conclusions about broadband performance at the local level.[22] The results only include measurement of the data path from content source to the consumer, and any bandwidth limitations or delays incurred in the consumer's home or in segments of the Internet outside an ISP's network are not reflected in the results.

For practical reasons, certain consumer broadband technologies are not analyzed in this Report. Mobile broadband services, which are increasingly important to consumers, were not included in this study due to the special challenges inherent in measuring the actual performance of mobile networks. The FCC has issued a Request for Information on measurement approaches for mobile broadband, as well as a Public Notice on this topic,[23] and is undertaking additional efforts to collect performance data on mobile data services. Due to the small number of consumer volunteers for satellite and fixed wireless services in the current study, limited data was collected on these technologies, and consequently these results are not included in this study. However, the data captured for both of these technologies is included in the raw bulk data set.

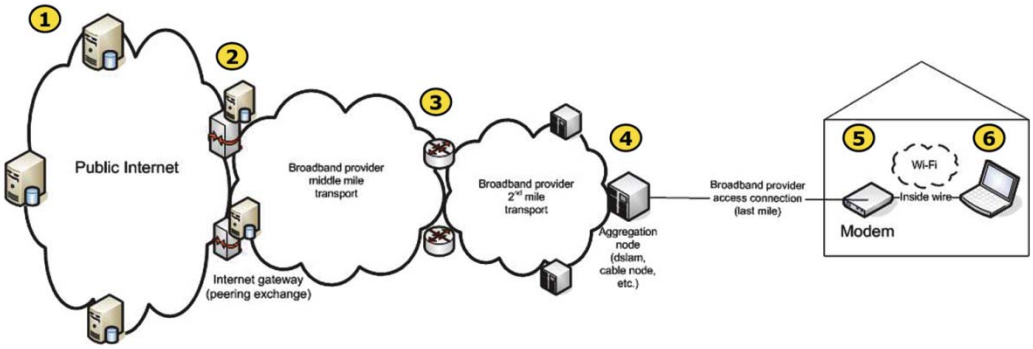
At the outset of this study, the Commission launched an open competition for entities that could assist with the design and management of a study of broadband performance. The FCC ultimately selected SamKnows to administer the FCC's broadband performance testing initiative. SamKnows is an analytics company that had recently completed a similar study of broadband performance for Ofcom, the United Kingdom's telecommunications regulatory agency. In July 2010 Commission staff held an open meeting to announce the start of the project and to seek input from interested parties. At the inaugural and subsequent meetings, industry, consumer groups, and academic attendees expressed an interest in participating in the study.

Overall, 22 stakeholders contributed to this project, including 13 wireline ISPs; academic researchers from MIT and Georgia Tech; technology vendors and consumer groups; and other industry representatives.[24] Most stakeholders, including all participating ISPs, signed a Code of Conduct, included in the Appendix to this Report, which helped ensure the integrity of the study and its results. Participants contributed significantly to this project by, among other things: creating and agreeing on a standard methodology for testing broadband performance; collaborating on the parameters for these tests; providing proposals for how to analyze the

data; validating the panelist information to ensure that the test results were properly correlated to the correct service tier; and developing strategies to maintain the privacy of the panelists and the integrity of the testing. Commission staff also held a number of open meetings where the public was able to express views on the study.

The basic objective of the study was to measure broadband service performance as delivered by an ISP to the home of a consumer. As illustrated below, many factors contribute to end-to-end consumer broadband performance.

Figure 1: Network diagram



DEFINITIONS

1. **Public Internet content:** public Internet content that is hosted by multiple service providers, content providers and other entities in a geographically diverse (worldwide) manner
2. **Internet gateway:** closest peering point between broadband provider and public Internet for a given consumer connection
3. **Link between 2nd mile and middle mile:** broadband provider managed interconnection between middle and last mile
4. **Aggregation node:** First aggregation point for broadband provider (e.g. DSLAM, cable node, satellite, etc.)
5. **Modem:** Customer premise equipment (CPE) typically managed by a broadband provider as the last connection point to the managed network (e.g. DSL modem, cable modem, satellite modem, optical networking terminal (ONT), etc.)
6. **Consumer device:** consumer device connected to modem through internal wire or Wi-Fi (home networking), including hardware and software used to access the Internet and process content (customer-managed)

Not all elements of broadband performance are under the control of the consumer's ISP, and there are factors that affect a consumer's broadband experience that were not measured in this study. For example, broadband performance experienced by the consumer may be affected by the capabilities or limitations of the consumer's own computer or local area network (LAN) devices such as home WiFi routers, or by the performance of the content and application providers the consumer is accessing, such as a search engine or video streaming site. In these instances, the broadband provider is controlling only a portion of the chain that determines the overall performance experienced by the consumer. There are other aspects of broadband performance that are technically outside the ISP's network, but that can be affected by the ISP's behavior, such as peering arrangements, which are the polices by which an ISP exchanges traffic with another ISP. In future performance measurements, it will be important to keep in mind that these arrangements by ISPs—which were not measured in the present study—can

affect broadband performance. The ultimate goal is to know how well consumer broadband is working in actual use conditions.

This study focused on those elements of the Internet pathway under the direct or indirect control of a consumer's ISP on that ISP's own network: from the consumer gateway—the modem used by the consumer to access the Internet—to a nearby major Internet gateway point (from the modem to the Internet gateway in Figure 1, above). This focus aligns with the broadband service advertised to consumers and allows a direct comparison across broadband providers of actual performance delivered to the household.

More than 78,000 consumers volunteered to participate in this study and a total of approximately 9,000 consumers were selected as potential participants and were supplied with specially configured routers. The data in this Report is based on a statistically selected subset of those consumers—approximately 6,800 individuals—and the measurements taken in their homes during March 2011. The participants in the volunteer consumer panel were recruited with the goal of covering ISPs within the U.S. across all broadband technologies, although only results from three major technologies—DSL, cable, and fiber-to-the-home—are reflected in this Report.[25] To account for network variances across the United States, volunteers were recruited from the four Census Regions: Northeast, Midwest, South, and West. Within each Census Region, consumers were selected to represent broadband performance in three typical speed ranges: less than 3 Mbps, between 3 and 10 Mbps, greater than 10 Mbps.[26]

The testing methodology itself required innovation on both the consumer, or "client," side and on the ISP, or "server," side. The server-side infrastructure, which comprised reference measurement points that were distributed geographically across nine different U.S. locations, was made available to SamKnows for the project by M-Lab, a non-profit organization that supports Internet research activities.[27] Each consumer participant's broadband performance was measured from a hardware gateway in his or her household to the off-net test node that had the lowest latency to the consumer's address.

On the "client" side of the test, consumers self-installed a measurement gateway that was provided by SamKnows. These gateways, or "Whiteboxes," were installed between the consumer's computer and Internet gateway and came pre-loaded with custom testing software. The "Whitebox" software was programmed to automatically perform a periodic suite of broadband measurements while excluding the effects of consumer equipment and household broadband activity. This approach permitted a direct measure of the broadband service an ISP delivered to a consumer's household.

The participating ISPs also volunteered to establish two kinds of additional reference measurement points within their own networks. Some ISPs installed a measurement reference point within their networks at a major peering facility, which represented the mirror image of the SamKnows peering reference points. These reference points served as a validity check and verified that the SamKnows measurements were not significantly affected by peering relationships or other network degradations. Some ISPs also installed measurement points at various ISP interior network points that did not correspond to the M-Lab peering locations. These reference points were principally intended to test for performance degradations caused

by bandwidth limitations in "middle mile" segments,[28] or for effects caused by the specific design of the network. Test results demonstrated that measurements from all ISP-installed reference points, regardless of location, agreed closely with the results from the M-Lab peering reference measurements, which strengthens confidence in the results. The general correspondence between results taken from the M-Lab and the independent ISP reference points also suggests that among the ISPs tested, broadband performance that falls short of expectations is caused primarily by the segment of an ISP's network from the consumer gateway to the ISP's core network.[29] The results contained in this Report are based on the measurements obtained from the M-Lab peering reference points only, while the raw bulk data set contains all results, including those from the ISP-only reference points.

Description of Tests Included in Report

The study developed 13 separate measurements that could be used to characterize various aspects of broadband performance to the consumer's home. This Report focuses on results from five of these tests for March 2011. The ISPs participating in the study agreed to base the Report on a full month of data, and following a prove-in period for the testing in February, participants in the study agreed to March as the test month, which afforded sufficient time for subsequent analysis of the data. Active data collection continued after March. Although each of the measurements taken over the course of the testing is useful for making determinations about the state of broadband performance in the U.S., this Report emphasizes two metrics that we believe are of particular interest to consumers: speed and latency.

Broadband throughput or speed, commonly expressed in Megabits/second or Mbps, is the primary performance characteristic advertised by ISPs. Broadband speed is the average rate at which information "packets" are delivered successfully over the communication channel. A higher speed implies a higher information delivery rate. A 10 Mbps service can, in theory, deliver ten times as much information as a 1 Mbps service in a given period of time.

The use of transient performance enhancements such as "PowerBoost," which are available as a part of many cable-based services, present a technical challenge when measuring speed. Services featuring burst techniques will deliver a far higher throughput for the earlier portion of a connection, although the duration of the speed burst may vary by ISP, service tier, and other factors. For example, a user who has purchased a 6 Mbps service tier might receive 18 Mbps for the first 10 megabytes[30] (MB) of a particular download. As supported by our test, this is of significant benefit to applications such as web browsing, which use relatively short-lived connections and transfer short bursts of data. But once the burst window lapses, throughput will return to the base rate, making the burst rate an inaccurate measure of performance for longer, sustained data transfers. In addition, other household broadband activities may decrease or eliminate the benefit of the speed burst. The speed test employed in this study isolated the effects of transient performance-enhancing services such as PowerBoost from the long-term sustained speed, and presents sustained and "boost" speed results separately.

Latency is another key factor in broadband performance. Latency is a measure of the time it takes for information to travel across a segment of a network and is commonly expressed in terms of milliseconds (ms). For practical reasons, latency measurements typically represent the round-trip latency, *i.e.*, from the consumer to the measurement point and back.[31] The impact of latency is felt in a number of ways. For example, high round-trip latencies may compromise the quality of voice services in ways that are perceptible to consumers.[32] Even lower latencies, which may not be directly noticeable by human perception, can still degrade network performance. Computer networks and applications are more sensitive to latency than humans. Latency affects the rate of information transmission for TCP protocol, which is commonly used to support Internet applications, and can therefore limit the maximum speed achievable for a broadband service regardless of the actual service speed. In the interactive

communications found in computing applications, latency is also additive, which means that the delay caused by the sum of a series of latencies adds to the time it takes to complete a computing process. Thus, latency can have a significant effect on the performance of applications running across a computer network. As service speeds increase, the impact of network latency can become more noticeable, and have a more significant impact on overall performance.

One of the key factors that affects all aspects of broadband performance is the time of day. At peak hours, designated for the purpose of this study as between 7:00 pm and 11:00 pm local time on weeknights, more people are attempting to use the Internet simultaneously, giving rise to a greater potential for congestion and degraded user performance. Unless otherwise noted, this Report concentrates on performance during peak hours as the period of highest interest to the consumer, while results for 24-hour averages and weekend performance are included in the Appendix.

This Report highlights the results of the following tests of broadband speed and latency, as measured on a national basis across DSL-, cable-, and fiber-to-the-home technologies:

- **Sustained download speed**: throughput in Mbps utilizing three concurrent TCP connections measured at the 25-30 second interval of a sustained transfer
- **Sustained upload speed**: throughput in Mbps utilizing three concurrent TCP connections measured at the 25-30 second interval of a sustained transfer
- **Burst download speed**: throughput in Mbps utilizing three concurrent TCP connections measured at the 0-5 second interval of a sustained transfer
- **Burst upload speed**: throughput in Mbps utilizing three concurrent TCP connections measured at the 0-5 second interval of a sustained transfer
- **UDP latency**: average round trip time for a series of randomly transmitted user datagram protocol (UDP) packets distributed over a long timeframe

Summary of Findings

We present the summary of our findings below. As noted earlier, the full results of all 13 tests from March 2011 are available at http://www.data.fcc.gov/download/measuring-broadband-america/statistical-averages-2011.xls. The Commission is separately releasing a validated[33] set of the data on which this Report was based, together with a non-validated data set covering the period from February 2011 through June 2011. The results below are reported by performance variation by ISP and by technology (DSL, cable, and fiber-to-the-home), for the most popular service tiers offered by each ISP. We focus on peak periods since this is the period of time when service performance is likely to suffer and it is also the period of highest utilization by the average consumer. As a final note, the results presented below represent average[34] measured performance across a range of consumers, and while these results are useful for comparison purposes, they should not be taken as an indicator of performance for any specific consumer.

PERFORMANCE VARIATION BY ISP AND SERVICE TIER

Chart 1 shows average download performance over a 24-hour period and during peak periods across all ISPs. Most ISPs delivered actual download speeds within 20% of advertised speeds, with modest performance declines during peak periods.[35]

As shown in Chart 2, upload performance is much less affected than download performance during peak periods. Almost all ISPs reach 90 percent or above of their advertised rate, even during peak periods.

Chart 1: Average peak period and 24-hour sustained download speeds as a percentage of advertised, by provider

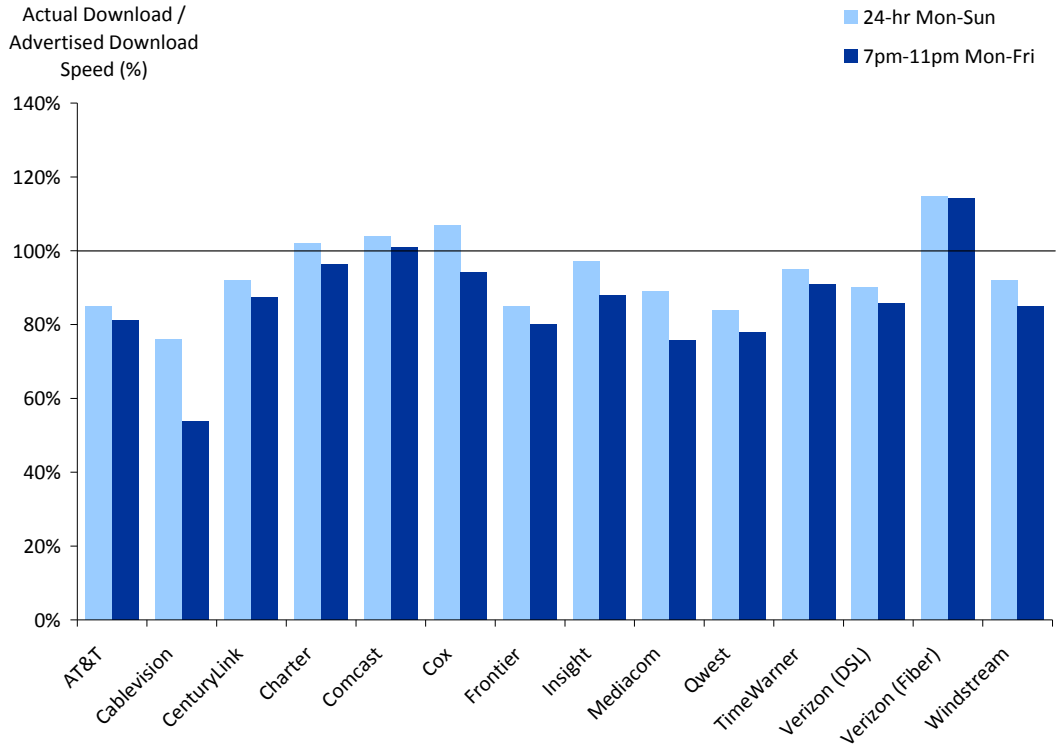
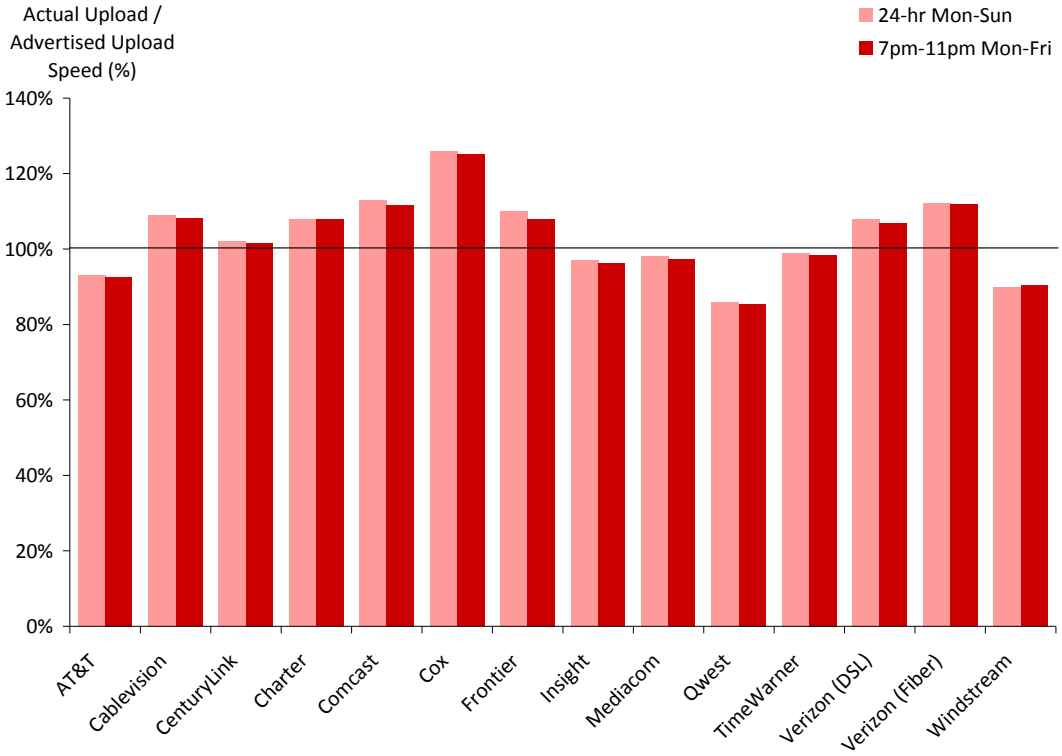
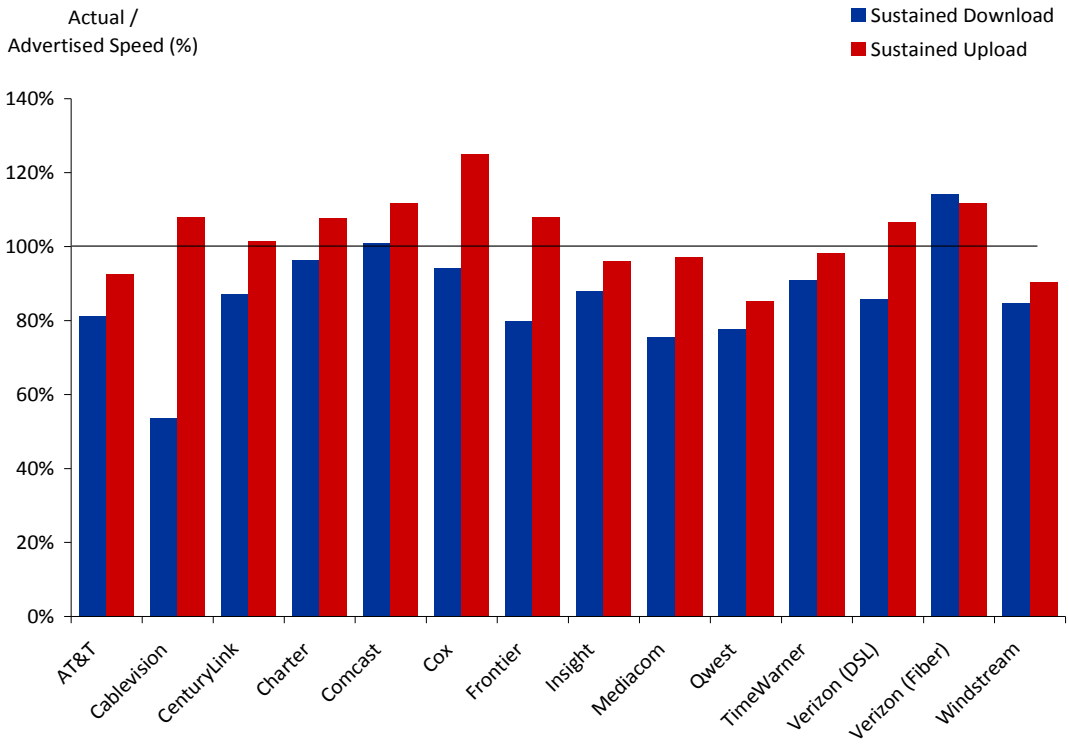


Chart 2: Average peak period and 24-hour sustained upload speeds as a percentage of advertised, by provider



In general, we found that even during peak periods, the majority of ISPs were providing actual speeds that were generally 80 percent or better than advertised rates, though there was considerable variation among the ISPs tested, as shown in Chart 3. As noted previously, performance was also found to vary by technology. Results from a particular company may include different technology platforms (*e.g.*, results for Cox include both their DOCSIS 2.0 and DOCSIS 3.0 cable technologies; results for AT&T include both DSL and U-Verse[36]).

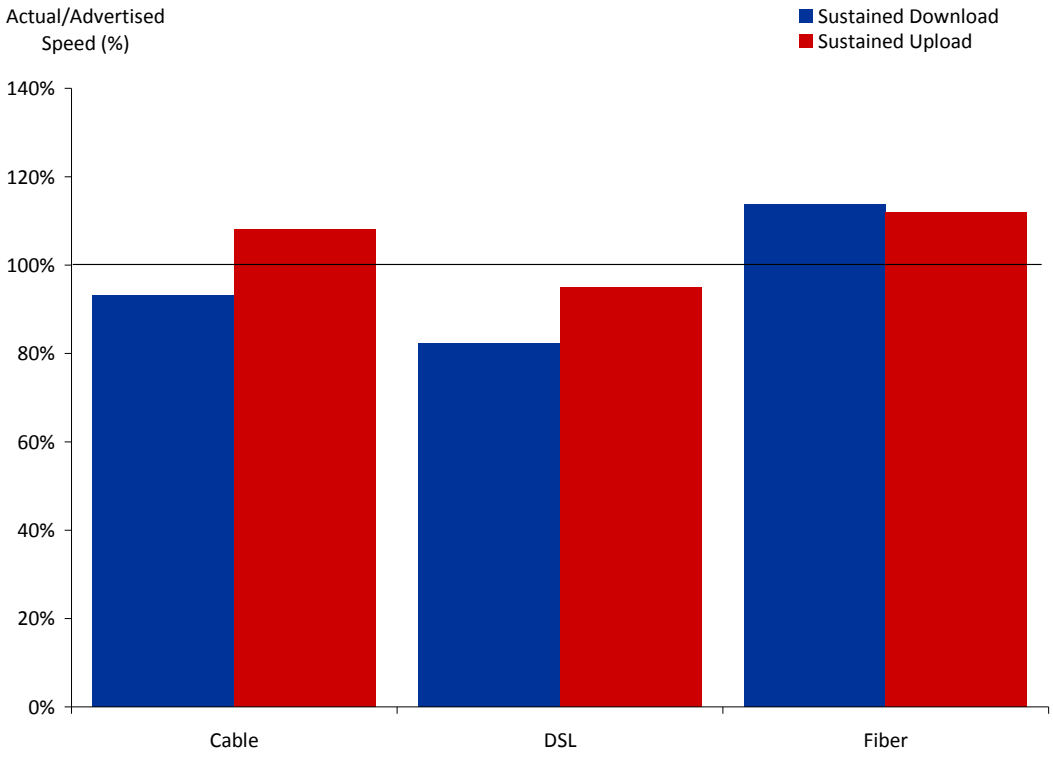
Chart 3: Average peak period sustained download and upload speeds as a percentage of advertised, by provider



PERFORMANCE VARIATION BY ACCESS TECHNOLOGY

As shown in Chart 4, there is some variance in performance by technology during peak periods. DSL on average meets 82 percent of advertised download speed during peak periods, cable meets 93 percent and fiber-to-the-home meets 114 percent of advertised speeds. Upload performance is, as noted, generally better than download performance during peak periods with all technologies meeting advertised upload speeds by 95 percent or better.[37]

Chart 4: Average peak period sustained download and upload speeds as a percentage of advertised, by technology

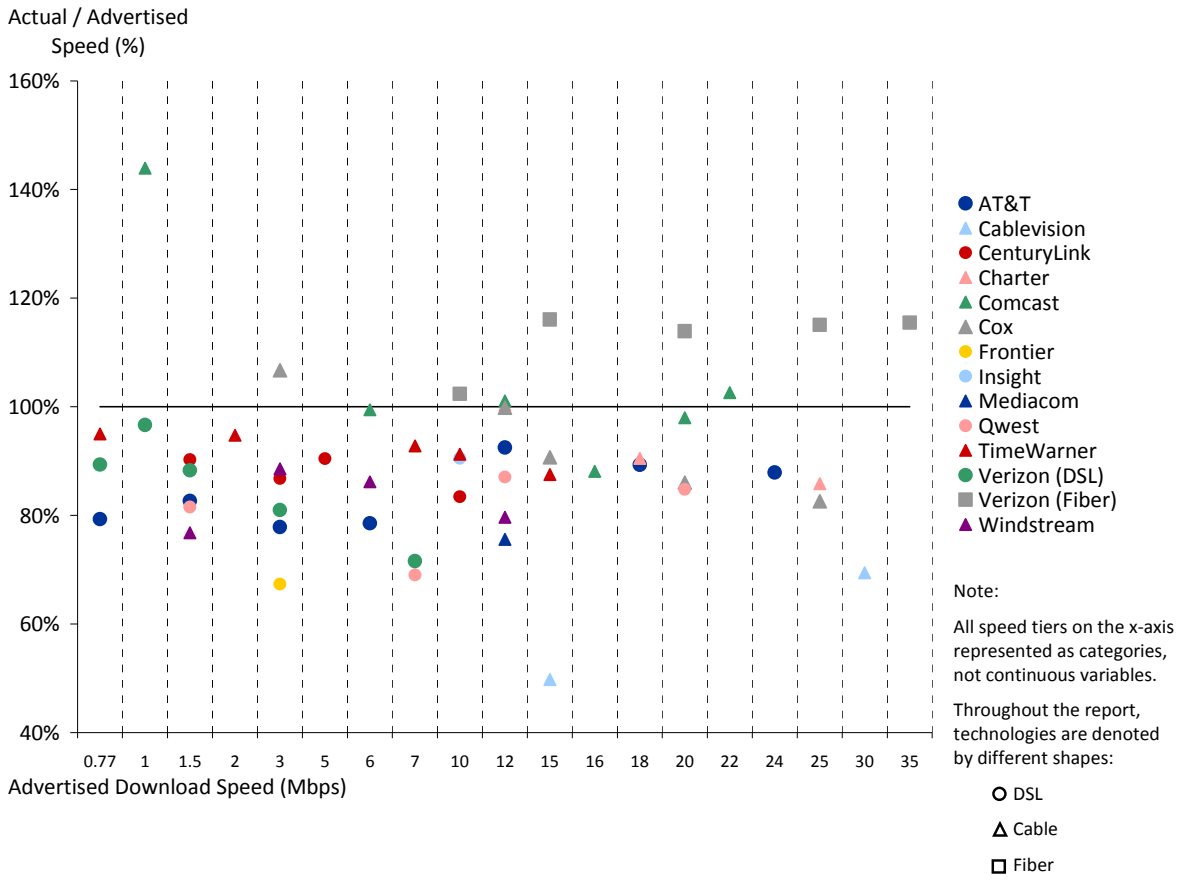


PERFORMANCE VARIATION BY SERVICE TIER

Download Peak Period Throughput

As shown in Chart 5, peak period performance varies by service tier among ISPs included in this study. Even during peak periods, the vast majority of service tiers offer performance levels approximately 80 percent or more of advertised speeds.[38] Fiber-to-the-home services typically outperform other service tiers, offering performance levels approximately 115 percent of advertised rates during peak periods. Other ISPs are either close to or exceed advertised rates.

Chart 5: Average peak period sustained download speeds as a percentage of advertised, by provider

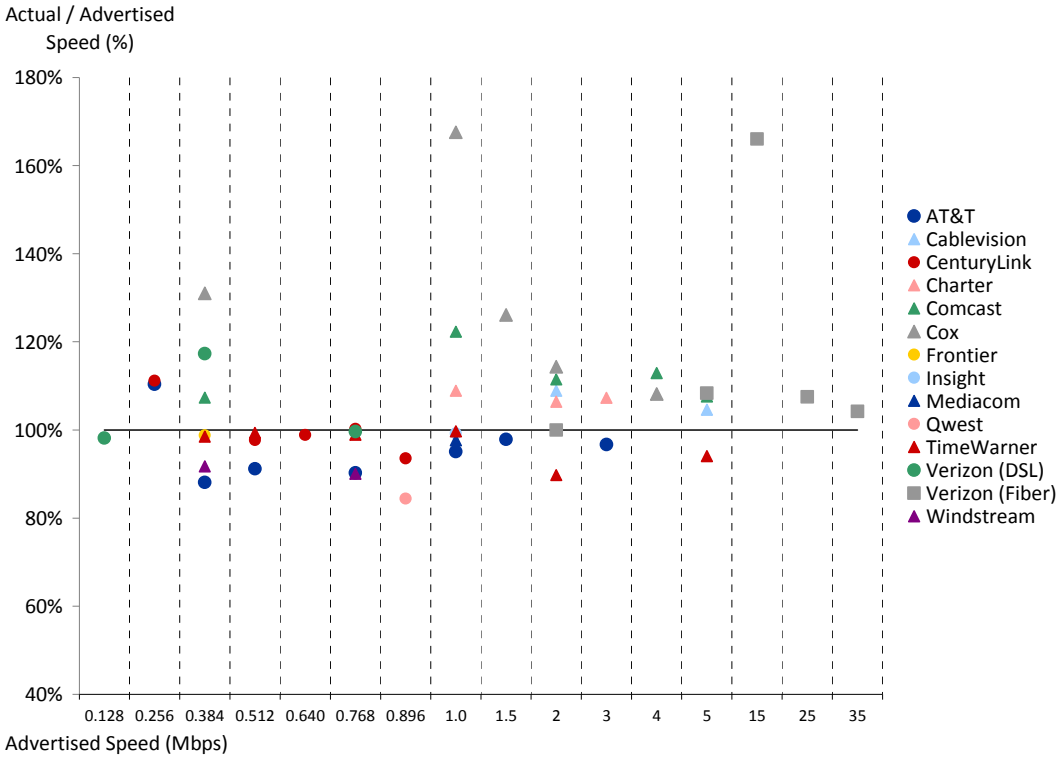


Upload Peak Period Throughput

With the exception of some fiber-to-the-home service offerings, consumer broadband services are typically offered with asymmetric download and upload rates, with the download rate typically many times faster than the upload rate.

In general, the ratio of actual to advertised speed for upload performance is slightly superior to the ratio measured for download performance. Fiber-to-the-home services outperform cable and DSL in upload throughput, with many of the current services available on the market operating at symmetric speeds or speeds that are much closer to symmetric than those offered by their DSL and cable counterparts. On average, all technologies and speed bands deliver at least 84 percent of the advertised upload rate. Many cable service tiers exceed 100 percent of the advertised upstream rate. As with the downstream throughput results, fiber-to-the-home services continually deliver over 100 percent of the advertised upload speeds.

Chart 6: Average peak period sustained upload speeds as a percentage of advertised, by provider



Burst Versus Sustained Download Throughput

Comparing burst download speeds versus advertised speeds demonstrates the effect that burst services such as PowerBoost have on data throughput. For DSL- and fiber-to-the-home services, which do not, in general, employ boost technologies, there are no significant differences between sustained and burst measurements. As can be seen in Chart 7, in contrast, cable services employing boost technology consistently exceed 100 percent of advertised speeds across all speed tiers in which they are offered, achieving as high as 152 percent of advertised speed for one service. Chart 7 also shows that the effectiveness of burst technology varies among cable ISPs.

Chart 7: Average peak period burst download speeds as a percentage of advertised speed, by provider

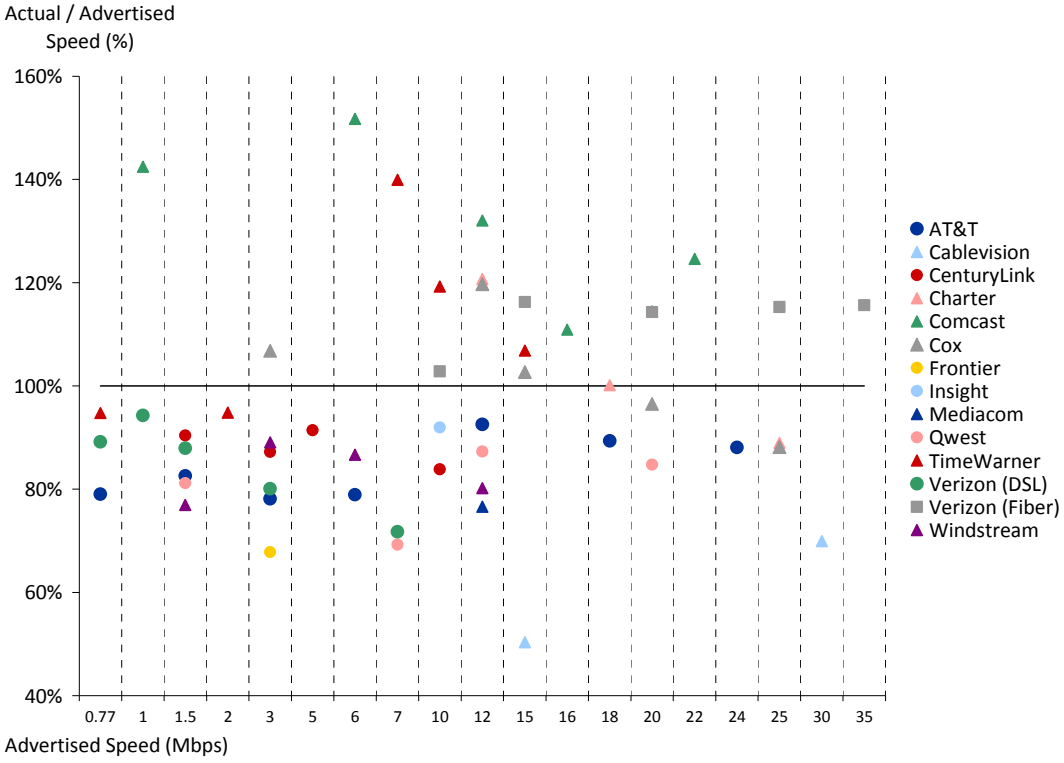
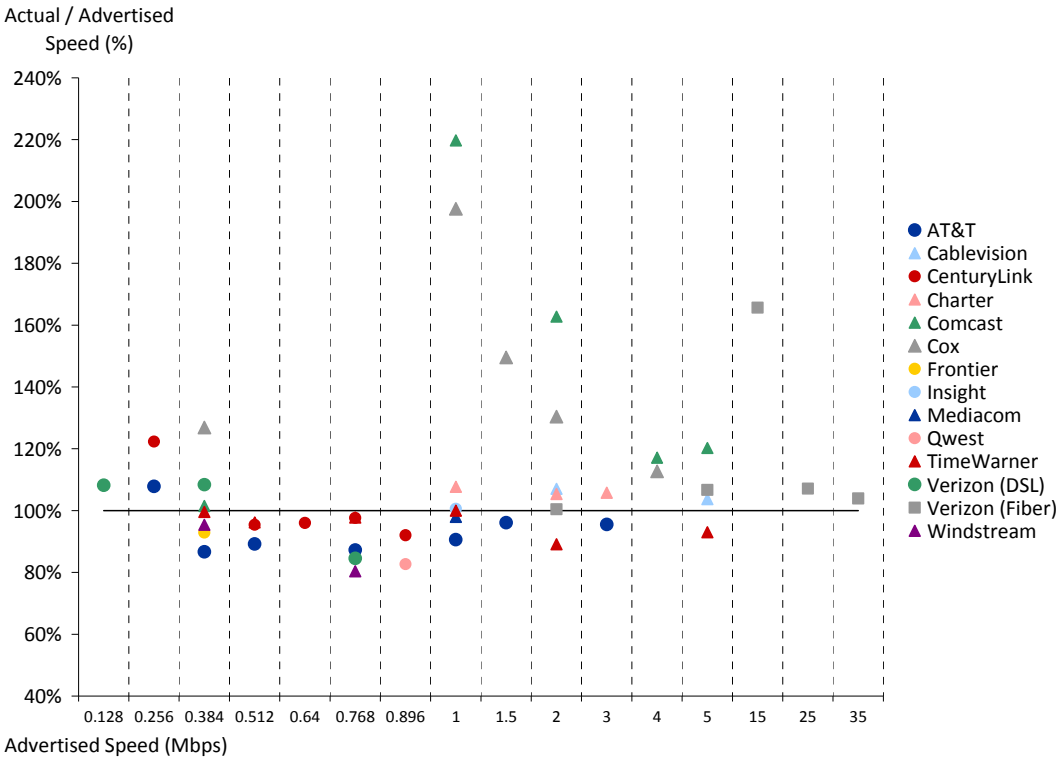


Chart 8: Average peak period burst upload speed as a percentage of advertised speed, by provider



The use of transient performance boosting features such as PowerBoost is less prevalent for upstream connections. The test results found marked improvement in burst upload speeds on some but not all service tiers, suggesting that PowerBoost might be applied to upstream performance by at least one or more ISPs. For example, in Chart 8, Cox and Comcast achieve average rates in the range of 130 percent to over 200 percent in service tiers ranging from 1 Mbps to 2 Mbps.

Latency

As can be seen from Chart 9,[39] latency varies by technology and by service tier.[40] Fiber-to-the-home has the best performance in terms of latency, with a 17 ms average during the peak period, cable averages 28 ms, and DSL averages 44 ms and ranges as high as approximately 75 ms.[41] Although the test results found variance in latencies among technologies, all of the latencies measured here should be adequate for common Internet applications such as VoIP.

Chart 9: Average peak period latency in milliseconds, by technology

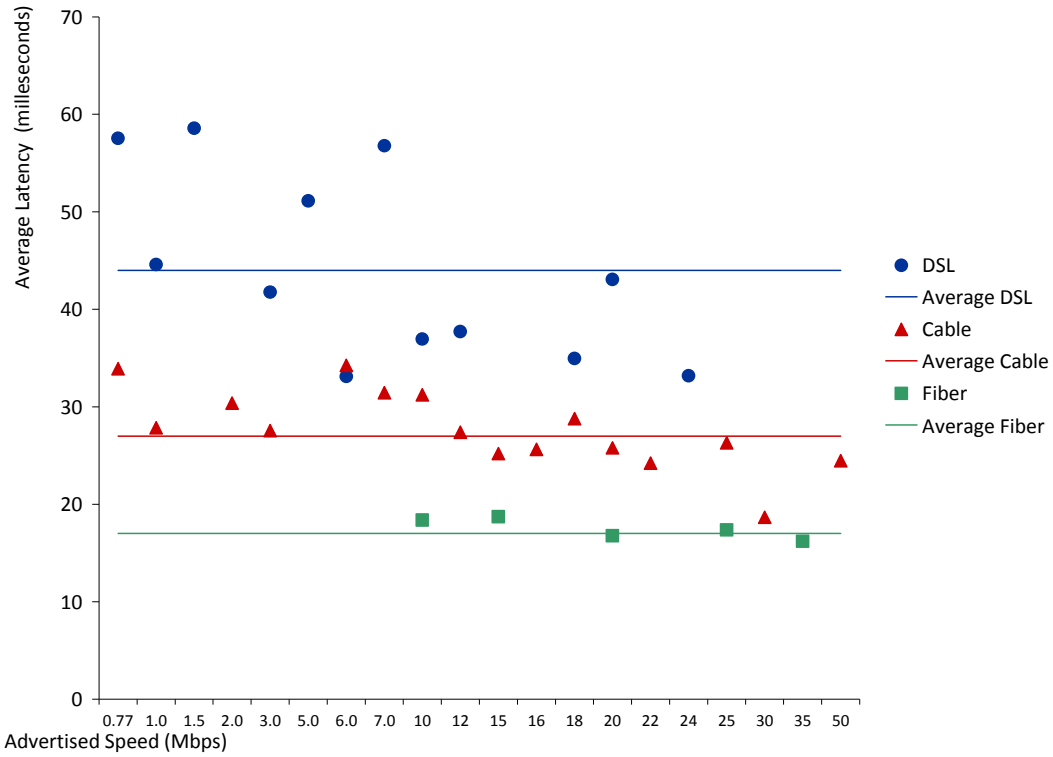
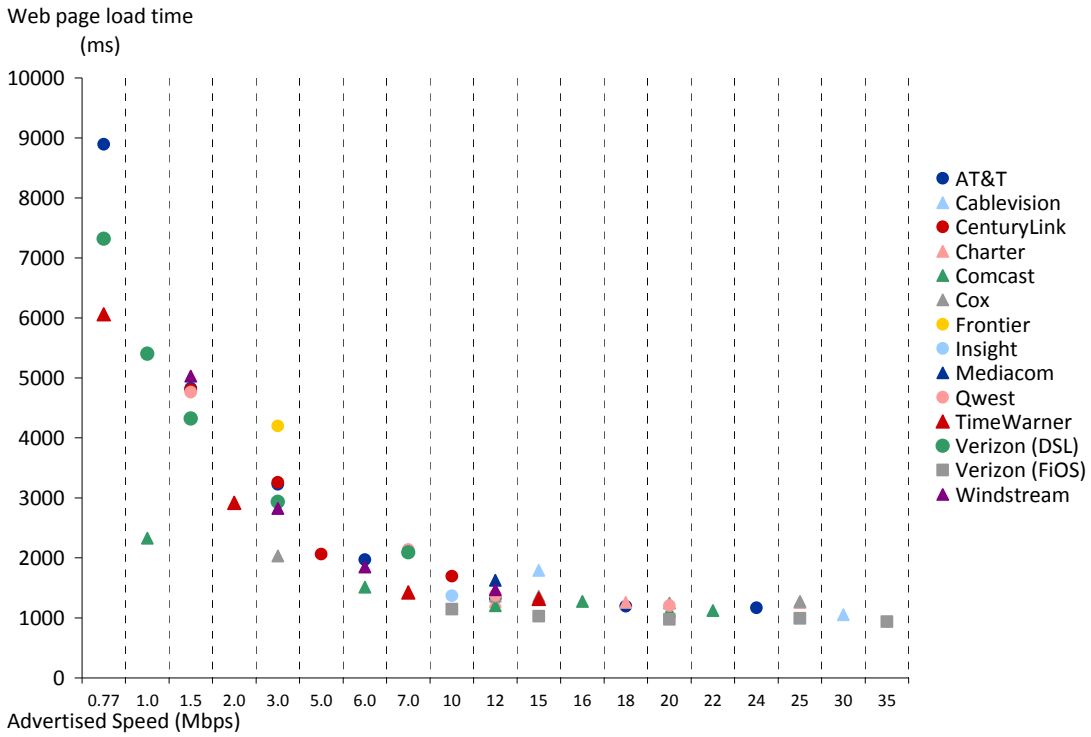


Chart 10 displays average web page loading[42] time by speed tier. Web pages load much faster as broadband speed increases, but beyond 10 Mbps, performance increases for basic web browsing are slight. The data indicate that a consumer subscribing to a 10 Mbps speed tier is unlikely to experience a significant performance increase in basic web browsing—*i.e.*, accessing web pages, but not streaming video or using other high-bandwidth applications such as video chat—by moving to a higher speed tier.

Chart 10: Web loading time by advertised speed, by technology



PERFORMANCE VARIATION BY TIME OF DAY

Chart 11 shows that performance during the day is not consistent for most technologies. During idle periods there is more capacity available for the consumer, while at peak periods, with many consumers online, available capacity per consumer diminishes. As shown in Chart 12, on average DSL and cable provide similar performance over this period, but results differ significantly among different ISPs.

Chart 11: Average sustained download speeds as a percentage of advertised over a 24-hour period, by provider

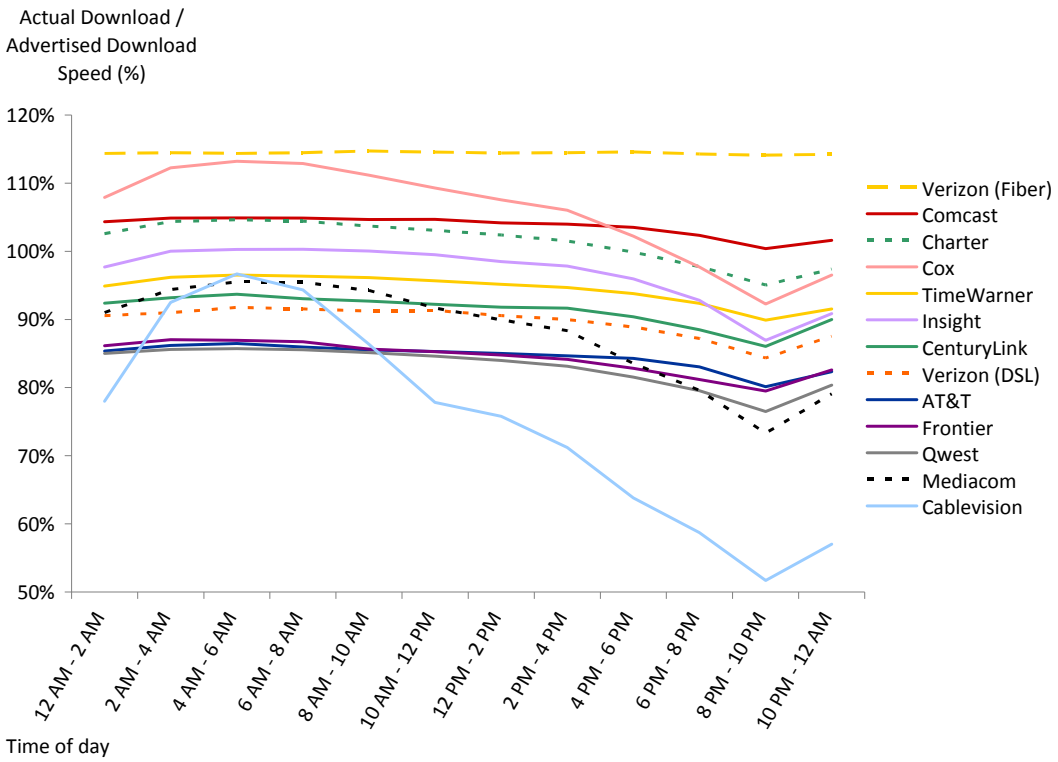
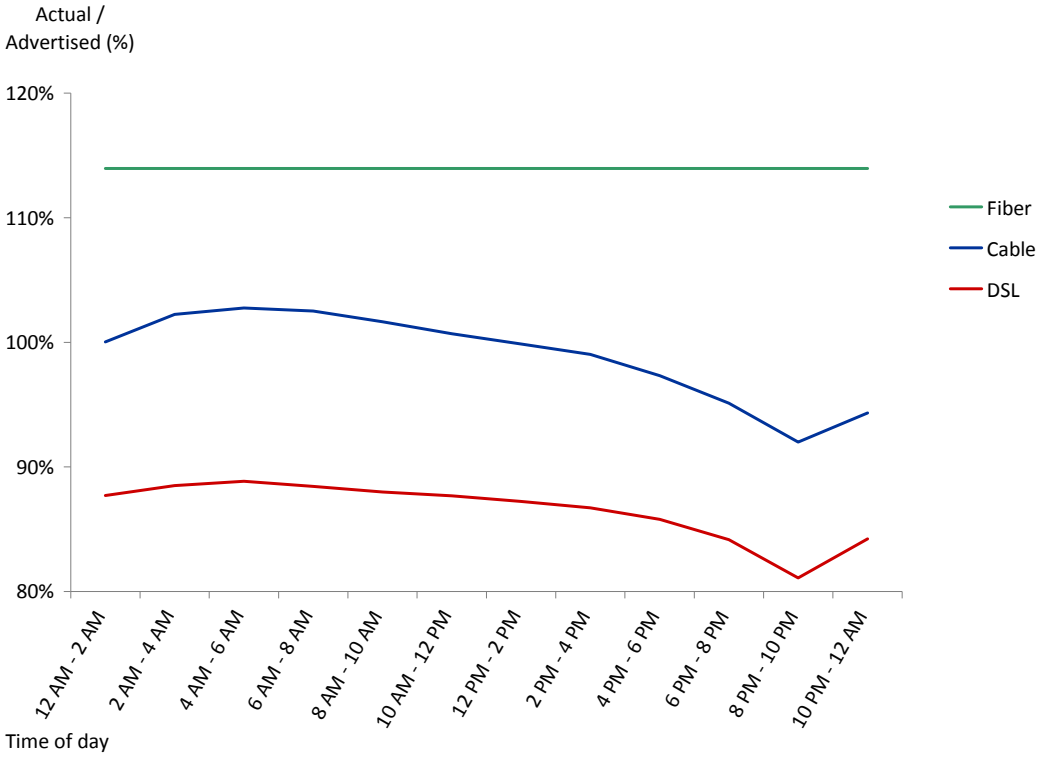


Chart 12: Hourly average sustained download speeds as a percentage of advertised speed, by technology



ACTUAL VERSUS ADVERTISED SPEEDS

The table below lists the advertised speed tiers included in this study, and compares this with the actual average peak performance results from March 2011. As before, we note that the actual sustained download speeds here were based on national averages, and should not be taken to represent the performance experienced by any one consumer in any specific market for these ISPs.

Figure 2: Peak period sustained download performance, by provider

Actual Sustained Speed (Mbps)	Advertised Speed Tier (Mbps)	Provider	Actual Sustained Speed / Advertised Speed Tier
0.60	0.768	AT&T	78%
0.69	0.768	Verizon (DSL)	89%
0.73	0.768	TimeWarner	95%
0.97	1	Verizon (DSL)	97%
1.15	1.5	Windstream	77%
1.22	1.5	Qwest	82%
1.24	1.5	AT&T	83%
1.32	1.5	Verizon (DSL)	88%
1.35	1.5	CenturyLink	90%
1.44	1	Comcast	144%
1.90	2	TimeWarner	95%
2.02	3	Frontier	67%
2.34	3	AT&T	78%
2.43	3	Verizon (DSL)	81%
2.60	3	CenturyLink	87%
2.66	3	Windstream	89%
3.20	3	Cox	107%
4.52	5	CenturyLink	90%
4.71	6	AT&T	79%
4.83	7	Qwest	69%
5.02	7	Verizon (DSL)	72%
5.17	6	Windstream	86%
5.97	6	Comcast	99%
6.49	7	TimeWarner	93%
7.47	15	Cablevision	50%
8.34	10	CenturyLink	83%
9.05	10	Insight	91%
9.07	12	Mediacom	76%
9.13	10	TimeWarner	91%
9.56	12	Windstream	80%
10.24	10	Verizon (Fiber)	102%
10.45	12	Qwest	87%
11.10	12	AT&T	92%

11.98	12	Cox	100%
12.04	12	Charter	100%
12.13	12	Comcast	101%
13.13	15	TimeWarner	88%
13.60	15	Cox	91%
14.10	16	Comcast	88%
16.07	18	AT&T	89%
16.29	18	Charter	91%
16.96	20	Qwest	85%
17.21	20	Cox	86%
17.41	15	Verizon (Fiber)	116%
19.59	20	Comcast	98%
20.65	25	Cox	83%
20.83	30	Cablevision	69%
21.10	24	AT&T	87%
21.46	25	Charter	86%
22.57	22	Comcast	103%
22.78	20	Verizon (Fiber)	113%
28.77	25	Verizon (Fiber)	115%
40.42	35	Verizon (Fiber)	115%

Conclusion and Next Steps

Consistent broadband metrics can help consumers assess their broadband service and compare service providers in meaningful ways. Actual data on broadband performance and deployment can serve as a tool for broadband providers by lowering customer support costs, by allowing consumers to verify performance of their broadband service without first contacting the ISP for support, and/or by facilitating an ISP's ability to assure that a consumer's service across all elements of an ISP's network is satisfactory. Such data can also assist the research community in understanding performance characteristics of consumer broadband services; encourage the development of future broadband testing methodologies; and lead to improvements in broadband policy and broadband deployment programs. Greater knowledge of the characteristics of consumer broadband performance can help facilitate the development of innovative Internet applications and services.

Scale Methodology Across All Broadband Providers

We believe that a standardized set of broadband measurements can be implemented across a range of ISPs and scaled to support detailed regional assessments of broadband deployment and performance. Discussions with ISPs and vendors during the course of this project have given us confidence that such an approach can be done at limited cost by leveraging ongoing technology deployment within the industry. Such measurement capabilities have the potential to provide consumers with more precise information about their actual service performance and to provide policy makers with an assessment of current and evolving broadband performance. By using sampling methodologies, additional network traffic from performance measurements can be kept to negligible levels. We note that today many ISPs make extensive network measurements for their own benefit. Extending the availability of sampled performance data to the consumer will likewise provide benefits to the end user and to content, application, and service developers.

We can also expand the methodology in this study to assess the overall broadband experience—not just the service delivered to a subscriber by his or her ISP, but the complete connection between a subscriber and the universe of content providers and services with which he or she interacts. Such work might include furthering the development and deployment of the Consumer Broadband Test.

Continue Dialogue with the Stakeholder Community

This collaborative effort across project participants significantly helped the development of the testing methodologies, sampling techniques, and consumer privacy protections that were critical to the study. We intend to continue this collaborative effort to explore ways such testing can be made more efficient and scalable. An ongoing assessment of broadband performance across all regions of the country, demographic groups, technologies, and speed tiers would be helpful in many ways.

Academic Code Review

Both the Commission and SamKnows recognize that while the methodology descriptions included in this document provide an adequate overview of the project as a whole, there will be experts, as well as members of the public and non-profit organizations, who are willing to contribute to the project by reviewing the actual software used in the testing. SamKnows welcomes review of its software and technical platform for non-commercial purposes only.[43]

All Data Released into the Public Domain

The full raw bulk data set acquired during this study is being made available to the public simultaneously with the release of this Report.

Acknowledgements

This Report benefited from the voluntary participation of a number of parties. The contribution of their expertise to the development of the methodologies employed in this Report materially increased its quality. We would like to extend our thanks to the following entities:

- Adtran
- AT&T
- Cablevision Systems Corporation
- CenturyLink
- Charter Communications
- Comcast
- Corning
- Cox Communications
- Frontier Communications Company
- Georgia Institute of Technology
- Insight Communications
- Intel
- Mediacom Communications Corporation
- Massachusetts Institute of Technology
- M-Lab
- National Cable & Telecommunications Association
- New America Foundation
- Qwest Communications
- Time Warner Cable
- US Telecom Association
- Verizon
- Windstream Communications

Finally, we would like to thank SamKnows for their extraordinary performance during this endeavor. Their experience and hard work on this project was critical to its success.

ENDNOTES

[1] John Horrigan and Ellen Satterwhite, *Americans' Perspectives on Online Connection Speeds for Home and Mobile Devices*, 1 (FCC 2010), at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-298516A1.doc (finding that eighty percent of broadband consumers did not know what speed they had purchased).

[2] Aaron Smith, HOME BROADBAND 2010, Pew Research Center's Internet & American Life Project at 8, available at http://www.pewinternet.org/~/media/Files/Reports/2010/Home%20broadband%202010.pdf (last accessed July 8, 2011).

[3] *See* CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN (2010), available at http://www.broadband.gov/plan/ ("NBP").

[4] *See* http://www.broadband.gov/qualitytest/?TB_iframe=true&height=500&width=470&qt=true (last accessed July 8, 2011).

[5] The Consumer Broadband Test allows consumers to choose between testing performed by one of two entities: Ookla and M-Lab. However, these tests use different upload and download criteria, and so can return different results for the same broadband connection.

[6] *Consumer Information and Disclosure; Truth-in-Billing and Billing Format; IP-Enabled Services*, Notice of Inquiry, 24 FCC Rcd 11380 (2009).

[7] *Need for Speed Information for Consumers of Broadband Services*, CG Docket No. 09-158, Public Notice, 26 FCC Rcd 5847 (2011).

[8] NBP, Recommendation 4.4 at 45.

[9] The only fiber-to-the-home broadband service studied in this report is Verizon's FiOS. Other services use fiber optic technology and may be marketed as "fiber." *See, e.g.*, note 36 *infra*.

[10] Participating ISPs were: AT&T (DSL); Cablevision (cable); CenturyLink (DSL); Charter (cable); Comcast (cable); Cox (cable); Frontier (DSL); Mediacom (cable); Insight (cable); Qwest (DSL); TimeWarner (cable); Verizon (DSL and fiber-to-the-home); and Windstream (DSL).

[11] As described more fully in the Appendix, this study allowed for a target deployment in up to 10,000 homes across the United States, and the final volunteer pool was created from over 75,000 initial volunteer broadband subscribers. Although test results were taken from 7,500 households over the course of the study, the results that are analyzed in this Report reflect broadband performance to 6,800 homes during the month of March 2011.

[12] In addition to the various data sets, the actual software code that was used for the testing will be made available for academic and other researchers for non-commercial purposes. *See infra* note 43.
[13] ISPs typically quote speeds or information rates in units of Megabits (millions of bits) per second, known as Mbps. A bit is the basic unit of information in computing.
[14] Sustained speeds are described in the Appendix and are averaged over five second intervals across the high and low rates that might dynamically occur in very short time interval measurements.
[15] Those earlier reports of broadband speeds in the United States and the United Kingdom had shown ISPs delivering a smaller percentage of advertised speeds. *See* FCC, BROADBAND PERFORMANCE, OBI Technical Paper No. 4, available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2010/db0813/DOC-300902A1.pdf; Ofcom, UK BROADBAND SPEEDS (2009), available at http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/broadbandspeeds.pdf.
[16] The term "average" applied to results in this Report always means the arithmetic mean of the sample set under consideration. There is no weighting of samples in calculating averages.
[17] Although DSL-based services demonstrated overall performance that was somewhat slower and more subject to latency than cable and fiber-to-the-home, DSL is generally less expensive than either of other technologies discussed in this Report, which could be a considerable benefit to some consumers, and a significant factor in their choice of broadband provider.
[18] A 24-hour average was computed each day and then averaged over Monday through Sunday.
[19] In this context, the closest server is the measurement server providing minimum round-trip time.
[20] For example, downloading a large file while browsing the web would limit the effectiveness of PowerBoost.
[21] ISPs typically advertise a smaller number of speed tiers but must support legacy tiers—tiers promoted at one time but no longer offered for new subscription—until they are migrated to higher speeds. During deliberations with ISPs for this trial, some noted that they maintain a larger number of service tiers than they currently promote and advertise and that they may support as many as ten service tiers at a given time.
[22] This was a result of the limited number of white boxes—approximately 9,000—that could be deployed over the course of the project. Region-specific data would have required an order of magnitude or greater deployment of equipment, at a corresponding increase in cost.

[23] *See Comment Sought on Measurement of Mobile Broadband Network Performance and Coverage*, Public Notice, 25 FCC Rcd 7069 (2010); *Request for Information: Measurement and Reporting of Mobile Broadband Performance and Coverage*, FEDBIZOPPS.GOV (Oct. 8, 2010), available at https://www.fbo.gov/index?s=opportunity&mode=form&id=987657347a39a85e109ee4e057517340&tab=core&_cview=1.

[24] In addition to the 13 ISPs who took part in this study, contributors included M-Lab, ADTRAN, Corning, Fiber to the Home Council, Georgia Tech, Intel, MIT, Motorola, National Cable Television Association, the New America Foundation, and the US Telecom Association.

[25] An initial goal for the project included measurements for satellite and fixed terrestrial wireless technologies as well. While consumer volunteers were obtained for these technologies, these test results were not included in this Report due to the low number of samples. Such results were included in the raw bulk data set. This data also includes test results for speed tiers for DSL, cable, and fiber-to-the-home technologies for which an insufficient number of panelists was recruited to create a statistically significant sample.

[26] These speed ranges were chosen to provide alignment with broadband tiers as categorized in the "Form 477" reports that the Commission uses as its primary tool for collecting data about broadband networks and services. *See Modernizing the FCC Form 477 Data Program*, Notice of Proposed Rulemaking, 26 FCC Rcd 1508, 1512 n.27 (2011), citing *Development of Nationwide Broadband Data to Evaluate Reasonable and Timely Deployment of Advanced Services to All Americans, Improvement of Wireless Broadband Subscribership Data, and Development of Data on Interconnected Voice over Internet Protocol (VoIP) Subscribership*, Report and Order and Further Notice of Proposed Rulemaking, 23 FCC Rcd 9691, 9700-01 (2008).

[27] M-Lab is a non-profit corporation supporting research on broadband networks that maintains an open, distributed server platform for researchers to deploy Internet measurement tools. More information on M-Lab can be found on its website, http://www.measurementlab.net/.

[28] "Middle mile" transport refers generally to the transport and transmission of data communications from the central office, cable headend, or wireless switching station to an Internet point of presence. In contrast, "last mile" refers to the connection between a consumer's home and that consumer's broadband service provider's first aggregation point.

[29] A simple view of an ISP's network from the consumer perspective is that it consists of a path connecting the consumer's modem to a major aggregation point and that such aggregation points are connected with high bandwidth facilities

forming a core or backbone network. Connecting paths joining one or more subscribers to these aggregation points typically have significantly less bandwidth or capacity than the connecting links between aggregation points and other major locations within this core network.

[30] A byte is a standard unit of measure in computing indicating 8 bits. A megabyte represents 8 million bits.

[31] This latency is often colloquially called the "ping time," named after a network tool used to measure the latency. The measurement methodology used in this Report differs slightly from that tool, but the results should be essentially the same.

[32] See International Telecommunication Union (ITU), *Series G: Transmission Systems and Media, Digital Systems and Networks; International Telephone Connections and Circuits – General Recommendations on the Transmission Quality for an Entire International Telephone Connection*, G.114 (May 2003).

[33] The March 2011 data set was validated to remove anomalies which would have produced errors in the Report. This data validation process is described in the Appendix.

[34] For a discussion of how averages were calculated for the purposes of this Report, *see supra* note 16.

[35] Throughout this Report, results are recorded separately for CenturyLink and Qwest. These two entities completed a merger on April 1, 2011; however, during the testing in March 2011, they were separate companies.

[36] U-Verse is a service mark offering of AT&T supporting a bundled service package of voice, video, and Internet services. U-Verse incorporates multiple technologies. The most common arrangement is a fiber-to-the-node architecture with DSL technology terminating to the home. All U-Verse panelists tested during this survey utilized DSL technology.

[37] As noted elsewhere, *see supra* note 16, all averages used in this Report are unweighted arithmetic averages of the relevant data sets. However, the sample plan was based on market share data for all ISPs. Comparison of unweighted averages with averages weighted by market share showed close agreement.

[38] Only 10 out of 53 service tiers tested in this study returned less than 80 percent of advertised performance during peak periods.

[39] A 50 Mbps service tier can be seen in this chart, but not in other charts that provide results for individual ISPs. This is a result of filtering for low sample counts. While a 50 Mbps service tier is offered by some of the ISPs included in the study, our survey did not obtain enough samples to include this service tier in results for individual ISPs. However, when aggregated by technology, the number of independent samples for 50 Mbps exceeded our threshold criteria for the study.

[40] We provide latency figures for peak periods. As noted earlier, latency during peak periods was seen to increase by about 7.6% across all technologies. Latencies

measured for other periods can be found in http://www.data.fcc.gov/download/measuring-broadband-america/statistical-averages.xls.

[41] *See* http://www.data.fcc.gov/download/measuring-broadband-america/statistical-averages.xls.

[42] For a definition of web loading time, see Appendix at 24-25.

[43] To apply for non-commercial review of the code, interested parties may contact SamKnows directly at team@samknows.com, with the subject heading "Academic Code Review."